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 management of a coffee roasting and packaging facility. The request included concerns about the potential health effects from exposure to diacetyl and 2,3-pentanedione during coffee processing, including roasting, grinding, and packaging.

What We Did

- We visited the coffee roasting and packaging facility in September 2017.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We measured real-time air levels of carbon monoxide and carbon dioxide.
- We assessed the ventilation at the facility.
- We administered a health questionnaire to employees and performed breathing tests.

What We Found

- At the time of the evaluation, multiple construction projects were occurring simultaneously throughout the building.
- One of three roasters in the production area was in operation during the evaluation.
- Flavoring was performed approximately four times per year for small batches of coffee; however, flavoring of coffee beans was not performed during the evaluation.
- During personal full-shift sampling, no employees were exposed to diacetyl at concentrations above the National Institute for Occupational Safety and Health recommended exposure limit for diacetyl of 5 parts per billion, with the highest measured concentration of 2.9

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 at a coffee roasting and packaging facility. None of the 10 personal full-shift samples collected in the production area exceeded the National Institute for Occupational Safety and Health recommended exposure limits for diacetyl (5 parts per billion) or 2,3-pentanedione (9.3 parts per billion). In addition, air sampling during short-term tasks identified roasting coffee beans resulted in higher exposures to alpha-diketones, including diacetyl, than other tasks; however, none of the task-based samples exceeded the National Institute for Occupational Safety and Health short-term exposure limits for diacetyl (25 parts per billion) or 2,3-pentanedione (31 parts per billion). Eye and nose symptoms were the most commonly reported symptoms. Two participants had spirometry tests that were interpreted as mild restriction. One participant had high exhaled nitric oxide, a marker of allergic airways inflammation. Because of ongoing construction and coffee beans were not flavored during the evaluation, we recommend air sampling after building construction is complete and during flavoring to determine if alpha-diketone exposures are above the recommended exposure limits. We also recommend implementing administrative controls such as modification of work practices, training employees about workplace hazards, and voluntary use of N95 disposable filtering facepiece respirators available for protection against coffee dust exposure. We recommend instituting a medical monitoring program for employees who flavor the small batches of coffee.

parts per billion.

- During personal full-shift sampling, no employees were exposed to 2,3-pentanedione at concentrations above the National Institute for Occupational Safety and Health recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion, with the highest measured concentration of 2.6 parts per billion.
- Levels of diacetyl and 2,3-pentanedione from personal task-based sampling were higher for tasks involving roasting coffee beans; however, none of the task-based samples exceeded the National Institute for Occupational Safety and Health short-term exposure limits for diacetyl of 25 parts per billion or 2,3-pentanedione of 31 parts per billion.
- Carbon monoxide levels were generally low throughout the facility but higher near the bag fill machine during coffee packaging.
- Eye and nose symptoms were the most commonly reported symptoms. Some employees reported their symptoms were caused or aggravated by burlap and dust.
- Two of 17 participants had spirometry tests that were interpreted as mild restriction.
- One participant had high exhaled nitric oxide, a marker of allergic airways inflammation.

What the Employer Can Do

- Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, carbon monoxide, carbon dioxide, green and roasted coffee dust) in the workplace and how to protect themselves.
- Minimize production tasks that require employees to place their heads inside roasted bean storage bins.
- Continue to cover bins of roasted coffee beans to reduce emissions of alpha-diketones, carbon monoxide, and carbon dioxide into the air.
- Conduct air sampling during flavoring and after building construction is complete to determine if alpha-diketone exposures are above the recommended exposure limits. Install engineering controls (e.g., local exhaust ventilation) if they become necessary.
- Make N95 disposable filtering facepiece respirators available for voluntary use for protection against coffee dust exposure, such as when working with burlap bags of green beans 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 flavor the small batches of coffee.

What Employees Can Do

- As much as possible, avoid placing your head directly above or inside roasted bean storage bins.
- Some employees might wish to use N95 disposable filtering facepiece respirators for some tasks, such as when working with burlap bags of green beans 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(s) and a designated individual at your workplace.
- Participate in your employer's medical monitoring program as instructed by your employer.

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Abbreviations

µg	Microgram
ACGIH®	American Conference of Governmental Industrial Hygienists
APF	Assigned protection factor
AX	Area of reactance
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV_1	1-second forced expiratory volume
ft^2	Square feet
Fres	Resonant frequency
FVC	Forced vital capacity
IDLH	Immediately dangerous to life or health
kPa/(L/s)	Kilopascals per liter per second
LOD	Limit of detection
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
RH	Relative humidity
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compound
TWA	Time-weighted average
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In February 2016, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health received a request from the management of a coffee roasting and packaging facility. The request stated concerns about potential health issues related to exposure to diacetyl and 2,3-pentanedione during coffee roasting, grinding, and packaging. In September 2017, we conducted an industrial hygiene survey, ventilation assessment, and a medical survey at the facility. The industrial hygiene survey consisted of the collection of air samples for the analysis of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. Continuous monitoring instruments were used to monitor total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. The medical survey consisted of a health questionnaire and breathing tests. One interim report with recommendations was sent to the company following our visit.

Overall, full-shift time-weighted average air concentrations of diacetyl and 2,3-pentanedione were higher in production areas of the facility. However, none of the personal full-shift samples collected in the production area exceeded the National Institute for Occupational Safety and Health recommended exposure limit for diacetyl of 5 parts per billion, with a maximum measured concentration of 2.9 parts per billion. Similarly, none of the personal full-shift samples collected in the production area exceeded the recommended exposure limit for 2,3-pentanedione of 9.3 parts per billion, with a maximum measured concentration of 2.6 parts per billion. We identified some work tasks that resulted in relatively higher air concentrations of diacetyl than other tasks. Specifically, coffee roasting tasks were associated with higher diacetyl levels. We recommend air sampling during flavoring and after building construction is complete to determine if alpha-diketone exposures are above the recommended exposure limits.

We also recommend implementing administrative controls such as modification of work practices, training employees about workplace hazards, and voluntary use of N95 disposable filtering facepiece respirators available for protection against green or roasted coffee dust and burlap exposure such as when working with green beans. Additionally, we recommend a medical monitoring program for employees who flavor the small batches of coffee approximately four times per year to identify any employees who might be developing lung disease (e.g., obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease.

Introduction

In February 2016, the Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health (NIOSH) received a request from the management at a coffee roasting and packaging facility. The request stated concerns about potential health issues related to exposure to diacetyl and 2,3-pentanedione during coffee roasting, grinding, and packaging. In September 2017, we conducted an industrial hygiene survey, ventilation assessment, and a medical survey at the facility. We collected area and personal breathing zone air samples for volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We also monitored and recorded carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs (TVOCs). The medical survey consisted of a health questionnaire and breathing tests. After the visit, we provided an interim report with recommendations.

Background

Diacetyl and 2,3-Pentanedione

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

NIOSH has recommended exposure limits (RELs) for diacetyl and 2,3-pentanedione in workplace air (Table 1). 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 guidelines 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 about 1 in 1,000 workers exposed to diacetyl levels of 5 parts per billion (ppb) as a time-weighted average

(TWA) for 8 hours a day, 40 hours a week for a 45-year working lifetime would develop reduced lung function (defined as forced expiratory volume in one second [FEV_1] below the lower limit of normal) as a result of that exposure. NIOSH predicted that around 1 in 10,000 workers exposed to diacetyl at 5 ppb for a 45-year working lifetime would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). Workers exposed for less time would be at lower risk for adverse lung effects.

2,3-Hexanedione

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

Carbon Monoxide and Carbon Dioxide

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

Exposure Limits

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

<u>Occupational Safety and Health Administration (OSHA) [Mandatory]</u>

The U.S. Department of Labor's OSHA permissible exposure limits (PELs) are legal limits that are enforceable in workplaces covered under the Occupational Safety and Health Act. OSHA PELs represent the legal maximum for a TWA exposure to a physical or chemical agent over a work shift [OSHA 2018]. OSHA short-term exposure limits (STELs) are the legal maximum average exposure for a 15-minute time period. Some chemicals also have an OSHA ceiling value, which represent levels that must not be exceeded at any time. Currently, there are no PELs for diacetyl, 2,3-pentanedione, or 2,3-hexanedione. For substances for which an OSHA PEL has not been issued, violation of the OSHA General Duty Clause can be considered using available occupational exposure references and recommendations [OSHA 1993; OSHA 2003], such as the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®) and NIOSH RELs.

<u>American Conference of Governmental Industrial Hygienists (ACGIH) [Recommendations]</u>

ACGIH is a professional, not-for-profit scientific association that reviews existing published, peer-reviewed scientific literature and publishes recommendations for levels of substances in air based on an 8-hour workday and 40-hour workweek. These recommendations are called TLVs [ACGIH 2018a]. ACGIH TLVs are not standards; they are health-based guidelines derived from scientific and toxicological information. ACGIH provides TLV-TWA guidelines that are levels that should not be exceeded during any 8-hour workday of a 40-hour workweek. ACGIH also provides TLV-STEL guidelines which are 15-minute exposure levels that should not be exceeded during a workday. Exposures above the TLV-TWA but less than the TLV-STEL should be (1) less than 15 minutes, (2) occur no more than four times a day, and (3) be at least 60 minutes between exposures [ACGIH 2018a]. Additionally, ACGIH provides TLV-Ceiling values, which are levels that should not be exceeded at any time during a work shift. The ACGIH TLV-TWA for diacetyl is 10 ppb. The TLV-STEL for diacetyl is 20 ppb. Currently, there is no TLV-TWA or TLV-STEL for 2,3-pentanedione. ACGIH has placed 2,3-pentanedione on the 2017 list of Chemical Substances and Other Issues Under Study [ACGIH 2018b].

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

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

Table 1. Personal exposure limits for compounds sampled during the NIOSH survey, September 2017.

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

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

Obliterative Bronchiolitis

Obliterative bronchiolitis is a serious, often disabling, lung disease that involves scarring of the very small airways (i.e., bronchioles). Symptoms of this disease might include cough, shortness of breath on exertion, or wheeze, that do not typically improve away from work [NIOSH 2012]. Occupational obliterative bronchiolitis has been identified in flavoring manufacturing workers and microwave popcorn workers who worked with flavoring chemicals or butter flavorings [Kreiss 2013; Kim et al. 2010; Kanwal et al. 2006]. It has also been identified in employees at a coffee roasting and packaging facility that produced unflavored and flavored coffee [CDC 2013b]. A NIOSH health hazard evaluation at that facility found diacetyl and 2,3-pentanedione concentrations in the air that were elevated and identified three sources: 1) flavoring chemicals added to roasted coffee beans in the flavoring area; 2) grinding unflavored roasted coffee beans and packaging unflavored ground and whole bean roasted coffee in a distinct area of the facility, and 3) storing roasted coffee in hoppers, on a mezzanine above the grinding/packaging process, to off-gas [Duling et al. 2016]. At the time of the health hazard evaluation, workers had excess shortness of breath and obstruction on spirometry, both consistent with undiagnosed lung disease. Respiratory illness was associated with exposure and not limited to the flavoring areas [Bailey et al.

2015]. However, all workers who were diagnosed with obliterative bronchiolitis had worked in the flavoring area. To date, no cases of obliterative bronchiolitis have been reported in workers at coffee roasting and packaging facilities that produce only unflavored coffee.

Work-related Asthma

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

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

Based on the findings of previous NIOSH health hazard evaluations regarding alpha-diketones, the coffee roasting and packaging company wanted to be proactive and characterize concentrations of alpha-diketones in the facility. In February 2016, the management submitted a health hazard evaluation request to NIOSH.

Process Description

The coffee roasting and packaging facility had recently moved to the current location in August 2017. The facility was approximately 11,000 square feet (ft^2) with 2,500 ft^2 used for production space that included a quality control area, office spaces, and storage. The production area was approximately 1,100 ft^2 with additional areas under construction. A ceiling height of nearly 14 feet was consistent throughout the production area; however, this could change as a result of the ongoing construction. The office spaces combined totaled approximately 250 ft^2; however, they were open to the production area, and several desks used by employees were located in the packaging area. There were 18 current employees at the time of the NIOSH survey. Seven of those employees were involved in production tasks including roasting, weighing and packaging, grinding, and quality control. The other employees were involved in various administrative tasks including bookkeeping, sales, marketing, reception and working at a café located in another facility. At the time of the NIOSH visit in September 2017, the process for roasting coffee from receiving green beans to distributing finished product was as described below.

Green beans were received in burlap bags from around the world including, but not limited to, Colombia, Mexico, Bolivia, Peru, Ecuador, Ethiopia, and Uganda. Upon arrival at the facility, burlap bags of green beans were stored on wooden pallets in the green bean storage area until they were ready to be roasted. To prepare a batch for roasting, a roaster operator filled plastic totes with green beans. Each bin was placed on a scale and filled with green beans until it reached the proper weight for a given roast. The roaster operator manually dumped the totes of green beans into the hopper on the floor to be vacuum fed into the Diedrich, (Diedrich Roasters, P.O. Box 430, Ponderay, Idaho 83852, U.S.A) Model CR25 Roaster. The roaster was capable of roasting up to 55 pounds of coffee per roast, but a 40-pound load was more typical. To initiate the roast, the roaster operator initiated the automated loading of the green beans from the hopper into the roasting drum where they were heated at a specific temperature and time period for the desired roast. Time and temperature varied between different types of roasts. At the end of each roast cycle, the door at the bottom of the roasting drum automatically opened to empty the roasted beans into the cooling drum where they were automatically mixed by an agitator to accelerate cooling. The cooling drum utilized a downdraft exhaust system that drew air over the roasted beans and down into the cooling drum to accelerate cooling. The downdraft system exhausted through the wall behind the roaster. The roaster operator monitored the roasting equipment carefully throughout the roasting and cooling process. After adequate cooling, the roasted beans were emptied from the cooling drum into plastic storage containers. The roaster operator then manually moved the containers to the roasted bean storage area. Two other roasters were located in the facility, a Diedrich Model IT 12 and an Ambex (Ambex Coffee Roasters, 2080-A Calumet St, Clearwater FL 33765, USA) Model YM 15; however, these roasters were not operated during the time of the NIOSH sampling.

To package roasted coffee beans, an employee used an All Fill (418 Creamery Way, Exton, PA 19341, USA) Weigh-Fill System. An employee would manually dump the tote of roasted beans into the hopper on top of the weigh-fill machine. The pneumatic system transferred beans from the weigh-fill hopper to fill 12-ounce, 2-kilogram, and 5-pound bags with whole roasted coffee beans.

For ground coffee, whole roasted beans were loaded into appropriate bags using the weigh-fill system. The beans from the bag were then dumped into a Bunn (1400 Stevenson Drive Springfield, Illinois 62703, USA) Model G3 22100-0000 grinder where they were ground and dispensed back into the bag for packaging. The grinder could be adjusted for type of grind (coarse, medium, or fine). After all packages were filled with either whole bean or ground coffee, the packages were heat sealed and placed on shelves or immediately in shipping boxes for shipment or local delivery. Beans were generally packaged within 12 hours of roasting, often sooner than that.

Flavoring of roasted coffee beans was reported to occur approximately once per quarter (approximately 50 pounds) by manually mixing liquid chestnut/hazelnut flavoring with roasted coffee beans. No flavoring of coffee beans was performed during the NIOSH visit.

Employees were not required to wear a company uniform or protective clothing. Hearing protection was used by some employees during their work activities.

Methods

We visited the coffee roasting and packaging facility in September 2017. We held an opening meeting with management and employees, collected air samples, performed a ventilation assessment, and conducted a medical survey. We provided a letter detailing our evaluation and preliminary recommendations to management in October 2017.

We had the following objectives for the health hazard evaluation:

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

Industrial Hygiene Survey

Sampling Times for Alpha-Diketones

We designed the sampling strategy to assess full-shift exposures and to identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. Sampling was conducted over two days during the site visit. For diacetyl, 2,3-pentanedione, and 2,3-hexanedione, air samples were collected over seconds, minutes, and hours. Samples collected over hours can help determine average concentrations that can be compared to the NIOSH RELs for diacetyl and 2,3-pentanedione. These average concentrations 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.

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

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

We collected personal and area air samples for diacetyl, 2,3-pentanedione, and 2,3-hexanedione on silica gel sorbent tubes during the industrial hygiene survey over two days. The samples were collected and analyzed according to the modified OSHA sampling and analytical Methods 1013/1016 [OSHA 2008; OSHA 2010; LeBouf and Simmons 2017]. In accordance with the two methods, two glass silica gel sorbent tubes were connected by a piece of tubing and inserted into a protective, light-blocking cover. The tubes were connected in series to a sampling pump pulling air through the tubes at a flow rate of 50 milliliters per minute (mL/min). The sampling setup was attached to an employee's breathing zone or placed in an area basket in various places throughout the facility. For full-shift sampling, we collected two consecutive 3-hour samples and calculated the TWA concentration from the two samples, assuming that the total 6-hour monitoring results reflected a full work shift (8-hour) TWA exposure. Although this might introduce some error, it is a conservative approach that is more protective of employees than the alternative assumption of no exposure during the last two hours of the shift. We refer to these samples as "full-shift samples" throughout this report. We also collected short-term task based samples in the same manner, but the sampling pump flow rate was 200 mL/min as detailed in OSHA Methods 1013 and 1016 [OSHA 2008; 2010]. Sampling times were dependent on the duration of the task being performed.

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

A limit of detection (LOD) is the lowest mass that an instrument can detect above background and is a criteria used to determine whether to report a result from a sample. LODs for the visit were 0.01 micrograms per sample (μg/sample) for diacetyl, 0.01 μg/sample for 2,3-pentanedione, and 0.01 μg/sample for 2,3-hexanedione; these were based on the lowest mass used in the calibration curve. These equate to 0.30 ppb for diacetyl, 0.31 ppb for 2,3-pentanedione, and 0.46 ppb for 2,3-hexanedione for a typical full-shift TWA air sample but will vary depending on the volume of air collected during the sampling period. The LODs for task samples are generally higher than typical LOD values for full-shift samples, 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.

Air Sampling and Analysis Using Evacuated Canisters

We collected instantaneous 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-milliliter (mL) evacuated canister equipped with an instantaneous flow controller that was designed for a short sampling duration (less than 30 seconds). Instantaneous samples were taken by opening the evacuated canister to grab a sample of air to help identify point sources of alpha-diketones. For source air samples, a NIOSH employee placed the inlet of the flow controller directly at the source of interest.

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA), and included the compounds diacetyl, 2,3-pentanedione, 2,3-hexanedione, acetaldehyde, acetone, acetonitrile, benzene, chloroform, d-limonene, ethanol, ethylbenzene, isopropyl alcohol, methyl methacrylate, methylene chloride, styrene, toluene, alpha-pinene, m,p-xylene, and o-xylene. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. LODs were 0.42 ppb for diacetyl, 0.28 ppb for 2,3-pentanedione, and 0.69 ppb for 2,3-hexanedione based on a three-times dilution factor, which is typical for restricted flow controller samplers. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they might be higher or lower than typical LOD values.

Real-time Air Sampling

We used three Tiger Handheld volatile organic compound detectors (Ion Science, Inc., Stafford, TX) to measure levels of TVOCs in the air. This sampling was conducted to identify areas where coffee could be releasing TVOCs. Areas where higher concentrations of TVOCs are measured might benefit from further sampling to characterize specific exposures to alpha-diketones. We also collected real-time measurements of CO, CO_2, temperature, and relative humidity (RH) using five TSI Incorporated (Shoreview, MN) VelociCalc Model 9555-X Multi-Function Ventilation Meters equipped with Model 982 IAQ probes. All real-time instruments were set to log data at 10-second intervals.

Ventilation Assessment

A detailed ventilation assessment was unable to be performed at the time of the NIOSH survey. Multiple construction projects were occurring simultaneously resulting in changes to the airflow patterns throughout the facility each day. The exhaust system for the roaster was inspected and functioning properly. There were no construction projects occurring in the area that housed the break room and restrooms, which was adjacent to but separated from the production area. A pressure reading was taken using an Energy Conservatory (Minneapolis, MN) DG-500 Pressure Gauge between the breakroom/restroom area and the production area.

NIOSH Medical Survey

Participants

We invited all current employees aged 18 years and older to participate in the medical survey at the workplace during September 14–15, 2017. Participation was voluntary; written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire

We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee roasting and packaging facility and other coffee or flavoring companies, and cigarette smoking history. Questions on respiratory health were derived from five standardized questionnaires, the European Community Respiratory Health Survey [Burney et al. 1994; ECRHS 2014], the American Thoracic Society adult respiratory questionnaire (ATS-DLD-78) [Ferris 1978], the International Union Against Tuberculosis and Lung Disease [Burney and Chinn 1987; Burney et al. 1989], and the Third National Health and Nutrition Examination Survey (NHANES III) [CDC 1996] and NHANES 2007-2012 questionnaires [CDC 2017]. Some of the questions appeared on more than one of the standardized questionnaires. We also supplemented our questionnaire with additional respiratory and systemic symptom questions.

Spirometry

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

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

Impulse Oscillometry

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

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

Fractional Exhaled Nitric Oxide (FeNO)

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

Statistical Analysis

Industrial Hygiene Survey and Ventilation Assessment

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

Medical Survey

We calculated frequencies and standardized morbidity ratios (SMRs) and their associated 95% confidence intervals (CI) using SAS version 9.4 (SAS Institute, Cary, NC). The SMRs compared prevalences of symptoms among participants to expected prevalences of a sample of the general population reflected in the NHANES III (1988–1994) and NHANES 2007–2012, adjusting for sex, race/ethnicity, age (less than 40 years old or 40 years or greater), and cigarette smoking categories (ever/never). For comparisons to the U.S. population, we used the most recent NHANES survey available for the specific comparisons.

Results

Industrial Hygiene Survey Results

Personal and Area Full-shift Air Sampling Results

Table A1 presents the personal and area full-shift air sampling results from our visit in September 2017. We collected 10 personal full-shift air samples on seven workers and 16 area full-shift air samples. None of the personal air samples were above the NIOSH REL for diacetyl of 5.0 ppb or the NIOSH REL for 2,3-pentanedione of 9.3 ppb. Employees in the roasting area had the highest exposure to diacetyl with a maximum observed concentration of 2.9 ppb. Employees in the production area had the highest exposure to 2,3-pentanedione with a maximum observed concentration of 2.6 ppb.

Area samples were collected in six locations throughout the facility. An area sample in packaging, next to the bag fill machine and grinder, resulted in highest concentrations of diacetyl and 2,3-pentanedione, with concentrations of 3.9 ppb and 3.3 ppb respectively. None of the area samples exceeded the NIOSH RELs for diacetyl or 2,3-pentanedione. We note NIOSH RELs are intended to be directly compared with personal full-shift measurements; therefore, if an area air sample were to exceed the NIOSH REL, it is only an indication of potential personal exposures.

Task-based Air Sampling Results

Table A2 presents the personal task-based air sampling results from our visit in September 2017. We collected nine personal task-based air samples, each with a duration of 15 minutes, using OSHA Methods 1013/1016. An employee that roasted coffee beans had the highest exposure to diacetyl (12.3 ppb) and 2,3-pentanedione (9.7 ppb). All task-based sample results were below the detection limit for 2,3-hexanedione.

All nine of the task-based samples had a duration of 15-minutes, allowing for comparison to the NIOSH STELs for diacetyl (25 ppb) and 2,3-pentanedione (31 ppb). None of the samples exceeded the NIOSH STELs for diacetyl or 2,3-pentanedione.

Source Air Sampling Results

We collected three samples using instantaneous evacuated canisters. All evacuated canisters were equipped with an instantaneous flow controller with a sample duration of approximately 30 seconds. Two of the three source samples were taken at the top of a freshly roasted bag of whole bean coffee, with resulting diacetyl concentrations of 2.2 ppb and 5.1 ppb, 2,3-pentanedione concentrations of 2.3 ppb and 5.7 ppb, and 2,3-hexanedione concentrations of 1.1 ppb and 1.0 ppb. We collected one source sample while freshly roasted coffee was cooling in the roaster cooling bin with resulting diacetyl concentration of 1.4 ppb; 2,3-pentanedione and 2,3-hexanedione were both below the LOD for this sample.

Background Pre- and Post-shift Diacetyl and 2,3-Pentanedione Canister Results
We collected pre- and post-shift background air samples in the center of the production area using evacuated canisters equipped with an instantaneous flow controller on both days of our industrial hygiene survey. The post-shift sample on the second day of the survey was 2.5 ppb diacetyl. All other samples were below 2 ppb for diacetyl, 2,3-pentanedione and 2,3-hexanedione.

Real-time Monitoring: Carbon Monoxide (CO), Carbon Dioxide (CO_2), Temperature, and Relative Humidity (RH)
Real-time monitoring at the roaster resulted in CO levels ranging from 0.0 ppm to 20.2 ppm and CO_2 levels ranging from 250 parts per million (ppm) to 921 ppm. The highest peak of CO (20.2 ppm) occurred near the bag fill station during the packaging of coffee. The highest CO_2 levels were observed in the production manager's office with a range from 250 ppm to 921 ppm.

Real-time Monitoring: Total Volatile Organic Compounds (TVOC)
Real-time monitoring of TVOCs resulted in peak concentrations of 11,215 ppb in the production manager's office. TVOC real-time monitoring at the roaster resulted in peaks as high as 5,941 ppb, corresponding with when roasted beans dumped into the cooling bin. TVOC real-time monitoring at the bag-fill and grinding area resulted in peak concentrations of 5,244 ppb, corresponding with when beans were packaged.

Ventilation Assessment
There was adequate air flow to/from all occupied areas on the office side of the facility to maintain temperature. The production area was under negative pressure to the breakroom/restroom area, meaning no migration of air from the production area into those areas was occurring at the time measurements were taken. The roasting room had an open make-up air fan suppling outdoor air to replenish what was drawn from the room via the roaster cooling bin. Windows and the shipping bay door were opened when weather conditions allowed supplying an abundance of outdoor air to the production area. Precise ventilation measurements were unable to be taken because of the openness of the facility due to the ongoing construction projects. Air from the production area circulated throughout the facility depending on weather/wind conditions and the configuration of the unfinished walls.

Medical Survey Results
Demographics
Seventeen of the 18 total employees were aged 18 years or older at the coffee roasting and packaging facility, and all 17 (100%) of these employees participated in the medical survey. The majority of participants were female (65%) and Caucasian (94%). The mean age of the participants was 33 years (range: 18 years–51 years), and average tenure at the company was four years (range: <1 year–7 years). The majority (71%) were never smokers, and the remaining (29%) were former smokers. Ten (59%) of the 17 participants worked at the company's café location either exclusively or in addition to working at the production location, and five participants worked in the coffee industry (e.g., barista, production) prior to working for this company.

The vast majority of participants (14 of 17, 82%) reported performing activities or tasks related to coffee processing in the production area, with time spent in the production area by these employees ranging five to 40 hours per week. Among all 17 participants, eight (47%) reported spending at least half of their total hours worked per week in the production area, and five of these eight spent virtually all (≥95%) of their time in the production area.

Symptoms and Self-reported Diagnoses
The prevalence of symptoms over the last year and last four weeks at the time of the survey are listed in Table A3. Nose symptoms were the most commonly reported symptom over the past 12 months (n=8, 47%) and four weeks (n=5, 29%), followed by eye symptoms over the past 12 months (n=7, 41%) and four weeks (n=4, 24%). The vast majority (91%) of the 11 participants who reported mucous membrane (either nose or eye) symptoms reported these symptoms did not improve when away from the workplace. However, some participants noted that some mucous membrane symptoms were caused or aggravated by burlap and dust.

Four (24%) participants reported one or more lower respiratory symptoms in the past 12 months: woken with chest tightness, woken by shortness of breath, trouble breathing, shortness of breath on level ground or walking up a slight hill, attack of asthma, usual cough, or wheeze or whistling in the chest. Woken with chest tightness was the most commonly reported lower respiratory symptom (n=2, 12%). All four of the participants with one or more lower respiratory symptoms reported these respiratory symptoms did not improve when away from the workplace. All four of these participants were never smokers.

Seven (41%) participants reported one or more systemic symptoms in the past 12 months: flu-like achiness or achy joints, fever or chills, or unusual tiredness or fatigue. Episodes of flu-like achiness or achy joints (n=5, 29%) was the most commonly reported systemic symptom. All seven of the participants with one or more systemic symptoms reported these symptoms did not improve when away from the workplace.

Six participants (35%) reported a diagnosis of hay fever or nasal allergies, and three participants (18%) reported ever being diagnosed with eczema, dermatitis, or skin allergy. One participant reported ever being diagnosed with asthma. Except for two participants with hay fever or nasal allergies, these conditions were diagnosed prior to employment at this facility. No participants reported a diagnosis of chronic bronchitis, emphysema, COPD, hypersensitivity pneumonitis, chemical pneumonitis, bronchiolitis obliterans, sarcoidosis, interstitial lung disease, vocal cord dysfunction, heart disease, or gastroesophageal reflux.

Medical Tests
All 17 participants completed a spirometry test and oscillometry test. Two spirometry tests, both in never smokers, were interpreted as mild restrictive pattern; one spirometry test result was not interpretable. Two impulse oscillometry tests, both in never smokers, were interpreted as consistent with possible small airways abnormality. One exhaled nitric oxide test was interpreted as elevated.

NHANES Comparison of Symptoms and Diagnoses
The prevalence of selected symptoms (including nose and eye symptoms) and diagnosis of asthma among participants was not different than expected from comparisons with the general U.S. population, adjusted for sex, race/ethnicity, age, and smoking history (Table A4).

Discussion

Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other chemicals such as CO and CO_2 are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for 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]. In addition, flavorings added to coffee can contain diacetyl or 2,3-pentanedione. 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
None of the 10 personal full-shift air samples taken at the coffee roasting and packaging facility using standard OSHA methods were above the NIOSH RELs for diacetyl or 2,3-pentanedione, and none were above the LOD for 2,3-hexanedione. The highest personal full-shift exposure to diacetyl was 2.9 ppb collected from an employee roasting coffee. While our sampling results indicate that workers in the roasting and production area were exposed to levels below the NIOSH RELs for diacetyl and 2,3-pentanedione while one of three roasters were in operation, increases in production volume, modifications to work practices, or changes in ventilation as construction is completed could result in worker exposures exceeding the REL.

As noted earlier, the RELs should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace. The risks associated with the levels we measured in September 2017 were acceptable under NIOSH recommendations. As described in the quantitative risk assessment from the NIOSH Criteria Document (Tables 5-27 and 5-34) [NIOSH 2016], after a 45-year working lifetime, exposure to 5 ppb (a concentration slightly higher than the highest concentration measured at this facility) NIOSH estimated about 1 in 1,000 workers would develop reduced lung function (FEV_1 below the lower limit of normal). NIOSH predicted that around 1 in 10,000 workers exposed to diacetyl at 5 ppb would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as at least moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). The effects of a working lifetime exposure at 2.9 ppb would be somewhat less than those for 5 ppb. NIOSH recommends keeping diacetyl concentrations below 5 ppb, because at this level the risk of reduced lung function after a working lifetime of exposure is below 1 in 1,000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

Area Air Sampling

All 16 area full-shift samples collected were below the NIOSH RELs for diacetyl and 2,3-pentanedione. Area samples are not directly comparable to RELs, because the samples are not collected directly on workers. However, using the RELs as points of reference can help determine areas of the facility with the potential for hazardous personal exposures. No specific areas of concern were identified from our September 2017 area sampling results.

Task-based Exposures

Coffee processing involves multiple tasks that might cause intermittent exposure to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these intermittent, peak exposures. Evaluating intermittent and task-based exposures to diacetyl and 2,3-pentanedione is difficult with current validated sampling methods (OSHA Methods 1013/1016). We collected 15-minute samples at this facility with the intention to compare to the NIOSH STELs. For tasks lasting longer than 15 minutes, we collected multiple samples during the task to understand which tasks could contribute to higher exposures to diacetyl and 2,3-pentanedione.

Our task-based air sampling revealed that some tasks had higher air concentrations of diacetyl or 2,3-pentanedione than other tasks. Using OSHA Method 1013/1016 (Table A2), roasting tasks in the production area resulted in the highest alpha-diketone exposures (12.3 ppb diacetyl; 9.7 ppb 2,3-pentanedione). Because roasted coffee beans are a source of alpha-diketone emissions, the frequency and duration of roasting tasks affect the resultant full-shift TWA air concentrations for alpha-diketones. Although all personal full-shift samples were below the RELs during our visit, increases in production volume, modifications to work practices, or changes in ventilation could result in worker exposures above the REL. If this were to occur, reducing exposures caused by roasting coffee would be a good first step to reducing overall exposures to coffee production workers. Potentially effective means of mitigating exposure to volatile coffee emissions are to install local exhaust ventilation on the roasting, grinding, and packaging equipment to eliminate the exposure at the source.

Real-time Sampling

CO and CO_2 concentrations in the air did not exceed applicable exposure limits. Because roasted coffee is known to emit CO, CO_2, and TVOCs, employees should not place their head or face inside storage bins or directly outside uncovered bins containing roasted coffee as a standard work practice. VOC sampling results could possibly have been affected by the construction projects within the facility as the instruments cannot differentiate between roasted coffee VOCs and those emitted from glues, solvents, and paints used in construction.

Ventilation

Detailed ventilation flow measurements and subsequent air-change calculations were unable to be taken due to the openness of the facility and the ongoing construction projects. Air from the production area circulated randomly throughout the facility depending on weather/wind conditions and the construction progress. The production area was under negative pressure to the breakroom/restroom area, meaning no migration of air from the production area into those areas was occurring at the time measurements were taken. This is a favorable setup that ensures no contaminants generated in the production area migrate into nonproduction areas. At the time of sampling, there was an abundance of fresh outdoor air supplied to the production area via open windows and doors.

Medical Survey

Overall, mucous membrane symptoms, specifically nose and eye symptoms were the most commonly reported symptoms. Some employees reported their symptoms were caused or aggravated by burlap and dust. Coffee dust is an organic dust, and exposure to coffee dust is known to cause respiratory symptoms and is a known risk factor for occupational asthma [Karr et al. 1978; Zuskin et al. 1979, 1985, 1993; Thomas et al. 1991; Sakwari et al. 2013].

Upper respiratory disease such as allergic rhinitis (hay fever, nasal allergies) and sinusitis are sometimes associated with lower respiratory symptoms and asthma and might precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis et al. 2008; Rondón et al. 2012, 2017; Sahay et al. 2016]. Some employees also reported a history of hay fever or nasal allergies, and upper respiratory involvement (e.g., rhinitis, sinusitis) can result in suboptimal control of asthma. Green coffee dust is thought to be a more potent allergen than roasted coffee dust because roasting destroys some of the allergenic activity [Lehrer et al. 1978]. As discussed in the recommendation section, one way to prevent symptoms related to green coffee dust and burlap might be to make N95 disposable filtering-face piece respirators available for voluntary use when working with burlap bags of green beans. However, because N95s are not protective against alpha-diketones (diacetyl, 2,3-pentanedione, or 2,3-hexanedione), NIOSH-certified organic vapor cartridges would be warranted during flavoring.

The number of participants with physician-diagnosed asthma was not different from that observed in the U.S. population. However, 24% of participants reported one or more lower respiratory symptoms in the past 12 months prior to the medical survey. Asthma symptoms often improve when away from exposures that trigger symptoms while other lung diseases such as obliterative bronchiolitis or COPD generally do not improve. Spirometry can be used to help detect and follow individuals with asthma and other lung diseases such as obliterative bronchiolitis or COPD. Spirometry can show if air is exhaled from the lungs more slowly than normal (i.e. obstructive abnormality) or if the amount of air exhaled is smaller than normal (i.e., restrictive abnormality). In asthma, there is intermittent airways obstruction which is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways are fixed and not responsive (reversible) to bronchodilator medicine. The obstructed airways prevent rapid emptying of the lung air sacs (alveoli) during exhalation. This explains why the respiratory symptoms of those with occupational obliterative bronchiolitis do not tend to improve when away from work-related exposures; however, avoidance of further exposure can stop progression of the disease [Akpinar-Elci et al 2004].

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

The lower respiratory symptoms and breathing test abnormalities seen in the medical survey participants are not specific to a particular respiratory problem or disease. They could be related to workplace exposures or to other factors. Indeed, some employees had respiratory diagnoses that preceded employment at this facility. Because of the small number of participants and the need to protect individuals' privacy, we cannot provide more detailed results that might shed light on possible work-relatedness, such as health measures by job title or task. We mailed each participant their individual lung function test results with an explanation of the results and recommended each participant provide the information to their personal physician.

Although none of the personal full-shift air samples were above the NIOSH REL for diacetyl of 5.0 ppb or the NIOSH REL for 2,3-pentanedione of 9.3 ppb, we recommend starting a medical monitoring program for employees who flavor small batches of coffee. At the time of the NIOSH visit, flavoring was performed quarterly (approximately four times per year) in small batches of approximately 50 pounds; however, flavoring of coffee beans was not performed during the NIOSH visit. 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 could serve as a baseline for employees who participated, if they choose to share these results with their provider.

Conclusions

All personal full-shift samples were below the NIOSH RELs for diacetyl and 2,3-pentanedione. Levels of diacetyl and 2,3-pentanedione from personal task-based sampling were higher for tasks involving roasting coffee beans; however, all task-based samples were below the NIOSH STELs for diacetyl and 2,3-pentanedione. Carbon monoxide and carbon dioxide concentrations in the air did not exceed applicable exposure limits. Some employees reported eye and nose symptoms, or lower respiratory symptoms. All participants with respiratory or systemic symptoms reported that these symptoms did not improve when away from the workplace. These symptoms and the lung function abnormalities could be related to workplace exposures or to other factors. However, some employees reported their symptoms were caused or aggravated by burlap and dust. We recommend a medical monitoring program for employees who flavor small batches of coffee to identify any employees who might be developing lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease. The completion of the construction projects might have an effect on the concentrations of alpha-diketones in the facility due to the erection of walls and reduction in volume of the production area. Recommendations are made to reduce worker exposure to these occupational hazards and to protect respiratory health.

Recommendations

At the time of the evaluation, construction projects were ongoing, and the recommendations below can be used as a guideline for construction and work practices to minimize employee exposures. 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 exposures 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 a dilution ventilation system that meets current local mechanical codes. This system should consistently supply fresh, outdoor air to the production space. If properly selected, it could also be used to help heat and cool the production space throughout the year. The system should be operated whenever production activities are ongoing, but it could be shut off during unoccupied periods.
2. Conduct air sampling during the flavoring task and after building construction is complete to verify that the flavoring task and the completed building configuration do not result in alpha-diketone exposures above the NIOSH RELs. If exposures above

the RELs are found, additional engineering controls will be necessary, such as local exhaust ventilation.

3. If increases to production volumes, modification to current work practices, and/or changes in ventilation occur, conduct additional air sampling to verify that the modifications have not resulted in alpha-diketone exposures above the NIOSH RELs. If exposures above the RELs are detected, additional engineering controls will be necessary.

Administrative Controls

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

1. Minimize production tasks that require employees to place their heads inside roasted bean bins. Only employees who need to be present should be close to the flavoring tasks.
2. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, CO_2, green and roasted coffee dust) in the workplace and how to protect themselves. OSHA's *Hazard Communication Standard*, also known as the "*Right to Know Law*" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.
3. Ensure employees are educated to consider the risks of further exposure if they develop lower respiratory symptoms (e.g., cough, shortness of breath, wheezing) that are progressive and severe in degree. Employees should report new, persistent, or worsening symptoms to their personal healthcare providers and to a designated individual at this workplace. Employees with new, persistent, or worsening symptoms should share this report with their healthcare providers.

Personal Protective Equipment

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

1. If air sampling performed during flavoring or after building construction is complete indicate levels of diacetyl or 2,3-pentanedione are above their respective NIOSH REL

or STEL, we recommend engineering and administrative controls. Until engineering and administrative controls are in place, respiratory protection is a potential option to reduce exposures to alpha-diketones (e.g., diacetyl and 2,3-pentanedione). If respiratory protection is used for diacetyl and 2,3-pentanedione, NIOSH-certified respirators should be fitted with organic vapor cartridges. The choice of respirator should be guided by personal exposure sampling for diacetyl and 2,3-pentanedione [NIOSH 2004]. For reference, air-purifying half-face respirators have an assigned protection factor (APF) of 10, and air-purifying full-face respirators have an APF of 50. Also, there are powered-air purifying respirators that have APFs of 25, 50, or 1000. A respirator's APF refers to the maximal level of protectiveness a specific respirator design can achieve under laboratory conditions. 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 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. Make N95 disposable filtering facepiece respirators available for voluntary use for protection against coffee dust exposure such as when working with green coffee beans or burlap bags. 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 (https://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, such as those in flavorings, NIOSH-certified organic vapor cartridges (for the alpha-diketones) and particulate cartridges/filters (for the dust) would be warranted.

Medical Monitoring

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

1. Some coffee processing workers who flavor coffee or have exposure to flavored coffee production using the flavoring chemicals diacetyl and 2,3-pentanedione have developed obliterative bronchiolitis [Bailey et al. 2015]. At the time of the NIOSH visit, flavoring was performed quarterly (four times per year), in small batches of approximately 50 pounds; however, flavoring of coffee beans was not performed during the NIOSH visit. As detailed in the NIOSH Criteria Document [NIOSH 2016], we recommend that the employer implement a medical monitoring program for all

employees who flavor these small batches of coffee.

2. According to the NIOSH Criteria Document, employees should have baseline evaluations before they are allowed to work in or enter areas where they might be exposed to diacetyl, 2,3-pentanedione, or similar flavoring compounds. The spirometry we conducted in September 2017 could serve as a baseline for survey participants. Employees in the medical monitoring program should be evaluated with a questionnaire (to obtain health and work task information) and spirometry (to assess lung function). If an employee is identified to have lung disease from exposure to diacetyl, 2,3-pentanedione, or a similar flavoring compound, then all employees who perform similar job tasks or have a similar or greater potential for exposure should also be included in the medical monitoring program [NIOSH 2016].

Appendix A: Tables

Table A1. OSHA Methods 1013/1016 personal and area full-shift air sampling results by location, NIOSH industrial hygiene survey, September 2017.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Administration	4	4 (100%)	0.7	1.5	0
Diacetyl	Personal	Production	2	2 (100%)	2.5	2.7	0
Diacetyl	Personal	Roasting	2	2 (100%)	2.1	2.9	0
Diacetyl	Personal	Shipping	2	2 (100%)	0.6	1.4	0
Diacetyl	Area	Outside	2	0 (0%)	<0.3	<0.3	N/A
Diacetyl	Area	Packaging	4	4 (100%)	0.7	3.9	N/A
Diacetyl	Area	Production Office	2	2 (100%)	0.6	1.4	N/A
Diacetyl	Area	Roasted Bean Storage	2	2 (100%)	1.0	1.7	N/A
Diacetyl	Area	Roasting	4	4 (100%)	0.7	1.6	N/A
Diacetyl	Area	Shipping	2	2 (100%)	0.7	1.6	N/A
2,3-Pentanedione	Personal	Administration	4	4 (100%)	0.4	1.1	0
2,3-Pentanedione	Personal	Production	2	2 (100%)	2.1	2.6	0
2,3-Pentanedione	Personal	Roasting	2	2 (100%)	1.6	2.4	0
2,3-Pentanedione	Personal	Shipping	2	2 (100%)	0.4	1.1	0
2,3-Pentanedione	Area	Outside	2	0 (0%)	<0.3	<0.3	N/A
2,3-Pentanedione	Area	Packaging	4	4 (100%)	0.4	3.3	N/A
2,3-Pentanedione	Area	Production Office	2	1 (50%)	<0.3	1.1	N/A
2,3-Pentanedione	Area	Roasted Bean Storage	2	2 (100%)	0.6	1.4	N/A
2,3-Pentanedione	Area	Roasting	4	4 (100%)	0.4	1.4	N/A
2,3-Pentanedione	Area	Shipping	2	2 (100%)	0.4	1.2	N/A
2,3-Hexanedione	Personal	Administration	4	0 (0%)	<0.5	<0.5	—
2,3-Hexanedione	Personal	Production	2	0 (0%)	<0.5	<0.6	—
2,3-Hexanedione	Personal	Roasting	2	0 (0%)	<0.5	<0.5	—
2,3-Hexanedione	Personal	Shipping	2	0 (0%)	<0.5	<0.5	—
2,3-Hexanedione	Area	Outside	2	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Packaging	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Production Office	2	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Roasted Bean Storage	2	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Roasting	4	0 (0%)	<0.5	<0.5	N/A
2,3-Hexanedione	Area	Shipping	2	0 (0%)	<0.5	<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 N (%)=number and percentage of samples above limit of detection (LOD); ppb=parts per billion; < indicates below the LOD; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); N/A indicates that NIOSH RELs are specified for personal air samples and cannot be directly applied to area air samples; "—" indicates that there is currently no REL for 2,3-hexanedione.

Table A2. OSHA Methods 1013/1016 personal task-based air sampling results NIOSH industrial hygiene survey, September 2017.

Analyte	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean* Sample Duration (minutes)
Diacetyl	Package coffee	3	2 (67%)	<0.9	1.1	15
Diacetyl	Roast coffee beans	6	6 (100%)	1.1	12.3	15
2,3-Pentanedione	Package coffee	3	0 (0%)	<1.0	<1.0	15
2,3-Pentanedione	Roast coffee beans	6	5 (83%)	<1.0	9.7	15
2,3-Hexanedione	Package coffee	3	0 (0%)	<1.4	<1.4	15
2,3-Hexanedione	Roast coffee beans	6	0 (0%)	<1.4	<1.4	15

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); ppb=parts per billion; < indicates below the LOD.
***All samples were 15 minutes in duration so a range is not reported.**

Table A3. Prevalence of reported symptoms, NIOSH medical survey, September 2017.

Symptom	Experienced in the last 12 months N=17 Number (%)	Experienced in the last 4 weeks N=17 Number (%)
Nose symptoms*	8 (47%)	5 (29%)
Eye symptoms†	7 (41%)	4 (24%)
Sinusitis or sinus problems	2 (12%)	0 (0%)
Problem with ability to smell	0 (0%)	—
Phlegm on most days for 3 months	0 (0%)	—
Lower respiratory symptoms (reported at least one of the following)‡	4 (24%)	1 (6%)
Awoke with chest tightness	2 (12%)	1 (6%)
Awoke with shortness of breath	1 (6%)	0 (0%)
Breathing trouble	1 (6%)	0 (0%)
SOB on level ground or walking up a slight hill	1 (6%)	—
Asthma attack	1 (6%)	0 (0%)
Usual coughβ	1 (6%)	0 (0%)
Chest wheezing or whistling	0 (0%)	0 (0%)
Systemic symptoms (reported at least one of the following)	7 (41%)	2 (12%)
Episodes of flu-like achiness or achy joints	5 (29%)	2 (12%)
Episodes of fever or chills	3 (18%)	0 (0%)
Unusual tiredness or fatigue	1 (6%)	0 (0%)

Note: N=number of participants; SOB=shortness of breath; "—"=A four week question was not asked for the symptom.
***Nose symptoms includes one or both of the following: 1) stuffy, itchy, or runny nose or 2) stinging, burning nose.**
†Eye symptoms includes one or both of the following: 1) watery, itchy eyes or 2) stinging, burning eyes.
‡All four of the participants with one or more lower respiratory symptoms reported these respiratory symptoms did not improve when away from the workplace.
βThis question did not specifically ask about a cough within the past 12 months; participants were asked, "Do you usually have a cough?" If the participant answered yes to that question, they were then asked, "Have you had a cough at any time in the last 4 weeks?"

Table A4. Adjusted* comparison of symptoms and self-reported asthma diagnosis among NIOSH medical survey participants (N=17) to U.S. adult population, September 2017.

Health condition	Comparative population†	Observed number	Expected number	SMR (95% CI)‡
Stuffy, itchy, or runny nose last 12 months	NHANES III	8	10.5	0.8 (0.4–1.5)
Watery, itchy eyes last 12 months	NHANES III	6	7.6	0.8 (0.4–1.7)
Sinus problems last 12 month	NHANES III	2	6.7	0.3 (0.1–1.1)
Shortness of breath on exertion	NHANES III	1	2.2	0.4 (0.1–2.5)
Ever asthma (physician-diagnosed)β	NHANES 2007–2012	1	1.3	0.8 (0.1–4.5)

Note: NHANES=National Health and Nutrition Examination Survey; SMR=standardized morbidity ratio.
***Adjusted for sex, race/ethnicity, age, and smoking categories.**
†We used the most recent NHANES survey available for each comparison.
‡95% confidence intervals (95% CI) that exclude one are statistically significantly different from comparison with U.S. adult population and are shown in bold.
βThe participant with asthma reported being diagnosed prior to employment at the coffee roasting and packaging facility.

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