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 and grinding.

What We Did

- We visited the coffee roasting and packaging facility on July 14-16, 2015 and March 9-11, 2016.
- We collected full-shift (hours), task (minutes), and instantaneous (seconds) air samples to measure concentrations of the alpha-diketones diacetyl, 2,3-pentanedione, and 2,3-hexanedione over multiple days during each visit.
- We collected roasted coffee beans (whole bean and ground) to measure their emission potential for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.
- We measured real-time air levels of carbon monoxide and carbon dioxide.
- We collected air samples for dust throughout the facility.
- 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 (roaster operator, grinder operator, and weigh/package employees) were exposed to diacetyl at concentrations above the recommended exposure limit for diacetyl of 5 parts per billion, with the highest measured concentration of 8.4 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. Diacetyl and 2,3-pentanedione were detected in a majority of full-shift personal breathing zone air samples, with a maximum concentration of diacetyl of 8.4 parts per billion and of 2,3-pentanedione of 5.7 parts per billion. Ten of the full-shift samples exceeded the NIOSH recommended exposure limit for diacetyl of 5 parts per billion. In addition, air sampling during short-term tasks identified several tasks (e.g., grinding roasted coffee beans and blending roasted coffee beans) with higher exposures to alpha-diketones, including diacetyl, than other tasks. Exposures were higher when bay doors were closed and increased over the course of the work shift. Eye, nose, and sinus symptoms were the most commonly reported symptoms. Wheezing was the most common lower respiratory symptom reported; four times as many employees as expected reported this symptom than in the U.S. population with a similar demographic distribution. One participant had abnormal spirometry not thought to represent flavoring-related lung disease. We recommend operating the exhaust fan and make-up air system in the production space whenever occupied; installing local exhaust ventilation; implementing administrative controls such as modification of work practices; and training employees about work-place hazards. We also recommend instituting a medical monitoring program.

- During the second visit, higher alpha-diketone exposures were measured likely due to decreased natural ventilation and higher production volumes. Bay doors were open in July 2015 and closed in March 2016 due to colder temperatures.
- Levels of diacetyl in the air during short-term sampling were higher for tasks involving grinding roasted beans (maximum 37.6 parts per billion), blending roasted beans by hand (maximum 33.4 parts per billion), and weighing and packaging roasted coffee (maximum 34.3 parts per billion).
- Carbon dioxide and carbon monoxide levels were higher inside roasted bean storage bins but generally low throughout the facility.
- All tested roasted coffee beans emitted diacetyl, 2,3-pentanedione, and/or 2,3-hexanedione.
- All area air samples for dust were below occupational exposure limits.
- During the first visit, the roof-top exhaust stack for one of the roasters had an accumulation of chaff that could negatively affect ventilation efficiency, energy usage, and roaster performance. During the second visit, both exhaust stacks had been cleaned and were clear of debris.
- Eye, nose, and sinus symptoms were the most commonly reported symptoms. Some employees reported their symptoms were caused or aggravated by green coffee dust, chaff, roasted coffee, ground coffee dust, or odors from the heat sealing machine.
- Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom; four times as many employees reported wheezing than expected.
- One of 16 participants had abnormal spirometry that significantly improved after bronchodilator treatment and was not thought to represent flavoring-related lung disease or asthma.
- One of 16 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.
- Ensure the continuous operation of the exhaust fan and the make-up air system in the production space at all times during production activities.
- Weather permitting, open the bay doors and outside windows during roasting, grinding, and packaging of roasted coffee beans.
- Follow manufacturer's guidelines for periodic cleaning of the roasters' exhausts.
- Automate transfer of roasted beans, whenever possible, to minimize manual handling.
- Minimize production tasks that require employees to place their heads inside roasted

bean bins.

- Provide an alternative method to hand-blending roasted coffee beans.
- Consider installing local exhaust ventilation to reduce air concentrations of alpha-diketones during the following tasks: 1) blending roasted coffee by hand, if an alternative method cannot be provided; 2) grinding roasted coffee, and 3) weighing and packaging roasted coffee.
- Conduct follow-up air sampling to verify that the modifications have been effective in reducing exposures to below the recommended exposure limits.
- Eliminate the use of compressed air as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet methods whenever possible.
- Make N95 disposable filtering-face piece respirators available for voluntary use for protection against dust exposure when emptying burlap bags of green beans into the storage silos, cleaning the roaster exhaust system of chaff, emptying the chaff containers, or cleaning the green bean storage area.
- Encourage employees to report new, 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

- Operate the exhaust fan at all times during production activities.
- Weather permitting, open the bay doors and outside windows during roasting, grinding, and packaging of roasted coffee beans.
- As much as possible, avoid placing your head directly inside roasted bean storage bins.
- Follow your employer's instructions for an alternative method to hand-blending roasted coffee beans.
- Use any local exhaust ventilation as instructed by your employer when it is installed.
- Although dust exposures were below exposure limits, some employees may wish to use N95 disposable filtering-facepiece respirators 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.
- 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

µm	Micrometer
µg	Microgram
°F	degrees Fahrenheit
ACGIH®	American Conference of Governmental Industrial Hygienists
APF	Assigned protection factor
AX	Area of reactance
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
DR5-R20	The difference between resistance at 5 and 20 Hertz
FEV_1	1-second forced expiratory volume
fpm	Feet per minute
Fres	Resonant frequency
FVC	Forced vital capacity
HVAC	Heating, ventilation, and air-conditioning
Hz	Hertz
kPa/(L/s)	Kilopascals per liter per second
IDLH	Immediately dangerous to life or health
IOM	Institute of Occupational Medicine
LPM	Liters per minute
LOD	Limit of detection
LOQ	Limit of quantitation
mg/m^3	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
RH	Relative humidity
SMR	Standardized morbidity ratio
STEL	Short-term exposure limit
TLV®	Threshold limit value
TVOC	Total volatile organic compound
TWA	Time-weighted average
US	United States
VOC	Volatile organic compound
X5	Reactance at 5 Hertz

Summary

In April 2014, the National Institute for Occupational Safety and Health's Health Hazard Evaluation Program received a request from the management of a coffee roasting and packaging facility with 26 employees regarding concerns about exposures to and health effects from diacetyl and 2,3-pentanedione during coffee roasting and grinding. In July 2015, we conducted the initial industrial hygiene survey and ventilation assessment at the facility. The industrial hygiene survey consisted of collecting personal breathing zone and area air samples for alpha-diketones (i.e., diacetyl, 2,3-pentanedione, and 2,3-hexanedione) and dust. Bulk samples of whole bean and ground roasted coffee were collected to evaluate the potential for emission of diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We used continuous monitoring instruments to measure total volatile organic compounds, carbon monoxide, carbon dioxide, temperature, and relative humidity in specific areas and during tasks. We also conducted a ventilation assessment in the production and office areas and held brief individual interviews with employees. Two interim reports with recommendations were sent to the company following our first visit. In March 2016, we conducted a second industrial hygiene survey, a second ventilation assessment, and a medical evaluation of employees. The industrial hygiene survey included the collection of air and bulk samples for diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We used continuous monitoring instruments to measure total volatile organic compounds, carbon monoxide, and carbon dioxide in specific areas and during specific work tasks. The medical survey consisted of a health questionnaire and breathing tests.

Overall, time-weighted average air concentrations of diacetyl and 2,3-pentanedione were consistently higher during our second industrial hygiene survey in March 2016. During our second visit, the production area exhaust fan was off, the bay doors were closed, and more coffee was processed, which likely contributed to the higher concentrations. Ten of the 49 full-shift samples collected during the two surveys exceeded the NIOSH recommended exposure limit for diacetyl of 5 parts per billion, with a maximum concentration of 8.4 parts per billion. We identified jobs where some work tasks resulted in relatively higher air concentrations of diacetyl than other tasks. Specifically, grinding roasted coffee beans, blending roasted coffee beans by hand, and weighing and packaging roasted coffee were associated with higher diacetyl levels. Overall, the most commonly reported symptoms were associated with mucous membranes, specifically the eyes, nose, and sinuses. Some production employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust or chaff, roasted coffee, or ground coffee dust. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom, and was four times higher than that expected when compared to the U.S. population of the same age, race/ethnicity, sex, and cigarette smoking distribution. One participant had abnormal spirometry not thought to represent flavoring-related lung disease and one participant had high exhaled nitric oxide, a marker of allergic airways inflammation. We recommend operating the exhaust fan and make-up air system in the production space during occupancy, installing local exhaust ventilation, and training employees about workplace hazards. We also recommend a medical monitoring program to identify any employees who may be developing work-related lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease.

Introduction

In April 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 regarding potential worker exposure to diacetyl and 2,3-pentanedione during coffee processing. In July 2015, we conducted an initial ventilation assessment and industrial hygiene survey at the facility while the bay doors on both ends of the coffee processing area were open, increasing natural ventilation. We collected area and personal breathing zone air samples for dust and volatile organic compounds (VOCs), including diacetyl, 2,3-pentanedione, and 2,3-hexanedione. We monitored carbon monoxide (CO), carbon dioxide (CO_2), and total VOCs. After the first visit, we provided two interim reports with recommendations. In March 2016, we conducted a second ventilation assessment and industrial hygiene survey while the bay doors were closed; 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 one-way valves to allow the coffee to off-gas after it is packaged. Sometimes, newly roasted coffee is placed in bins or containers and allowed to off-gas before packaging.

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

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

2,3-Hexanedione

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

Carbon Monoxide and Carbon Dioxide

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

Inhalable and Respirable Dust

Dust refers to the particles present in air, either from natural forces or from mechanical processes. Inhalable and respirable dust particles differ by their size. Inhalable dust particles are larger and can enter the nose and mouth during breathing and can deposit in the upper and lower respiratory tract. Respirable dust particles are very small and can reach the deepest (gas exchange) parts of the lungs. Occupational exposure limits for inhalable and respirable dust are listed in Table 1.

Obliterative Bronchiolitis

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

Work-related Asthma

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

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

Previous Industrial Hygiene Sampling at This Coffee Roasting and Packaging Facility

On March 3, 2015, an industrial hygienist, hired by a local newspaper, collected personal air samples using OSHA Method 1012 on three employees during roasting (two roaster operators) and grinding (one grinder operator) at the facility that is the subject of this report. The bay doors in the production area were closed during sampling. According to the industrial hygiene report dated March 15, 2015, measureable levels of diacetyl were detected in all three personal air samples. Measureable levels of 2,3-pentanedione (using OSHA method 1016) were detected from the two roaster operators but not the grinder operator. TWA personal exposures to diacetyl for the two roaster operators and the grinder operator were 6.9 ppb (roaster operator #1), 8.1 ppb (roaster operator #2), and 19.3 ppb (grinder operator) and exceeded the NIOSH REL for diacetyl in all samples. The TWA personal air concentrations for 2,3-pentanedione were 5.3 ppb (roaster operator #1), 5.6 ppb (roaster operator #2), and 6.4 ppb (grinder operator) and did not exceed the NIOSH REL for 2,3-pentanedione.

Based on these air sampling results, the coffee roasting and packaging company wanted to be proactive and more fully characterize concentrations of alpha-diketones in the air and assess the efficiency of the existing ventilation systems. In April 2015, the management submitted a health hazard evaluation request to NIOSH.

Process Description

In April 2013, the company moved from another facility to the location that was evaluated. Their evaluated facility was approximately 16,000 square feet with 11,000 square feet dedicated to production activities and 5,000 square feet for office space. The company had approximately 26 onsite employees at the time of the first survey and 25 at the time of the second survey. The employees were not represented by a union. Production was divided into two shifts with seven production employees from 8 am to 4 pm and three employees from 1 pm to 9 pm. About half of the employees were involved in various administrative tasks including accounts receivable, customer service, inventory control, graphic design, sales, and farmer relations. The remaining employees worked in the production area (described below). There was no café onsite. The following describes activities at the time of the NIOSH visits in July 2015 and March 2016. Roasted coffee production was greater during the second visit.

Green beans were received in burlap bags from countries around the world including, but not limited to, Colombia, Guatemala, Mexico, and Honduras. Upon arrival at the facility, pallets of green beans in burlap bags were stored on shelves in the green bean receiving department until they were dispensed into large green bean storage silos, located next to the roasters. At the time of our first visit, roaster operators climbed an A-frame ladder to empty burlap bags of green beans into the green bean storage silos. At our second visit, a permanent stair structure had replaced the A-frame ladder to the green bean storage silos, following NIOSH recommendations made as a result of our first visit. To prepare a batch for roasting, a roaster operator opened a small door at the bottom of the green bean storage silo and dispensed green beans into a container, on a scale, to achieve the proper weight needed for a roast. The green beans were manually emptied into the hopper of either one of two roasters (convection or conduction roasters). The green beans were automatically conveyed from the hopper into the roasting drum where they were heated at a specific temperature and time period for the desired roast. At the end of each roast cycle, a roaster operator opened a slot at the bottom of the roaster that emptied the roasted beans into a cooling drum where they were automatically mixed by an agitator to accelerate cooling.

The cooling drum utilized a downdraft exhaust system that drew air over the roasted beans and down into the cooling drum to accelerate cooling. The downdraft system exhausted out through the roof. A roaster operator monitored the roasting equipment carefully throughout the roasting and cooling process. After cooling, the roasted beans were emptied from the cooling drum into plastic containers. A roaster operator then manually moved the containers to an elevator lift that raised one or more buckets of roasted coffee beans to an elevated platform. At the time of our first visit, there was an unguarded section of the platform by the hydraulic lift which increased the risk for unintentional fall injuries. At our second visit, a guard had been added to the platform by the hydraulic lift, following NIOSH recommendations from our first visit. On the platform, the roaster operator emptied the buckets of roasted coffee beans into their respective storage bins on the other side of the platform.

An employee in the weigh and pack area dispensed the roasted beans from small doors at the bottom of the roasted bean storage bins into a plastic container to obtain the desired amount for grinding or packaging. For orders requiring mixtures of different roasted coffee beans, blends were completed by either automatically mixing batches in the cooling drum or manually mixing batches in storage containers. For whole bean coffee, the roasted beans were manually transferred using buckets into an automatic weigh-fill packaging machine where mainly three different amounts were dispensed for packaging: 12 ounces, 2 pounds, and 5 pounds. The company also packaged smaller, fraction packs in 2.5-ounce, 3-ounce, and 8-ounce bags. For ground coffee, individual, pre-weighed packages of roasted whole beans were manually emptied into a grinder. The packages were placed at the bottom of the grinder to collect the ground coffee during grinding. There were three grinding machines, one of which was only used for grinding espresso beans. The grinders could be adjusted for type of grind (coarse, medium, or fine).

One or more employees (often grinder operators) heat-sealed packages of whole bean and ground coffee and placed the bags on storage shelves in the storage and holding area or immediately packed them for shipment or local delivery. All packages were equipped with one-way valves for off-gassing.

Quality Control

The company took measures to ensure the quality of green and roasted beans. The facility had a quality control room located between the production and office areas where roasted beans and brews could be prepared and assessed. Upon receipt, an employee profiled the green beans to determine the best roast temperature and time. Green beans stored in silos were monitored over time as they aged and roasting specifications were adjusted to account for any changes in the green beans. Within each specific type of roast, the roasted beans were packaged in the order they were roasted to ensure freshness.

Cleaning Activities

Various cleaning techniques were used throughout the production areas. Employees used brooms to sweep the production floor, wet or dry wipes on table tops and equipment surfaces, and compressed air to remove coffee bean dust from surfaces and equipment. The facility had a wash station equipped with a commercial dishwasher that washed buckets and containers for reuse.

Repair Activities

One employee repaired production equipment and customers' coffee roasting equipment (roasters, grinders, and espresso machines).

Personal Protective Equipment

Employees were not required to wear a company uniform or protective clothing. We did not observe employees wearing respiratory protection for chemicals or dust during either of our visits. Hearing protection was available for voluntary use at each roaster.

Methods

We initially visited the coffee roasting and packaging facility in July 2015. We held an opening meeting with management and employees, collected bulk samples and air samples, performed a ventilation assessment, and had informal interviews with employees. The bay doors in the production area were open during this visit. At the conclusion of our site visit, we held a closing meeting with management and employees. Two interim reports with recommendations were sent to the company following our first visit. We visited the facility again in March 2016. We collected bulk samples and air samples and performed another ventilation assessment with the bay doors closed; we also conducted a medical survey.

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, CO_2, and inhalable and respirable dust throughout the facility;
4. Assess ventilation systems and their effect on exposure levels;
5. Determine if employees had mucous membrane, respiratory, or systemic symptoms and the proportion of those symptoms that were work-related or aggravated by work;
6. Determine if employees had abnormal lung function tests;
7. Compare employees' prevalence of lower respiratory symptoms and healthcare provider-diagnosed asthma to expected levels based on general population values.

Industrial Hygiene Survey

Sampling Times for Alpha-Diketones

We designed the sampling strategy to assess full-shift exposures and to identify tasks and processes that were the greatest contributors to worker exposure to alpha-diketones. Sampling was conducted over multiple days during each 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.

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

A limit of detection (LOD) is the lowest mass that an instrument can detect above background and is a 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 decreased between the first and second visit. The LODs for the first visit were 0.049 micrograms per sample (μg/sample) for diacetyl, 0.046 μg/sample for 2,3-pentanedione, and 0.053 μg/sample for 2,3-hexanedione; these were based on the lowest mass used in the calibration curve. These equate to 1.5 ppb for diacetyl, 1.6 ppb for 2,3-pentanedione, and 1.3 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 LOQs for the first visit equate to 5.0 ppb for diacetyl, 5.3 ppb for 2,3-pentanedione, and 5.7 ppb for 2,3-hexanedione for a typical full-shift air sample. The LODs for the second visit were 0.01 μg/sample for diacetyl, 0.012 μg/sample for 2,3-pentanedione, and 0.02 μg/sample for 2,3-hexanedione; these were based on variability of low-level spiked samples. These equate to 0.32 ppb for diacetyl, 0.33 ppb for 2,3-pentanedione, and 0.48 ppb for 2,3-hexanedione for a typical full-shift TWA air sample. The LOQs for the second trip equate to 1.1 ppb for diacetyl, 1.1 ppb for 2,3-pentanedione, and 1.6 ppb for 2,3-hexanedione for a typical full-shift air sample. The LODs for task samples are generally higher than typical LOD values for full-shift samples since the air volumes collected during task samples are lower. When the values presented in the report are from samples below the LOD they are denoted by a "<" symbol.

Air Sampling and Analysis Using Evacuated Canisters

We collected personal and area full-shift air samples (during the first visit) and instantaneous task-based and source air samples (during both visits) for VOCs including diacetyl, 2,3-pentanedione, and 2,3-hexanedione using evacuated canisters. We also collected instantaneous air samples before and after the work shift to determine if air concentrations of alpha-diketones increased over a work shift. The evacuated canister sampling setup consisted of a 450-mL evacuated canister equipped with either a restricted flow controller set at a 15-minute or 6-hour duration (first visit only), or an instantaneous flow controller that was designed for a short sampling duration (less than 30 seconds). Instantaneous samples were taken by opening the evacuated canister to grab a sample of air to help identify point sources of alpha-diketones. For task-based air samples, a NIOSH employee placed the inlet of the flow controller by the employee's personal breathing zone as they performed their work task to replicate exposure. For source air samples, a NIOSH employee placed the inlet of the flow controller directly at the source of interest.

The canister air samples were analyzed using a pre-concentrator/gas chromatograph/mass spectrometer system pursuant to a published method validation study [LeBouf et al. 2012], with the following modifications: the pre-concentrator was a Model 7200 (Entech Instruments, Inc., Simi Valley, CA), and six additional compounds, diacetyl, 2,3-pentanedione, 2,3-hexanedione, acetaldehyde, acetonitrile, and styrene, were included. At present, this canister method is partially validated [LeBouf et al. 2012] and not considered the standard method. For the first visit, the LODs were 0.84 ppb for diacetyl, 1.38 ppb for 2,3-pentanedione, and 2.49 ppb for 2,3-hexanedione based on a three-times dilution factor, which is typical for restricted flow controller samplers. For the second visit, the LODs were 0.78 ppb for diacetyl, 1.08 ppb for 2,3-pentanedione, and 1.92 ppb for 2,3-hexanedione based on a three-times dilution factor. However, LODs are dependent on the pressure inside each canister after the samples have been collected, and they may be higher or lower than typical LOD values.

Bulk Sampling and Headspace Analysis

We used 50-mL sterile polypropylene centrifuge tubes to collect approximately 40-mL bulk samples of roasted coffees (whole bean and ground). For headspace analysis of alpha-diketones, we transferred 1 gram of solid bulk material into a sealed 40-mL amber volatile organic analysis vial and let it rest for 24 hours at room temperature (70°F) in the laboratory. Then 2 mL of headspace air was transferred to a 450-mL canister and pressurized to approximately 1.5 times atmospheric pressure. Using the canister analysis system, the concentrations were calculated in ppb of analytes in the headspace as an indicator of emission potential.

Real-time Air Sampling

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

Area Air Sampling and Analysis for Inhalable and Respirable Dust (1st visit only)
We collected area air samples for inhalable dust using the Institute of Occupational Medicine (IOM) sampler loaded with a pre-weighed 25-mm polyvinyl chloride filter with air pulled through the filter at a flow rate of 2 liters per minute (LPM) during our first visit in July 2015. Inhalable dust samples were collected and weighed following NIOSH Method 0500 [NIOSH 2003]. Air samples for respirable dust were collected using a GK 2.69 cyclone (Waltham, MA) mounted onto a close-face, two-piece cassette loaded with a 37-mm polyvinyl chloride filter with air pulled through the filter at a flow rate of 4.2 LPM. Respirable dust samples were collected and weighed following NIOSH Method 0600 [NIOSH 2003].

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

<u>Occupational Safety and Health Administration (OSHA)</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 2016]. OSHA short-term exposure limits (STELs) are the legal maximum average exposure for a 15-minute time period. Some chemicals also have an OSHA ceiling value which represent levels that must not be exceeded at any time. Currently, there are no PELs for diacetyl, 2,3-pentanedione, or 2,3-hexanedione. For substances for which an OSHA PEL has not been issued, violation of the OSHA General Duty Clause can be considered using available occupational exposure references and recommendations [OSHA 1993; OSHA 2003], such as the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®) and NIOSH RELs.

<u>American Conference of Governmental Industrial Hygienists (ACGIH®)</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 threshold limit values (TLVs) [ACGIH 2016]. 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 2016]. 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 2017].

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

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

Table 1. Personal exposure limits for compounds sampled for during the NIOSH surveys, July 2015 and March 2016.

Compound	OSHA*	ACGIH		NIOSH		
	PEL	TLV	STEL	REL	STEL	IDLH
Diacetyl	-	10 ppb	20 ppb	5.0 ppb†	25 ppb	-
2,3-Pentanedione	-	-	-	9.3 ppb†	31 ppb	-
2,3-Hexanedione	-	-	-	-	-	-
Total dust	15 mg/m^3	-	-	-	-	-
Respirable dust	5.0 mg/m^3	3.0 mg/m^3‡	-	-	-	-
Inhalable dust	-	10 mg/m^3‡	-	-	-	-
Carbon dioxide	5,000 ppm	5,000 ppm	30,000 ppm	5,000 ppm	30,000 ppm	40,000 ppm
Carbon monoxide§	50 ppm	25 ppm	-	35 ppm	200 ppm (ceiling limit)¶	1,200 ppm

Note: OSHA=Occupational Safety and Health Administration; ACGIH=American Conference of Governmental Industrial Hygienists; NIOSH=National Institute for Occupational Safety and Health; PEL=permissible exposure limit; STEL=short-term exposure limit; TLV=threshold limit value; REL=recommended exposure limit; IDLH=immediately dangerous to life or health; mg/m^3=milligram per cubic meter; ppb=parts per billion; ppm=parts per million; "-"=no exposure limit available.
***There are no OSHA STELs for the compounds in the table.**
†The NIOSH RELs for diacetyl and 2,3-pentanedione are time-weighted averages for up to an 8- or 10-hour day, during a 40-hour workweek.
‡ACGIH does not have a TLV for inhalable or respirable dust but does provide guidelines for inhalable and respirable dust; ACGIH guidelines suggests airborne concentrations be kept below 3 mg/m^3 for respirable particles and 10 mg/m^3 for inhalable particles.
§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

We collected physical measurements of all rooms and calculated approximate room volumes. Air flow measurements of supply vents and exhaust outlets were taken using an Accubalance Plus Model 8373 Air Capture Hood (TSI Incorporated, St. Paul, MN) or a TSI VelociCalc Plus Model 8324 Rotating Vane Anemometer (Shoreview, MN), depending on which was most appropriate for the ventilation component being measured. The complete set of ventilation measurements allowed the calculation of volumetric flow rates in cubic feet per minute (cfm) into and out of each area. Differential pressure measurements between adjacent spaces were taken under various ventilation scenarios using an Energy Conservatory DG-500 Pressure Gauge (Minneapolis, MN).

Informal Interviews during First Site Visit in July 2015

A NIOSH medical officer conducted private individual interviews with 22 employees about their work history and health concerns.

NIOSH Medical Survey

Participants

We invited all current employees to participate in the medical survey at the workplace on March 14-16, 2016. Participation was voluntary; written informed consent was obtained from each participant before testing. The survey included, in the order performed, a medical and work history questionnaire, quantification of exhaled nitric oxide, impulse oscillometry, spirometry, and if indicated the administration of a bronchodilator with repeat impulse oscillometry and spirometry. We mailed participants their individual reports explaining their breathing test results and recommended each participant provide the information to their personal physician.

Questionnaire

We used an interviewer-administered computerized questionnaire to ascertain symptoms and diagnoses, work history at this coffee 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 [NCHS 2015]. Some of the questions appeared on more than one of the standardized questionnaires. We also supplemented our questionnaire with additional respiratory and systemic symptom questions.

Spirometry

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

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

Impulse Oscillometry

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

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

Bronchodilator Reversibility Testing for Impulse Oscillometry and Spirometry

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

Fractional Exhaled Nitric Oxide (FeNO)

We used the NIOX MINO® device (Aerocrine Inc., Morrisville, NC) to measure the amount of nitric oxide in the air the participant breathed out. Nitric oxide is a gas that is produced by the airways, and elevated levels can be a sign of eosinophilic airway inflammation in asthma

[Dweik et al. 2011]. In adults, fractional nitric oxide concentration in exhaled breath levels above 50 ppb are considered elevated. In adults with asthma, elevated levels may indicate that their asthma is uncontrolled [Dweik et al. 2011].

Statistical Analysis

Industrial Hygiene Survey and Ventilation Assessment

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

Medical Survey

We calculated frequencies and standardized morbidity ratios (SMRs) and their associated 95% confidence intervals (CI) using SAS version 9.3 (Cary, NC). The SMRs compared prevalences of symptoms and spirometric abnormalities among participants to expected prevalences of a sample of the general population reflected in the NHANES III (1988–1994, symptom and spirometry data), NHANES 2007–2012 (symptom data), and NHANES 2007–2010 (spirometry data) adjusting for sex, race/ethnicity, age (less than 40 years old or 40 years or greater), and cigarette smoking categories (ever/never). For comparisons to the U.S. population, we used the most recent NHANES survey available for the specific comparisons.

Results

Industrial Hygiene Survey Results

Personal and Area Full-shift Air Sampling Results

<u>OSHA Methods 1013/1016</u>

First visit: Table A1 presents the personal and area full-shift air sampling results from our first visit in July 2015. We collected 23 personal and 30 area full-shift air samples over three days. Two personal air samples were above the NIOSH REL for diacetyl of 5.0 ppb and all were below the NIOSH REL for 2,3-pentanedione of 9.3 ppb. The samples exceeding the REL for diacetyl were collected on different days. A roaster operator had the highest exposure to diacetyl (7.2 ppb) and 2,3-pentanedione (6.9 ppb). A grinder operator had the second highest exposure to diacetyl (5.3 ppb) and 2,3-pentanedione (3.7 ppb). All personal samples were below the LOD for 2,3-hexanedione. All area air samples were below the LOD for diacetyl, 2,3-pentanedione, and 2,3-hexanedione.

Second visit: Table A2 presents the personal and area full-shift air sampling results from our second visit in March 2016. We collected 26 personal and 41 area full-shift air samples over three days. Eight of the 26 personal air samples (31%) exceeded the NIOSH REL for diacetyl of 5.0 ppb and all were below the NIOSH REL for 2,3-pentanedione of 9.3 ppb. The samples exceeding the diacetyl REL were collected on different days (two on day 1, five on day 2, and one on day 3). Overall, weigh/package employees had the highest exposure to diacetyl and 2,3-pentanedione. The 11 weigh/package employee measurements for diacetyl ranged from

3.1 ppb – 8.4 ppb; seven (64%) of these exceeded the NIOSH REL for diacetyl. All weigh/package employee measurements for 2,3-pentanedione were below the NIOSH REL. One of five roaster operator measurements for diacetyl (5.1 ppb) was above the NIOSH REL. All personal samplers were below the LOD for 2,3-hexanedione. The difference in personal sample results between the first and second visits is likely due to differences in sampling conditions including an increase in production volume, decreased natural ventilation caused by closed bay doors, and not continuously operating the ceiling exhaust fan in the production area.

Area sampling showed the storage/holding area had the highest air concentrations of diacetyl with a range of 9.4 ppb – 10.7 ppb. The range was 5.0 ppb – 5.8 ppb for 2,3-pentanedione and less than 0.5 ppb – 0.6 ppb for 2,3-hexanedione. The weigh/package area had air concentration of 2,3-pentanedione with a range of 0.8 ppb – 4.7 ppb. All area samples in the weigh/package areas were below LOD for 2,3-hexanedione.

Full-shift Evacuated Canisters

First visit: Table A3 presents the personal and area full-shift air concentrations from our first visit in July 2015 by location. We collected 10 personal and 31 area TWA air samples. None were above the NIOSH RELs for diacetyl or 2,3-pentanedione. An employee involved in weighing and packaging activities had the highest exposure to diacetyl (4.9 ppb) and 2,3-pentanedione (8.3 ppb). A roaster operator had the second highest exposure to diacetyl (3.6 ppb). An employee involved in multiple tasks labeled "All Over" had the second highest exposure to 2,3-pentanedione (3.7 ppb). All area air samples for diacetyl and 2,3-pentanedione were below 4.0 ppb. The grinding area had the highest concentration of diacetyl (3.3 ppb) and 2,3-pentanedione (3.8 ppb).

Second visit: We did not collect personal or area full-shift evacuated canister samples.

Task-based Air Sampling Results

OSHA Methods 1013/1016

First visit: Table A4 presents the personal and area task-based diacetyl, 2,3-pentanedione, and 2,3-hexanedione air concentrations from our first visit in July 2015 by task location. We collected 20 personal and 18 area air samples. An employee that ground roasted beans for 17 minutes had an exposure to diacetyl of 26.9 ppb, which exceeded the NIOSH STEL, and to 2,3-pentanedione of 18.2 ppb. An employee that weighed and packaged roasted beans for 11 minutes had the second highest exposure to diacetyl (23.1 ppb) and 2,3-pentanedione (10.9 ppb). All samples were below the LOD for 2,3-hexanedione.

All task-based area air samples were below the LOD. Area air samples from the roasting area (N=15) were collected directly above the downdraft cooling drum of the roaster while the roasted beans cooled.

Second visit: Table A5 presents the personal task-based air concentrations from our second visit in March 2016 by individual task. We collected 36 personal task-based air samples. An employee that blended roasted beans by hand exceeded the NIOSH STEL for diacetyl (33.4

ppb diacetyl; 22.1 ppb 2,3-pentanedione). An employee that ground roasted beans for 14 minutes had the highest diacetyl (37.6 ppb) and third highest 2,3-pentanedione (20.9 ppb) concentration. This exposure exceeded the NIOSH STEL assuming either the same exposure or a zero ppb exposure for the remaining one minute. An employee that ground roasted beans for 12 minutes had a personal exposure to diacetyl of 27.9 ppb. This exposure exceeded the NIOSH STEL assuming the same exposure for the remaining three minutes. However, this exposure did not exceed the NIOSH STEL assuming a zero ppb exposure for the remaining three minutes. All samples were below the LOD for 2,3-hexanedione.

Evacuated Canisters

First visit: We collected one personal task-based air sample in July 2015 during the grinding process that lasted 15 minutes. 2,3-Hexanedione air concentration was less than the LOD (less than 2.3 ppb). Diacetyl (23.6 ppb) and 2,3-pentanedione (11.0 ppb) air concentrations were both below their respective NIOSH STELs. This result is not included in the tables.

Second visit: Table A6 presents the personal task-based air concentrations from our second visit in March 2016. All evacuated canisters were equipped with an instantaneous flow controller with a sample duration of approximately 30 seconds. Results should not be compared to the 15-minute STELs. We collected 14 personal task-based canister air samples. We sampled four employees that blended roasted beans by hand who had diacetyl concentrations ranging from 15.7 ppb – 193 ppb, 2,3-pentanedione concentrations ranging from 19.5 ppb – 90.7 ppb, and 2,3-hexanedione concentrations ranging from 1.5 – 5.3 ppb. Blending roasted beans by hand had the highest measured concentration of these task-based samples (193 ppb diacetyl; 90.7 ppb 2,3-pentanedione; and 5.3 ppb 2,3-hexanedione). We sampled eight employees that transferred roasted beans from storage containers into a blending bucket. This task was labelled "Pouring of roasted beans" and had diacetyl concentrations ranging from 4.9 ppb – 44.6 ppb, 2,3-pentanedione concentrations ranging from 2.6 ppb – 21.2 ppb, and 2,3-hexanedione concentrations ranging from less than 0.9 – 2.9 ppb. We sampled a single employee that ground roasted beans (64.3 ppb diacetyl; 51.9 ppb 2,3-pentanedione; and 1.9 ppb 2,3-hexanedione). We sampled a single employee that was packaging roasted beans (69.7 ppb diacetyl; 80.5 ppb 2,3-pentanedione; and 5.5 ppb 2,3-hexanedione).

Source Air Sampling Results

OSHA Methods 1013/1016

First visit: We collected four source air samples from inside roasted bean storage bins during our July 2015 visit with a sample duration of 15 minutes. These results are not included in the tables. Diacetyl concentrations ranged from 33.1 ppb – 308 ppb; 2,3-pentanedione concentrations ranged from 44.0 ppb – 206 ppb; and 2,3-hexanedione concentrations ranged from 5.2 ppb – 12.5 ppb.

Second visit: Source air samples were not collected using OSHA Methods 1013/1016.

Evacuated Canisters

First visit: Table A7 presents the source air sampling results using instantaneous evacuated canisters. We followed a French roast source that measured lower diacetyl and 2,3-pentanedione concentrations when it was hot (Roasting #3 8.9 ppb diacetyl) than when it was cooled and placed in a transfer bucket (Roasting #4 109 ppb diacetyl or Roasting #2 87.1 ppb diacetyl). The two samples from the cooled French roast were sampled sequentially. We captured two samples from a grinding source with air concentrations of 146 ppb and 521 ppb for diacetyl and 113 ppb and 229 ppb for 2,3-pentanedione. We collected 30 instantaneous air samples directly inside the roasted bean storage bins. Diacetyl air concentrations ranged from 99.4 ppb – 7,011 ppb; 2,3-pentanedione air concentrations ranged from 47.0 ppb – 4,419 ppb, and 2,3-hexanedione air concentrations ranged from 5.0 ppb – 219 ppb.

Second visit: Table A8 presents source air sampling results using instantaneous evacuated canisters from our March 2016 visit. We collected 20 source air samples using instantaneous evacuated canisters. Two samples were collected directly above roasted beans in the downdraft cooling drum (9.3 ppb and 6.0 ppb for diacetyl; 3.0 and 3.3 ppb for 2,3-pentanedione). Six samples were collected at the lip of open roasted bean transfer containers with diacetyl concentrations ranging from 0.5 ppb – 30.5 ppb (0.6 ppb – 18.6 ppb for 2,3-pentanedione). Five samples were collected at the discharge point of the grinder during grinding with diacetyl concentrations ranging from 127 ppb – 520 ppb (124 ppb – 462 ppb for 2,3-pentanedione). Four samples were collected during the transfer of roasted beans into the top of roasted bean storage bins (3.4 ppb – 184 ppb for diacetyl; 12.2 ppb – 98.0 ppb for 2,3-pentanedione). Three samples were collected at the transfer point of roasted beans into a bucket (10.9 ppb – 23.7 ppb for diacetyl; 6.3 ppb – 17.5 ppb for 2,3-pentanedione). 2,3-Hexanedione concentrations were generally less than diacetyl and 2,3-pentanedione concentrations and ranged from less than 0.9 ppb to 35.6 ppb.

Background Pre- and Post-Shift Diacetyl and 2,3-Pentanedione Canister Results

Table A9 presents the instantaneous evacuated canister pre- and post-shift background air sampling results from our second visit collected in the storage/holding area. Both diacetyl and 2,3-pentanedione air concentrations increased over the course of the work day. The pre-shift diacetyl concentration was 3.5 ppb and post-shift air concentration was 15.5 ppb. The pre-shift 2,3-pentanedione air concentration was 1.6 ppb and post-shift air concentration was 8.5 ppb. 2,3-Hexanedione was below the LOD (<0.6 ppb) for both pre- and post-shift measurements.

Bulk Samples and Headspace Results

Table A10 presents the bulk sample results using headspace analysis from our two visits. Overall, bulk samples from the second visit contained higher headspace air concentrations of diacetyl and 2,3-pentanedione than the first visit. The higher concentrations from the samples collected in March 2016 may be in part due to the fact that the samples were analyzed within 40 days of collection, approximately three times faster than the bulk samples from the first visit. The highest air concentrations of diacetyl (2,069 ppb and 2,012 ppb) and 2,3-pentanedione (1,350 ppb and 1,042 ppb) were associated with whole roasted bean #10. Green coffee beans did not have any air concentrations of diacetyl or 2,3-pentanedione.

2,3-Hexanedione concentrations were generally below the LODs (19 of 22 air samples) or lower than 2,3-pentanedione when above the LOD.

Real-time Monitoring: Carbon Dioxide (CO2), Carbon Monoxide (CO), and Total Volatile Organic Compounds (TVOCs)

First visit: Table A11 presents the results from real-time monitoring for CO, CO_2, temperature, and RH collected in July 2015. Indoor CO levels ranged from 0.7 ppm – 1.6 ppm; the outdoor CO level was less than 0.1 ppm. CO_2 levels within the facility ranged from 800 ppm – 820 ppm, with the outdoor CO_2 at 430 ppm. When the real-time monitor was placed directly inside roasted coffee bean storage bins, we observed elevated levels of CO_2 (540 ppm – 5,200 ppm) and CO (130 ppm – 410 ppm). We did not collect TVOC measurements during our first visit.

Second visit: Table A12 presents the results from real-time monitoring of CO_2, CO, temperature, and RH collected in March 2016. Average CO_2 levels at the roasting machines were 502 ppm and 463 ppm over two days, and average CO levels were 0.8 ppm and 0.3 ppm. The roasted bean storage area had an average CO_2 level of 599 ppm and an average CO level of 2.4 ppm. In addition, we found increased concentrations of TVOCs around areas that stored roasted coffee, especially the storage bins, and areas where grinding occurred (data not shown).

Area Air Sampling and Analysis for Inhalable and Respirable Dust (1st visit only)

Table A13 presents the area dust sampling results from our July 2015 visit by location. All area air samples for respirable and inhalable dust were below OSHA and ACGIH occupational exposure limits. We did not observe any visible dust in the air; however, we did observe dust on surfaces during this visit.

Ventilation Assessment

First visit: There was adequate total air flow to and from all occupied areas on the office side of the facility to maintain temperature control in July 2015.

The ventilation on the production side of the facility consisted of one large rooftop make-up air system providing ventilation to the space and one exhaust fan through the eastern wall of the facility. The ventilation plans for the facility call for the make-up air system to be interlocked so that it is always operational when the roasters are on. This may be the case, but it was not specifically verified during our visit. Regardless, it was operational while we were onsite and provided 3,030 cfm of air into the production area. The exhaust fan was reported to be operated intermittently depending on employee preferences and comfort level. When on, the exhaust fan removed 1,850 cfm of air from the production area. It should be noted that these measurements were taken while the bay doors on both ends of the production space were open, as is typical for the summer months. This made determining any pressure relationships between the production space and office areas unrepresentative.

Although the ventilation systems were well maintained, we did notice an area of concern regarding the afterburner stacks from the roasters in July 2015. While we were outside checking on an area sample, the parking lot was briefly filled with thick smoke. Upon investigating the smoke from the parking lot, we found that the afterburner stack for one of the roasters was smoking due to a build-up of chaff residue (Figure B1). During our inspection on the roof, we also noted that the other roaster exhaust stack was also significantly plugged with chaff and debris (Figure B2). In our first interim report, we recommended that the exhaust stacks be cleaned in accordance with manufacturer instructions to prevent possible safety hazards, improve roaster performance, and enhance energy efficiency.

Second visit: During our second visit in March 2016, total air flow to and from all occupied areas on the office side of the facility were roughly 10% to 15% lower than the values measured in July 2015. Even in the winter months, the three air-handling units on the office side were easily capable of maintaining temperature control.

During the March 2016 visit, the make-up air handling unit was supplying 2,585 cfm of air into the production space. The exhaust fan was not being operated during our visit, so we did not turn it on to measure air flow. The bay doors on both ends of the production space were down during this visit, as is typical for the winter months. This made determining pressure relationships between the production space and office areas possible. Differential pressure measurements showed that the production space was neutral or under slightly positive pressure in relationship to the administrative side of the facility. The pressure readings across all doorways between the production space and the office side of the facility were all +0.002 inches of water.

We inspected the roaster exhaust stacks again during our March 2016 visit. It was obvious that the stacks had been cleaned in response to our recommendation after the July 2015 visit. Both exhaust stacks were largely clean and clear of debris.

Informal Employee Interviews during July 2015 Site Visit

Twenty-two of 26 onsite employees were interviewed individually. Some employees noted symptoms that they attributed to work: occasional sneezing due to odors, sinus problems due to green coffee dust, and skin issues due to cardboard or roasted coffee beans. Diagnoses reported among interviewed employees included seasonal allergies, asthma, and COPD. Approximately half noted they were current or past smokers. Some employees in production noted that once they completed the tasks for their primary job title, they often helped with other production tasks, or sometimes, they would fill-in if someone was absent for the day. On any given day, some supervisors also helped, as needed, with production tasks (e.g., roasting, grinding, weighing, and/or packaging). Some office employees started at the company in coffee processing jobs before moving to office positions. Some employees reported working at another coffee roasting and packaging facility before working at this facility. Multiple employees noted that hearing protection was available for voluntarily use when roasting.

Medical Survey Results March 2016

Demographics

Sixteen of 25 onsite employees (64%) participated in the medical survey, including six of 12 production employees. The majority of participants were male (75%) and Caucasian (88%), with a mean age of 38 years and average tenure at the company (including previous locations) of four years. Four (25%) participants worked at one or more of the company's prior locations or at another coffee roasting and packaging facility prior to working at this facility. Ten (63%) participants were current or former smokers.

All 16 participants reported working in or entering the production area, ranging from 30 minutes to 40 hours a week. All reported being within an arm's length of roasted coffee in one or more areas of the production process. Six of 16 participants worked full-time in the production area processing coffee while some of the other participants assisted with production activities when necessary.

Symptoms and Self-Reported Diagnoses

The prevalences of symptoms over the last year and last four weeks at the time of the survey are listed in Table A14. Nose symptoms were the most commonly reported symptom (n=13, 81%), followed by eye symptoms (n=8, 50%) and sinusitis or sinus problems (n=7, 44%). Five participants reported improvement in their symptoms away from the workplace. Some production employees noted that their symptoms were caused or aggravated by green coffee bean dust, chaff, particular blends of roasted coffee, grinding coffee, ground coffee dust, or an odor from a heat sealing machine used to seal individual bags of coffee.

Wheeze was the most commonly reported lower respiratory symptom (n=9, 56%). None reported improvement in wheeze away from the workplace. Four (n=4, 25%) participants reported shortness of breath, while fewer reported usual cough or phlegm. Flu-like achiness or achy joints was the most commonly reported systemic symptom (n=11, 69%). Two (13%) participants reported that their systemic symptoms were aggravated at work or better when away from work.

Nine participants reported a diagnosis of hay fever or nasal allergies; three reported COPD or asthma. All these conditions were diagnosed prior to employment at the coffee roasting and packaging 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 an obstructive pattern, with significant improvement after bronchodilator. Based on this finding and on questionnaire responses, flavoring-related lung disease was thought to be unlikely. One impulse oscillometry test was interpreted as consistent with a large airway abnormality. Four impulse oscillometry tests, including one performed by the participant with abnormal spirometry, were interpreted as consistent with small airway abnormality; three of these four participants were given bronchodilator, and two had significant improvement in impulse oscillometry. One exhaled nitric oxide test was interpreted as elevated. Most of the participants with abnormalities on medical tests were current or former smokers and reported lower respiratory symptoms, such as wheezing, that did not improve away from work.

NHANES Comparison of Symptoms, Diagnoses, and Spirometry
The SMR for wheeze was elevated at 4.5 (Table A15). SMRs for cough, phlegm, sinus problems, eye symptoms, and physician-diagnosed asthma were not elevated. In addition, there was not an excess of obstructive spirometry abnormalities in comparison to the general U.S. population, adjusted for age distribution, race/ethnicity, sex, and smoking history.

Discussion

Diacetyl, 2,3-pentanedione, 2,3-hexanedione, other VOCs, and other chemicals such as CO and CO_2 are naturally produced when coffee beans are roasted, and grinding the roasted coffee beans produces greater surface area for 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
Ten personal (two roaster operator, one grinder operator, and seven weigh/package employee measurements) full-shift air samples taken inside the facility using standard OSHA methods were above the NIOSH REL for diacetyl. The highest full-shift personal exposure to diacetyl was 8.4 ppb collected from a weigh/package employee during the second site visit. This elevated average exposure was likely due to peak exposures that occurred during handling and transferring roasted coffee beans combined with periods of lower exposures. As noted earlier, the REL should be used as a guideline to indicate when steps should be taken to reduce exposures in the workplace. The risks associated with the measured levels are higher than NIOSH recommends. As described in the quantitative risk assessment from the NIOSH Criteria Document (Table 5-27) [NIOSH 2016], after a 45-year working lifetime exposure to 10 ppb (a concentration slightly higher than the highest concentration measured at this facility) NIOSH estimated less than 2 in 1,000 workers would develop reduced lung function (FEV_1 below the 5th percentile). NIOSH predicted that around 2 in 10,000 workers exposed to diacetyl at 10 ppb would develop more severe lung function reduction (FEV_1 below 60% predicted, defined as moderately severe by the American Thoracic Society [Pellegrino et al. 2005]). The effects of a working lifetime exposure at 8.4 ppb would be somewhat less than those for 10 ppb. NIOSH recommends keeping diacetyl concentrations below 5 ppb because at this level, the risk of reduced lung function after a working lifetime of exposure is below 1 in 1000 workers. NIOSH recommends taking steps to reduce diacetyl exposures to below the REL of 5 ppb whenever possible.

Overall, personal exposures to diacetyl and 2,3-pentanedione were higher during our second visit compared to our first visit. Alpha-diketone emissions of diacetyl and 2,3-pentanedione into the workplace air were directly related to the amount of roasted coffee being produced. During the second visit, the company was roasting and processing more coffee than during the first visit. Since more beans were being roasted and subsequently packaged, weigh/package employees were handling roasted beans more often, which may have resulted in elevated exposures compared to our first visit. Additionally, during our first visit in July 2015, the company left the two production bay doors open to assist in reducing potential exposures and keeping employees cool during warm weather. However, during our second visit in March 2016, the two bays were closed, which likely caused diacetyl and 2,3-pentanedione to build up over the work shift. Additionally, the large exhaust fan in the production space was not operating.

During both visits, the roaster operators often remained at the roaster control panels during the roasting process, approximately three feet from each roaster. Each roasting drum was fully enclosed, and air was exhausted through the roof, minimizing exposures indoors. The only time the roasting drum was opened was during the transfer of roasted beans into the cooling drum. The downdraft system on the roaster machines pulled air over the roasted beans and down into the cooling drum to accelerate cooling which likely decreased the roaster operator's exposure. During both visits, all roasting area samples (Tables A1 and A2) had low concentrations of diacetyl and 2,3-pentanedione indicating the effectiveness of the roasters' downdraft exhaust system.

Two full-shift personal air sample diacetyl and 2,3-pentanedione measurements of roaster operators (one during each visit) were higher than other samples of roaster operators. Peak exposures to diacetyl and 2,3-pentanedione likely contributed to the higher full-shift air sample results for these two employees; throughout the shift, these roaster operators emptied buckets of freshly roasted coffee beans into roasted coffee bean storage bins. The roasted coffee beans off-gassed in these bins. We measured high instantaneous concentrations of diacetyl (99.4 ppb – 7,011 ppb) and 2,3-pentanedione (47.0 ppb – 4,419 ppb) inside the roasted bean storage bins (Table A7). Since these samples were collected inside the storage bins, they were not reflective of employee exposure, but they do indicate an off-gassing source of alpha-diketones.

Both of these higher personal full-shift air samples for the roaster operators exceeded a personal full-shift air sample for a grinder operator. During both visits, grinding was performed infrequently because the majority of sales were whole bean. During task-based air sampling, an employee that ground roasted beans for 14 minutes had the highest diacetyl (37.6 ppb) and third highest 2,3-pentanedione (20.9 ppb) levels. If grinding tasks were performed more often, full-shift air concentrations for the alpha-diketones may have been higher; this was the case at another coffee roasting and packaging facility NIOSH evaluated [Duling et al. 2016].

Area Air Sampling

Area samples collected from the storage/holding area, where package coffee was stored, were higher during our second visit (Table A2) compared to our first visit (Table A1). The increased volume of roasted beans in the storage/holding area during the second visit likely led to more off-gassing of diacetyl and 2,3-pentanedione, as reflected in the area sampling results. The closed bay doors as well as the non-functioning large exhaust fan in the production space also likely contributed to the increased concentrations of diacetyl and 2,3-pentanedione.

Task-Based Exposures

Coffee processing involves multiple tasks that may cause intermittent exposure to diacetyl and 2,3-pentanedione. Traditional full-shift sampling will not characterize these intermittent, peak exposures. Evaluating intermittent and task-based exposures to diacetyl and 2,3-pentanedione is difficult with current validated sampling methods (OSHA Methods 1013/1016). Since tasks are so sporadic in coffee processing, with some only lasting a few seconds or minutes, we used instantaneous evacuated canisters to sample tasks that were only a few seconds to minutes long and OSHA Methods 1013/1016 for longer duration tasks. We sampled by task, with varying durations, to understand which tasks may have contributed to higher exposures to diacetyl and 2,3-pentanedione.

Our task-based air sampling revealed that some tasks had higher air concentrations of diacetyl and/or 2,3-pentanedione than other tasks. During our second visit, packaging coffee tasks had higher levels of diacetyl and 2,3-pentanedione compared to the first visit. Using OSHA Methods 1013/1016, packaging coffee tasks resulted in air concentrations of diacetyl ranging from 3.0 ppb – 34.3 ppb and 2,3-pentanedione ranging from less than 1.0 ppb – 28.4 ppb (Table A5). As previously stated, during our second visit, the company was processing more coffee than the first visit, which likely contributed to the higher exposures during weigh/package tasks. Employees often had to weigh and pack different blends of roasted beans. For orders requiring mixtures of different roasted coffee beans, blends were completed by using the agitator arm of a cooling drum to automatically blend roasted beans or by blending roasted beans by hand inside a plastic tote. An employee's bending over and placing their head above the tote while blending the roasted beans by hands likely contributed to higher measured alpha-diketones. Using instantaneous evacuated canisters, we also observed that blending by hand resulted in the highest diacetyl (maximum 193 ppb) and 2,3-pentanedione (maximum 90.7 ppb) air concentrations compared to other tasks (Table A6).

During our first visit, we observed maximum levels of CO at 410 ppm and CO_2 at 5200 ppm directly inside roasted bean storage bins (Table A11). During our second visit, we monitored CO and CO_2 levels in specific work areas over the course of the day (Table A12). Although CO and CO_2 levels were high inside the roasted bean storage bins, CO and CO_2 were generally low throughout the other areas of the facility. However, during our second visit we noticed a slight increase in CO and CO_2 when we left the real-time monitor in the roasted bean storage area for the day, likely caused by the close proximity to the off-gassing roasted beans. We recommend employees do not place their head or face inside the bins.

Bulk Samples

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

Dust

Although area inhalable and respirable dust concentrations were below OSHA and ACGIH occupational exposure limits, coffee dust, even at low concentrations, is known to cause respiratory symptoms [Zuskin et al. 1993; Sakwari et al. 2013]. Green and roasted coffee dust and castor beans (from cross-contamination of bags used to transport coffee) are known risk factors for occupational asthma [Figley and Rawling 1950; Karr et al. 1978; Zuskin et al. 1979, 1985; Thomas et al. 1991]. People who become sensitized (develop an immune reaction) to coffee dust can subsequently react to relatively low concentrations in the air. Others may experience irritant-type symptoms from exposure to coffee dust [Oldenburg et al. 2009].

Ventilation

The ventilation systems serving the administrative areas provided adequate total air flow to maintain temperature control during both visits. However, we did not have the equipment to accurately determine the amount of fresh, outdoor air being supplied to those spaces. Measured levels of CO_2 in the administrative spaces were all 790 ppm or below (well less than 700 ppm above the 430 ppm measured outside), which provides an indication that adequate fresh, outdoor air was being supplied.

In March 2016, we determined that air from the production side can flow into the administrative areas, although the production space was neutral to only slightly positive to the administrative side of the facility under the conditions of testing. As noted earlier the large exhaust fan in the production space was not operating at the time the measurements were taken. Operating the exhaust fan would likely change these differential pressures or cause the production space to be negative compared to the administrative areas, which is desirable. Also, it should be noted that large cooling fans were being operated in the roasting and packaging areas to keep employees cool, and this could easily have an impact on the differential pressure measurements. While the pressure relationships did show that contaminated air from the production area can migrate into the administrative areas, none of our personal or area sampling results indicated elevated exposures to office workers.

In looking at our sampling results with regard to ventilation, the pre- and post-shift canister samples (see Table A9) taken in March 2016 showed that the concentrations of diacetyl and 2,3-pentanedione increased over the course of the work shift. This indicates that the generation rate of these compounds exceeded the rate at which ventilation removed them under the conditions when the samples were taken. Operating the large production area exhaust fan would likely impact this result. Likewise, operating with the bay doors open at either end of the production area would have an impact on this result. Another similar finding was that the levels of alpha-diketones we measured in area samples were generally higher in March 2016 compared to July 2015. Again, this is likely the result of the production space being sealed up with no exhaust air flowing from the space and the increase in production volume during the second visit.

Medical Survey

Overall, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Some production employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust, chaff, roasted coffee, or roasted coffee dust. Coffee dust is an organic dust and, as noted earlier, 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 may precede the diagnosis of asthma [Shaaban et al. 2008; EAACI Task Force on Occupational Rhinitis 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 10 participants that reported lower respiratory symptoms also reported nasal or sinus problems or physician-diagnosed hay fever or nasal allergies. Green coffee dust is thought to be a more potent allergen than roasted coffee dust because roasting destroys some of the allergenic activity [Lehrer et al. 1978]. As discussed in the recommendations section, to prevent symptoms related to green coffee dust and chaff, 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, 63% (n=10) of participants (including participants with asthma) reported one or more lower respiratory symptoms in the 12 months prior to the medical survey. None of these participants perceived their lower respiratory symptoms were work-related. Asthma symptoms often improve when away from exposures that trigger symptoms while other lung diseases such as obliterative bronchiolitis or COPD generally do not improve. Spirometry can be used to help detect and follow individuals with asthma and other lung diseases such as obliterative bronchiolitis or COPD. Spirometry can show if air is exhaled from the lungs more slowly than normal (i.e. obstructive abnormality) or if the amount of air exhaled is smaller than normal (i.e., restrictive abnormality). In asthma, there is intermittent airways obstruction which is reversible after treatment with bronchodilator medications (e.g., albuterol). In obliterative bronchiolitis, scar tissue prevents the small airways (bronchioles) from opening up when albuterol is given. In other words, the airways are fixed and not responsive (reversible) to bronchodilator medicine. The obstructed airways prevent rapid emptying of the lung air sacs (alveoli) during exhalation. This explains why the respiratory symptoms of those with occupational obliterative bronchiolitis do not tend to improve when away from work-related exposures; however, avoidance of further exposure can stop progression of the disease [Akpinar-Elci et al. 2004].

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

Our findings of upper respiratory symptoms with a work-related pattern in many employees, four-fold excess of wheeze, and abnormalities on lung function testing in about a third 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 individuals' privacy, we cannot provide more detailed results that might shed light on possible work-relatedness, such as health measures by job title or task. We mailed each participant their individual lung function test results with an explanation of the results and recommended each participant provide the information to their personal physician.

We recommend starting a medical monitoring program because air sampling detected employee exposures to diacetyl that exceeded the NIOSH REL, and there were a number of participants with 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 may be developing lung disease (e.g., asthma, obliterative bronchiolitis) and can help prioritize interventions to prevent occupational lung disease. The NIOSH medical survey results can serve as a baseline for employees who participated, if they choose to share these results with the provider. In a workplace with risk of occupational lung disease, prevention of smoking-related lung disease is important and makes the detection of work-related adverse effects easier. The Centers for Disease Control and Prevention offers tools and resources for setting up a smoking cessation program [CDC 2017].

Conclusions

We identified specific work tasks that resulted in air concentrations of diacetyl that exceeded the NIOSH REL and STEL. Grinding roasted coffee beans, blending roasted coffee beans by hand, and weighing and packaging roasted coffee were associated with higher diacetyl levels, likely due to the close proximity of the employee's breathing zone to the roasted beans. CO and CO_2 levels were low throughout most of the facility, and the highest CO and CO_2 levels were observed at the openings of roasted bean storage bins; however, this may not be representative of employee exposure. Area inhalable and respirable dust concentrations were below OSHA and ACGIH occupational exposure limits; however, coffee dust, even at low concentrations, is known to cause respiratory symptoms and is a known risk factor for occupational asthma. Overall, full-shift air concentrations of diacetyl and 2,3-pentanedione were consistently higher during our second industrial hygiene survey in March 2016 when the bay doors were down. Air concentrations increased over the course of the work day, indicating opening the bay doors, if weather permits, may help decrease the accumulation of diacetyl and 2,3-pentanedione over the day. Recommendations are made to reduce worker exposure and protect respiratory health.

Ventilation measurements supported sampling results which showed the air concentrations of alpha-diketones (e.g., diacetyl, 2,3-pentanedione, 2,3-hexanedione) were higher in March 2016 than during our initial visit in July 2015 when the bay doors were open. Increased production during the second visit may also have contributed to the increase in measured air concentrations of alpha-diketones. In March 2016, pressure measurements showed that the production space was under neutral to slightly positive pressure to the office areas, which could allow contaminated air from production activities to flow into the offices. This pressure relationship is not ideal. It is likely that these results were related to the fact that the large exhaust fan in the production space was off and the two bay doors at either end of the plant were closed in March 2016. Simply operating the exhaust fan at all times during production activities would help reduce airborne contaminants in the space and reduce the pressure in the production space relative to the administrative side of the facility. Operating with the bay doors open when weather permits would serve to further dilute contaminants in the production space; however, the impact on pressure relationships would be variable, depending on weather conditions outdoors.

Overall, mucous membrane symptoms, specifically eye, nose, and sinus symptoms, were the most commonly reported symptoms. Some production employees reported their mucous membrane symptoms were caused or aggravated by green coffee dust or chaff, roasted coffee, or ground coffee dust. Wheezing or whistling in the chest was the most commonly reported lower respiratory symptom. A statistically significant four-fold excess of wheezing existed in the participants compared to the U.S. noninstitutionalized population of the same age, race/ethnicity, sex, and cigarette smoking distribution. Six of 16 medical survey participants had abnormal breathing tests. We recommend a medical monitoring program to identify any employees who may be developing lung disease (e.g., asthma, obliterative bronchiolitis) and to help management prioritize interventions to prevent occupational lung disease. All production workers and 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.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this coffee processing facility to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. 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. Operate the make-up air unit and the large exhaust fan in the production space continuously during the work shift. Operating this equipment in combination will help dilute and remove airborne alpha-diketones (e.g., diacetyl, 2,3-pentanedione, and 2,3-hexanedione) as they are generated and help maintain the production space under negative pressure relative to the administrative offices.
2. When seasonally possible, open the bay doors to assist in mitigating the accumulation of alpha-diketones.
3. If other engineering and administrative controls (see below) do not reduce air concentrations of alpha-diketones, work with a ventilation engineer to install local exhaust ventilation during the following tasks:

a. blending roasted coffee by hand;
b. grinding roasted coffee; and
c. weighing and packaging roasted coffee.

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. Periodically clean the roasters' exhausts in accordance with manufacturer instructions to remove chaff build up to reduce a fire hazard and to improve the efficiency, energy usage, and roaster performance.
2. Include roaster exhaust checks and any future local exhaust systems in a preventive maintenance schedule to ensure they operate appropriately.
3. Continue to cover bins of roasted beans to reduce the overall emission of alpha-diketones and other chemicals (e.g., CO, CO_2) into the workplace and lower worker exposure.
4. To reduce exposures to VOCs (including alpha-diketones), CO, and CO_2, minimize production tasks that require employees to place their heads inside the roasted bean bins.
5. Do not blend roasted beans by hand. Instead, use the agitator of the cooling drum or some other automatic mechanism that minimizes employee contact with roasted beans during blending.
6. Eliminate the use of compressed air and dry sweeping as much as possible during cleaning. Instead, use a vacuum system with a high-efficiency particle air filter and wet methods whenever possible.
7. Ensure the guard rail on the platform for the storage bins of roasted coffee beans is in use to reduce the risk of falls.
8. Ensure employees understand potential hazards (e.g., diacetyl, 2,3-pentanedione, CO, CO_2, dust) in the workplace and how to protect themselves. OSHA's Hazard Communication Standard, also known as the "Right to Know Law" [29 CFR 1910.1200] requires that employees are informed and trained on potential work hazards and associated safe practices, procedures, and protective measures.
9. 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

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment might be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

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

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

2. Offer employees the voluntary use of N95 disposable filtering-facepiece respirators when emptying burlap bags of green beans into the storage silos, when cleaning the exhaust system of chaff, when 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 at each roaster.

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

Smoking Cessation Program

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

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Appendix A: Tables

Table A1. OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, 1st NIOSH industrial hygiene survey, July 2015.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Administration	3	0 (0%)	<3.1	<3.1	0
Diacetyl	Personal	All Over	4	0 (0%)	<3.0	<3.2	0
Diacetyl	Personal	Grinding	1	1 (100%)	5.3	5.3	1
Diacetyl	Personal	Roasting	6	2 (33%)	<3.0	7.2	1
Diacetyl	Personal	Weigh/Package	9	1 (11%)	<=2.9	2.9	0
Diacetyl	Area	Administration	5	0 (0%)	<3.1	<3.2	-
Diacetyl	Area	Breakroom	3	0 (0%)	<3.0	<3.4	-
Diacetyl	Area	Grinding	3	0 (0%)	<3.1	<3.2	-
Diacetyl	Area	Outside	3	0 (0%)	<3.1	<3.3	-
Diacetyl	Area	Quality Control	3	0 (0%)	<2.9	<3.2	-
Diacetyl	Area	Roasting	9	0 (0%)	<2.8	<3.8	-
Diacetyl	Area	Storage/Holding	4	0 (0%)	<3.0	<3.2	-
2,3-Pentanedione	Personal	Administration	3	0 (0%)	<2.5	<2.5	0
2,3-Pentanedione	Personal	All Over	4	0 (0%)	<2.5	<2.6	0
2,3-Pentanedione	Personal	Grinding	1	1 (100%)	3.7	3.7	0
2,3-Pentanedione	Personal	Roasting	6	2 (33%)	<2.4	6.9	0
2,3-Pentanedione	Personal	Weigh/Package	9	1 (11%)	<=2.1	2.1	0
2,3-Pentanedione	Area	Administration	5	0 (0%)	<2.5	<2.6	-
2,3-Pentanedione	Area	Breakroom	3	0 (0%)	<2.4	<2.7	-
2,3-Pentanedione	Area	Grinding	3	0 (0%)	<2.5	<2.6	-
2,3-Pentanedione	Area	Outside	3	0 (0%)	<2.5	<2.7	-
2,3-Pentanedione	Area	Quality Control	3	0 (0%)	<2.4	<2.6	-
2,3-Pentanedione	Area	Roasting	9	0 (0%)	<2.2	<3.1	-
2,3-Pentanedione	Area	Storage/Holding	4	0 (0%)	<2.4	<2.5	-
2,3-Hexanedione	Personal	Administration	3	0 (0%)	<2.5	<2.5	-
2,3-Hexanedione	Personal	All Over	4	0 (0%)	<2.5	<2.6	-
2,3-Hexanedione	Personal	Grinding	1	0 (0%)	<2.5	<2.5	-
2,3-Hexanedione	Personal	Roasting	6	0 (0%)	<2.4	<3.9	-
2,3-Hexanedione	Personal	Weigh/Package	9	0 (0%)	<2.4	<3.1	-
2,3-Hexanedione	Area	Administration	5	0 (0%)	<2.5	<2.7	-
2,3-Hexanedione	Area	Breakroom	3	0 (0%)	<2.5	<2.7	-
2,3-Hexanedione	Area	Grinding	3	0 (0%)	<2.5	<2.6	-
2,3-Hexanedione	Area	Outside	3	0 (0%)	<2.5	<2.7	-
2,3-Hexanedione	Area	Quality Control	3	0 (0%)	<2.4	<2.6	-
2,3-Hexanedione	Area	Roasting	9	0 (0%)	<2.2	<3.1	-
2,3-Hexanedione	Area	Storage/Holding	4	0 (0%)	<2.5	<2.6	-

Note: OSHA=Occupational Safety and Health Administration; NIOSH=National Institute for Occupational Safety and Health; N=number of samples; Above LOD N (%) = number and percentage of samples above the limit of detection (LOD); < indicates below the LOD; <= indicates less than or equal to the LOD; Above REL N=number of samples above the NIOSH recommended exposure limit (REL); ppb=parts per billion; "-" NIOSH RELs are specified for personal air samples and area air samples cannot be used for comparison; "All Over" location includes employees that were cross-trained and performed tasks at different areas.

Table A2. OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, 2nd NIOSH industrial hygiene survey, March 2016.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Administration	4	4 (100%)	0.9	2.6	0
Diacetyl	Personal	Grinding	1	1 (100%)	3.1	3.1	0
Diacetyl	Personal	Production Area	5	5 (100%)	1.4	4.8	0
Diacetyl	Personal	Roasting	5	5 (100%)	3.0	5.1	1
Diacetyl	Personal	Weigh/Package	11	11 (100%)	3.1	8.4	7
Diacetyl	Area	Administration	8	8 (100%)	0.6	3.0	-
Diacetyl	Area	Breakroom	3	3 (100%)	0.9	2.5	-
Diacetyl	Area	Grinding	6	6 (100%)	1.9	3.8	-
Diacetyl	Area	Pack/Ship	3	3 (100%)	2.3	3.9	-
Diacetyl	Area	Production Area	3	3 (100%)	1.9	2.8	-
Diacetyl	Area	Quality Control	3	3 (100%)	2.2	3.1	-
Diacetyl	Area	Roasting	6	6 (100%)	2.8	4.2	-
Diacetyl	Area	Storage/Holding	3	3 (100%)	9.4	10.7	-
Diacetyl	Area	Weigh/Package	6	6 (100%)	1.4	5.3	
2,3-Pentanedione	Personal	Administration	4	4 (100%)	0.6	1.9	0
2,3-Pentanedione	Personal	Grinding	1	1 (100%)	2.4	2.4	0
2,3-Pentanedione	Personal	Production Area	5	5 (100%)	1.0	2.8	0
2,3-Pentanedione	Personal	Roasting	5	5 (100%)	2.0	3.4	0
2,3-Pentanedione	Personal	Weigh/Package	11	11 (100%)	1.5	5.7	0
2,3-Pentanedione	Area	Administration	8	8 (100%)	0.5	1.9	-
2,3-Pentanedione	Area	Breakroom	3	3 (100%)	0.8	1.8	-
2,3-Pentanedione	Area	Grinding	6	6 (100%)	1.0	3.1	-
2,3-Pentanedione	Area	Pack/Ship	3	3 (100%)	1.5	2.8	-
2,3-Pentanedione	Area	Production Area	3	3 (100%)	1.0	2.0	-
2,3-Pentanedione	Area	Quality Control	3	3 (100%)	1.2	2.3	-
2,3-Pentanedione	Area	Roasting	6	6 (100%)	1.9	3.0	-
2,3-Pentanedione	Area	Storage/Holding	3	3 (100%)	5.0	5.8	-
2,3-Pentanedione	Area	Weigh/Package	6	6 (100%)	0.8	4.7	-
2,3-Hexanedione	Personal	Administration	4	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Grinding	1	0 (0%)	<0.8	<0.8	-
2,3-Hexanedione	Personal	Production Area	5	0 (0%)	<0.4	<0.5	-
2,3-Hexanedione	Personal	Roasting	5	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Personal	Weigh/Pack	11	0 (0%)	<0.5	<0.8	-
2,3-Hexanedione	Area	Administration	8	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Breakroom	3	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Grinding	6	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Pack/Ship	3	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Production Area	3	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Quality Control	3	0 (0%)	<0.5	<0.5	-

Table A2 cont. OSHA Methods 1013/1016 full-shift personal and area air sampling results by location, 2nd NIOSH industrial hygiene survey, March 2016.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
2,3-Hexanedione	Area	Roasting	6	0 (0%)	<0.5	<0.5	-
2,3-Hexanedione	Area	Storage/Holding	3	1 (33%)	<0.5	0.6	-
2,3-Hexanedione	Area	Weigh/Package	6	0 (0%)	<0.2	<0.5	-

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); Above REL N = number of samples above the NIOSH proposed recommended exposure limit (REL); ppb=parts per billion; "-" NIOSH RELs are specified for personal air samples and area air samples cannot be used for comparison; < indicates below the LOD.

Table A3. Evacuated canister method time-weighted average personal and area air sampling results by location, 1st NIOSH industrial hygiene survey, July 2015.

Analyte	Sample Type	Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Above REL N
Diacetyl	Personal	Administration	1	1 (100%)	3.0	3.0	0
Diacetyl	Personal	All Over	2	1 (50%)	<0.9	3.1	0
Diacetyl	Personal	Delivery	1	1 (100%)	0.6	0.6	0
Diacetyl	Personal	Outside	1	0 (0%)	<3.4	<3.4	0
Diacetyl	Personal	Roasting	2	2 (100%)	1.7	3.6	0
Diacetyl	Personal	Weigh/Package	3	3 (100%)	2.6	4.9	0
Diacetyl	Area	Administration	5	3 (60%)	<0.3	1.0	-
Diacetyl	Area	Breakroom	3	2 (67%)	<0.8	1.4	-
Diacetyl	Area	Grinding	3	3 (100%)	1.6	3.3	-
Diacetyl	Area	Outside	3	0 (0%)	<0.8	<0.9	-
Diacetyl	Area	Quality Control	3	2 (67%)	<=0.5	1.0	-
Diacetyl	Area	Roasting	9	6 (67%)	<=0.7	2.1	-
Diacetyl	Area	Storage/Holding	5	1 (20%)	<=0.2	0.2	-
2,3-Pentanedione	Personal	Administration	1	0 (0%)	<1.2	<1.2	0
2,3-Pentanedione	Personal	All Over	2	1 (50%)	<1.2	3.7	0
2,3-Pentanedione	Personal	Delivery	1	0 (0%)	<1.5	<1.5	0
2,3-Pentanedione	Personal	Outside	1	0 (0%)	<4.7	<4.7	0
2,3-Pentanedione	Personal	Roasting	2	2 (100%)	2.2	2.8	0
2,3-Pentanedione	Personal	Weigh/Package	3	3 (100%)	2.7	8.3	0
2,3-Pentanedione	Area	Administration	5	0 (0%)	<0.4	<1.3	-
2,3-Pentanedione	Area	Breakroom	3	1 (33%)	<1.1	1.7	-
2,3-Pentanedione	Area	Grinding	3	2 (67%)	<1.1	3.8	-
2,3-Pentanedione	Area	Outside	3	0 (0%)	<1.1	<1.2	-
2,3-Pentanedione	Area	Quality Control	3	0 (0%)	<1.1	<1.2	-
2,3-Pentanedione	Area	Roasting	9	3 (33%)	<=0.9	1.5	-
2,3-Pentanedione	Area	Storage/Holding	5	0 (0%)	<1.1	<1.2	-
2,3-Hexanedione	Personal	Administration	1	0 (0%)	<2.1	<2.1	-
2,3-Hexanedione	Personal	All Over	2	1 (50%)	<2.2	4.5	-
2,3-Hexanedione	Personal	Delivery	1	0 (0%)	<2.7	<2.7	-
2,3-Hexanedione	Personal	Outside	1	0 (0%)	<8.4	<8.4	-
2,3-Hexanedione	Personal	Roasting	2	0 (0%)	<2.2	<2.8	-
2,3-Hexanedione	Personal	Weigh/Package	3	3 (100%)	2.7	13.2	-
2,3-Hexanedione	Area	Administration	5	0 (0%)	<0.6	<2.3	-
2,3-Hexanedione	Area	Breakroom	3	0 (0%)	<2.0	<2.1	-
2,3-Hexanedione	Area	Grinding	3	1 (33%)	<2.0	4.5	-
2,3-Hexanedione	Area	Outside	3	0 (0%)	<2.0	<2.1	-
2,3-Hexanedione	Area	Quality Control	3	0 (0%)	<2.0	<2.1	-
2,3-Hexanedione	Area	Roasting	9	0 (0%)	<2.0	<2.1	-
2,3-Hexanedione	Area	Storage/Holding	5	0 (0%)	<2.0	<2.1	-

Note: 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); Above REL N =number above the NIOSH proposed recommended exposure limit (REL); ppb=parts per billion; "-" NIOSH RELs are specified for personal air samples and area air samples cannot be used for comparison; "All Over" location includes employees that were cross-trained and performed tasks at different areas; < indicates below the LOD.

Table A4. OSHA Methods 1013/1016 task-based personal and area air sampling results by location, 1st NIOSH industrial hygiene survey, July 2015.

Analyte	Type of Sample (area/ personal)	Task Location	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (minutes) Sample Duration (range)
Diacetyl	Personal	All Over	2	0 (0%)	<7.7	<9.4	17 (15-18)
Diacetyl	Personal	Grinding	3	2 (67%)	<=6.6	26.9	16 (15-17)
Diacetyl	Personal	Roasting	6	1 (17%)	<=5.8	5.8	15 (13-16)
Diacetyl	Personal	Weigh/Package	9	1 (11%)	<8.7	23.1	15 (11-16)
Diacetyl	Area	Grinding	3	0 (0%)	<8.1	<9.2	16 (15-17)
Diacetyl	Area	Roasting	15	0 (0%)	<3.5	<17.3	16 (8-40)
2,3-Pentanedione	Personal	All Over	2	0 (0%)	<6.2	<7.5	17 (15-18)
2,3-Pentanedione	Personal	Grinding	3	2 (67%)	<7.5	18.2	16 (15-17)
2,3-Pentanedione	Personal	Roasting	6	0 (0%)	<7.0	<8.6	15 (13-16)
2,3-Pentanedione	Personal	Weigh/Package	9	1 (11%)	<7.0	10.9	15 (11-16)
2,3-Pentanedione	Area	Grinding	3	0 (0%)	<6.5	<7.4	16 (15-17)
2,3-Pentanedione	Area	Roasting	15	0 (0%)	<2.8	<14.0	16 (8-40)
2,3-Hexanedione	Personal	All Over	2	0 (0%)	<6.3	<7.6	17 (15-18)
2,3-Hexanedione	Personal	Grinding	3	0 (0%)	<6.7	<7.6	16 (15-17)
2,3-Hexanedione	Personal	Roasting	6	0 (0%)	<7.1	<8.7	15 (13-16)
2,3-Hexanedione	Personal	Weigh/Package	9	0 (0%)	<7.1	<10.5	15 (11-16)
2,3-Hexanedione	Area	Grinding	3	0 (0%)	<6.6	<7.5	16 (15-17)
2,3-Hexanedione	Area	Roasting	15	0 (0%)	<2.8	<14.1	16 (8-40)

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

Table A5. OSHA Methods 1013/1016 personal task-based air sampling results, 2nd NIOSH industrial hygiene survey, March 2016

Analyte	Task	N	Above LOD N (%)	Minimum Concentration (ppb)	Maximum Concentration (ppb)	Mean (minutes) Sample Duration (range)
Diacetyl	Cleaning Roaster	1	1 (100%)	2.4	2.4	- (7-7)
Diacetyl	Grind coffee beans	4	4 (100%)	21.9	37.6	11 (4-14)
Diacetyl	Blending roasted beans by hand	3	3 (100%)	7.5	33.4	18 (15-25)
Diacetyl	Package coffee	19	19 (100%)	3.0	34.3	15 (5-24)
Diacetyl	Roast coffee beans	9	5 (56%)	<0.9	4.7	16 (15-19)
2,3-Pentanedione	Cleaning Roaster	1	0 (0%)	<2.1	<2.1	- (7-7)
2,3-Pentanedione	Grind coffee beans	4	4 (100%)	8.8	20.9	11 (4-14)
2,3-Pentanedione	Blending roasted beans by hand	3	3 (100%)	5.3	22.1	18 (15-25)
2,3-Pentanedione	Package coffee	19	18 (95%)	<1.0	28.4	15 (5-24)
2,3-Pentanedione	Roast coffee beans	9	7 (78%)	<0.9	2.5	16 (15-19)
2,3-Hexanedione	Cleaning Roaster	1	0 (0%)	<3.1	<3.1	- (7-7)
2,3-Hexanedione	Grind coffee beans	4	0 (0%)	<1.5	<5.5	11 (4-14)
2,3-Hexanedione	Blending roasted beans by hand	3	0 (0%)	<0.8	<1.4	18 (15-25)
2,3-Hexanedione	Package coffee	19	0 (0%)	<0.9	<4.3	15 (5-24)
2,3-Hexanedione	Roast coffee beans	9	0 (0%)	<1.1	<1.4	16 (15-19)

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 A6. Instantaneous* evacuated canister task-based air sampling concentration results, 2nd NIOSH industrial hygiene survey, March 2016.

Task Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Blending roasted beans by hand #1	193	90.7	5.3
Blending roasted beans by hand #2	24.0	23.1	1.9
Blending roasted beans by hand #3	15.7	19.5	2.6
Blending roasted beans by hand #4	21.3	21.9	1.5
Grinding roasted beans (Blend #1)	64.3	51.9	1.9
Packing roasted beans	69.7	80.5	5.5
Pouring of roasted beans #1	4.9	2.6	<0.9
Pouring of roasted beans #2	5.5	4.0	<0.9
Pouring of roasted beans #3	12.8	7.9	1.7
Pouring of roasted beans #4	9.2	8.7	<0.9
Pouring of roasted beans #5	10.4	6.6	1.0
Pouring of roasted beans #6	13.1	10.7	2.3
Pouring of roasted beans #7	15.7	8.8	<0.9
Pouring of roasted beans #8	44.6	21.2	2.9

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 A7. Instantaneous evacuated canister source air sampling results* for diacetyl, 2,3-pentanedione and 2,3-hexanedione, 1st NIOSH industrial hygiene survey, July 2015.

Source	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
After grinding 14 pounds in 19 minutes	146	113	8.0
After grinding 14 pounds in 19 minutes	521	229	24.0
Inside roasted bean storage bin #1	3248	2064	173
Inside roasted bean storage bin #2	99.4	127	6.5
Inside roasted bean storage bin #3	1725	814	16.7
Inside roasted bean storage bin #4	563	576	17.3
Inside roasted bean storage bin #5	454	461	17.4
Inside roasted bean storage bin #6	120	98.0	5.1
Inside roasted bean storage bin #7	4911	1774	161
Inside roasted bean storage bin #8	2038	820	124
Inside roasted bean storage bin #9	940	252	26.0
Inside roasted bean storage bin #10	310	182	7.5
Inside roasted bean storage bin #11	2380	1277	26.4
Inside roasted bean storage bin #12	1122	632	35.8
Inside roasted bean storage bin #13	125	50.0	13.0
Inside roasted bean storage bin #14	920	432	14.0
Inside roasted bean storage bin #15	669	380	13.4
Inside roasted bean storage bin #16	7011	4419	156
Inside roasted bean storage bin #17	2392	1424	219
Inside roasted bean storage bin #18	997	607	96.2
Inside roasted bean storage bin #19	1931	773	91.3
Inside roasted bean storage bin #20	991	1195	50.6
Inside roasted bean storage bin #21	2744	3216	108
Inside roasted bean storage bin #22	986	412	33.0
Inside roasted bean storage bin #23	229	84.0	8.8
Inside roasted bean storage bin #24	119	47.0	5.0
Inside roasted bean storage bin #25	304	235	5.0
Inside roasted bean storage bin #26	580	607	12.0
Inside roasted bean storage bin #27	1119	678	18.0
Inside roasted bean storage bin #28	427	235	5.0
Inside roasted bean storage bin #29	431	472	18.6
Inside roasted bean storage bin #30	987	881	32.0
Roasting #1	<0.3	<0.4	<0.6
Roasting #2	87.1	44.5	5.9
Roasting #3	8.9	7.7	7.2
Roasting #4	109	45.7	6.8

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

Table A8. Instantaneous evacuated canister source air sampling results for diacetyl, 2,3-pentanedione and 2,3-hexanedione, 2nd NIOSH industrial hygiene survey, March 2016.

Source Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
Freshly roasted beans at conduction roaster door to cooling drum #1	9.3	3.0	<1.0
Freshly roasted beans at conduction roaster door to cooling drum #2	6.0	3.3	<1.0
Freshly roasted beans at convection roaster door to cooling bin	4.2	3.3	<0.9
Freshly roasted beans at lip of open transfer container #1	12.9	6.7	1.6
Freshly roasted beans at lip of open transfer container #2	12.8	4.8	<1.0
Freshly roasted beans at lip of open transfer container #3	0.5	0.6	0.8
Freshly roasted beans at lip of open transfer container #4	11.6	7.6	1.2
Roasted beans at lip of open transfer container	30.5	18.6	1.5
Roasted beans at lip of open transfer container	17.2	9.7	2.8
Grinding 16 ounce roasted bean blend	158	124	2.8
Grinding blend #1	359	309	35.6
Grinding blend #2	127	127	2.9
Grinding blend #2	364	439	11.3
Grinding blend #2	520	462	13.7
Transfer of roasted beans from convection roaster cooling bin to bucket	10.9	6.3	<0.9
Transfer of roasted beans from storage bin into bucket	12.7	12.2	<0.9
Transfer of roasted beans from conduction roaster cooling bin to bucket	23.7	17.5	1.3
Transfer of roasted beans	56.2	48.1	5.8
Transfer of roasted beans for blending	184	98.1	12.0
Transfer of roasted beans from convection roaster cooling bin to container	3.4	1.1	<1.0

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

Table A9. Instantaneous evacuated canister pre-and-post shift background air sampling results, 2nd NIOSH industrial hygiene, March 2016.

Analyte	Sample Type	Sample Location	Pre- or Post- shift	Concentration (ppb)
Diacetyl	Background	Storage/Holding	Pre-shift	3.5
Diacetyl	Background	Storage/Holding	Post-shift	15.5
2,3-Pentanedione	Background	Storage/Holding	Pre-shift	1.6
2,3-Pentanedione	Background	Storage/Holding	Post-shift	8.5
2,3-Hexanedione	Background	Storage/Holding	Pre-shift	<0.6
2,3-Hexanedione	Background	Storage/Holding	Post-shift	<0.6

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

Table A10. Bulk coffee sample results using headspace analysis from both NIOSH industrial hygiene surveys, July 2015 and March 2016.

Survey	Bulk Sample Description	Diacetyl (ppb)	2,3-Pentanedione (ppb)	2,3-Hexanedione (ppb)
First	Green bean #1	<170	<203	<275
First	Green bean #2	<171	<204	<277
First	Whole roasted bean #1	<169	189	<273
First	Whole roasted bean #2	606	705	302
First	Whole roasted bean #3	600	781	<275
First	Whole roasted bean #4	434	311	<280
First	Whole roasted bean #5	<171	171	<276
First	Whole roasted bean #6	167	<204	338
First	Whole roasted bean #7	526	1069	648
First	Whole roasted bean #8	308	161	<275
First	Whole roasted bean #9	787	1172	<277
First	Whole roasted bean #10	497	875	<276
First	Ground roasted bean #1	<171	<204	<276
First	Ground roasted bean #2	297	175	<277
First	Ground roasted bean #3	<171	<204	<277
Second	Green bean #3	<84	<117	<208
Second	Fresh whole roasted bean #10	2,012	1,042	<208
Second	Whole roasted bean #10	2,069	1,350	<208
Second	Whole roasted bean #11	1,172	207	<207
Second	Whole roasted bean #12	1,324	1,314	<207
Second	Whole roasted bean #13	1,083	1,258	<207
Second	Whole roasted bean #14	1,558	907	<206

Note: NIOSH = National Institute for Occupational Safety and Health; ppb=parts per billion; < indicates below the limit of detection; detection limits improved from first to second visit.

Table A11. Real-time air monitoring for carbon dioxide, carbon monoxide, temperature, and relative humidity, 1st NIOSH industrial hygiene survey, July 2015.

Location	CO_2 (ppm)	CO (ppm)	Temp (°F)	RH (%)
Outside facility	430	<0.1	75	71
Break room	571	0.7	74	-
Shipping and receiving	820	1.1	79	68
Roaster machine	800	1.6	80	66
Auto-weigh machine	490	0.9	-	-
Storage/Holding	600	0.5	79	65
Administrative office	790	0.9	78	59
Customer service office	660	1	78	59
Quality control room	610	0.7	77	55
Roasted bean storage bin #1 *	5,200	386	77	35
Roasted bean storage bin #2*	5,200	130	78	29
Roasted bean storage bin #3*	2,400	410	83	26
Roasted bean storage bin #4*	1,500	160	84	33
Roasted bean storage bin #5* †	4,200	-	83	32
Roaster machine†	476	-	78	42
Roasted bean storage bin #6* †	900	-	76	45
Roasted bean storage bin #7*†	750	-	76	48
Roasted bean storage bin #8*†	950	-	76	45
Roasted bean storage bin #8*†	860	-	76	47
Roasted bean storage bin #9*†	1,850	-	77	47
Roasted bean storage bin #10*†	1,100	-	78	43
Roasted bean storage bin #11*†	2,300	-	78	43
Roasted bean storage area†	670	-	77	48
Green bean storage area†	540	-	76	49

Note: NIOSH = National Institute for Occupational Safety and Health; CO_2=carbon dioxide; CO=carbon monoxide; ppm=parts per million; °F=degrees Fahrenheit; < indicates below the limit of detection; "-"indicates that the measurement was not recorded.
***Probe was placed directly inside roasted coffee bean storage bin with cover on bin.**
†CO probe sensor did not provide a reading.

Table A12. Real-time air monitoring for carbon dioxide, carbon monoxide, temperature, and relative humidity, 2nd NIOSH industrial hygiene survey, March 2016.

Area sample location	Measurement	Minimum	Maximum	Average
Roaster machine (1)	CO_2 (ppm)	289	3,612	502.8
Roaster machine (1)	CO (ppm)	<0.1	7.8	0.8
Roaster machine (1)	Temperature (°F)	71	112.7	91.7
Roaster machine (1)	Relative Humidity (%)	11.6	52.2	25.4
Roaster machine (2)	CO_2 (ppm)	334	746	463
Roaster machine (2)	CO (ppm)	<0.1	4.5	0.3
Roaster machine (2)	Temperature (°F)	68.3	85	77.6
Roaster machine (2)	Relative Humidity (%)	18.9	35.2	23.8
Roasted bean storage area	CO_2 (ppm)	438	2,246	599
Roasted bean storage area	CO (ppm)	0.6	21.3	2.4
Roasted bean storage area	Temperature (°F)	66.6	68	67.1
Roasted bean storage area	Relative Humidity (%)	23.4	39.8	27.3

Note: NIOSH = National Institute for Occupational Safety and Health; ppm=parts per million; CO=carbon monoxide; CO_2=carbon dioxide; °F =degrees Fahrenheit; < indicates below the limit of detection.

Table A13. Area air sampling results for inhalable and respirable dust, 1st NIOSH industrial hygiene survey, July 2015.

Dust	Location	N	% Above LOD	Minimum Concentration (mg/m^3)	Maximum Concentration (mg/m^3)
Inhalable	Administration	2	100	0.051	0.117
Inhalable	Grinding	1	100	0.1	0.1
Inhalable	Outside	1	100	0.069	0.069
Inhalable	Quality Control	1	100	0.069	0.069
Inhalable	Roasting	3	100	0.099	0.139
Inhalable	Storage/Holding	2	100	0.068	0.075
Respirable	Administration	2	0	<0.006	<0.009
Respirable	Breakroom	1	0	<0.006	<0.006
Respirable	Grinding	1	100	0.008	0.008
Respirable	Outside	1	100	0.008	0.008
Respirable	Quality Control	1	0	<0.006	<0.006
Respirable	Roasting	3	100	0.012	0.016
Respirable	Storage/Holding	2	100	0.01	0.012

Note: NIOSH = National Institute for Occupational Safety and Health; N=number of samples; mg/m^3=milligram per cubic meter; % Above LOD=percentage of samples above limit of detection (LOD) for the instrument used to detect inhalable or respirable dust; < indicates below the limit of detection for the instrument used to detect respirable dust.

Table A14. Prevalence of reported symptoms, NIOSH medical survey, March 2016

Symptom	Experienced in the last 12 months N = 16 Number (%)	Experienced in the last 4 weeks N = 16 Number (%)
Nose symptoms*	13 (81%)	9 (56%)
Eye symptoms†	8 (50%)	2 (13%)
Sinusitis or sinus problems	7 (44%)	5 (31%)
Problem with ability to smell	6 (46%)	-
Phlegm on most days for 3 months	3 (19%)	-
Lower respiratory symptoms (reported at least one of the following)	10 (63%)	6 (38%)
Chest wheezing or whistling	9 (56%)	5 (31%)
SOB on level ground or walking up a slight a hill	4 (25%)	-
Breathing trouble	2 (13%)	2 (13%)
Awoke with chest tightness	2 (13%)	0
Awoke with shortness of breath	1 (6%)	0
Usual cough	1 (6%)	1 (6%)
Asthma attack	1 (6%)	0
Systemic symptoms (reported at least one of the following)	11 (69%)	6 (38%)
Flu-like achiness or achy joints	9 (56%)	4 (25%)
Fever or chills	8 (50%)	4 (25%)
Unusual tiredness or fatigue	5 (31%)	3 (19%)

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

Table A15. Adjusted* comparisons of symptoms and self-reported physician diagnosis among NIOSH medical survey participants (N=16) to U.S. adult population, March 2016

Health condition	Comparative population†	Observed Number	Expected Number	SMR (95% CI)‡
Watery, itchy eyes last 12 months	NHANES III	7	5.9	1.2 (0.6–2.5)
Stuffy, itchy, or runny nose last 12 months	NHANES III	12	8.6	1.4 (0.8–2.4)
Sinus problems last 12 months	NHANES III	6	5.4	1.1 (0.5–2.4)
Phlegm 3 consecutive month or more	NHANES III	3	1.2	2.5 (0.9– 7.5)
Wheeze last 12 months	NHANES 2007-2012	**9**	**2.0**	**4.5 (2.4–8.6)**
Shortness of breath on exertion	NHANES III	4	2.6	1.6 (0.6–4.0)
Cough 3 consecutive months or more	NHANES III	1	1.1	0.9 (0.2–5.0)
Chronic bronchitis (physician-diagnosed)	NHANES III	0	0.71	0 (0–5.4)
Ever asthma (physician-diagnosed)	NHANES 2007-2012	2	2.3	0.9 (0.2 –3.2)
Current asthma (physician-diagnosed)	NHANES 2007-2012	2	1.1	1.8 (0.5– 6.7)

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

Appendix B: Figures

Figure B1. Roaster exhaust stack plugged with chaff residue and debris, NIOSH ventilation assessment, July 2015.

Figure B2. Other roaster exhaust stack plugged with chaff residue and debris, NIOSH ventilation assessment, July 2015.

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Keywords: NAICS 311920 (Coffee roasting), Wisconsin, diacetyl, 2,3-pentanedione, 2,3-hexanedione, coffee, carbon monoxide, carbon dioxide, volatile organic compounds (VOCs).

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

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The recommendations in this report are made on the basis of the findings at the workplace evaluated and may not be applicable to other workplaces.

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Availability of Report

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