Original Research

Comparing Particulate Matter Exposures During Two Work Shifts in a Large University Dining Commons Kitchen

Shalom Emmanuel, MPH and Atin Adhikari, PhD

Department of Biostatistics, Epidemiology and Environmental Health Sciences, Jiann-Ping Hsu College of Public Health, Georgia Southern University, Statesboro, Georgia

Corresponding Author: Atin Adhikari, PhD • Department of Biostatistics, Epidemiology and Environmental Health Sciences • Jiann-Ping Hsu College of Public Health • P.O. Box: 8015, Georgia Southern University Statesboro, Georgia 30460 • 912-478-2289 • Email: aadhikari@georgiasouthern.edu

ABSTRACT

Objective: Cooking emits a huge concentration of indoor air pollutants, including particulate matter (PM). Exposure to PM can lead to long-term adverse respiratory effects among workers engaged in cooking. Only a few studies have measured cooking-related air pollutants in large school cafeterias where young student workers are frequently employed. The objective of this research was to compare stationary exposures to PM from cooking during two work shifts at a very large university dining commons kitchen.

Methods: Number concentrations of PM of varying aerodynamic sizes (1, 2.5, 5, and 10 µm) were measured at the back kitchen, DC grill, and brick oven during two work shifts using the CEM DT-9881 air monitor and mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} were measured simultaneously using the DustTrak™ aerosol monitor. PM number concentrations were higher in the afternoon shift than in the evening shift.

Results: The mean number concentrations of $PM_{2.5}$, PM_5, and PM_{10} during the afternoon shift were 1,335,783, 320,471, and 87,915 particles/m^3 respectively. In the evening shift, the values were 207,020, 23,745, and 4,146 particles/m^3 respectively. The mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} were higher during the afternoon shift compared to the evening shift. $PM_{2.5}$ levels at the back kitchen and PM_{10} levels at the brick oven exceeded the 24h US-EPA NAAQ and WHO mean standards. The brick oven had the highest concentrations of PM compared to the other cooking sites.

Conclusions: The increased concentration of PM could be associated with increased cooking activities and the number of staff.

Keywords: Indoor air quality; Occupational health; Exposure science; Particulate matter; Cooking

BACKGROUND

Indoor air pollution accounts for about 2 million deaths per year and 2.7% of the global burden of disease (Sanbata et al., 2014). Cooking, which is a major source of indoor air pollution, emits a significant concentration of air pollutants, like particulate matter (PM) (Sofuoglu et al., 2015). The American style of cooking which involves boiling, frying, grilling, roasting, and baking, is a common daily practice in a large cafeteria or restaurant setting. Stationary exposure to PM causes long-term adverse respiratory effects such as pulmonary obstruction, asthma, pulmonary edema, and irritation of the nasal tract and lungs (Downward et al., 2018). This is because particulate matter is a mixture of airborne particles, including dust, solid or liquid residues of airborne particles which are tiny and can easily be inhaled into the lungs, as a result of their aerodynamic nature which impacts their dispersion in the air, as well as their entrance into the lungs.

Indoor air pollution has gained significant attention in recent times. This is because humans spend more time indoors than outdoors, be it in occupational or home settings. It has been estimated that about 90% of the time is spent indoors and there are higher levels of pollutants indoors than outdoors (Alves et al., 2020). Hence, indoor air pollutants can pose more significant health threats than outdoor air pollutants. Stationary exposures to indoor air pollutants are of importance because people are exposed to these pollutants for a long period, either through emission from the equipment used for routine activities or just by spending long work hours in a setting that is susceptible to generating a variety of indoor air pollutants.

In the past decades, the use of biomass fuels and stoves has encouraged poor indoor air quality in private and large cooking settings like restaurants. However, modern-day restaurants and cafeterias that make use of gas and electric cooking appliances have also been shown to be major sources of occupational indoor air pollution (Zhao & Zhao, 2018), which are often overlooked. Recent studies have also revealed that indoor air pollution levels are way higher than outdoor pollution levels, and some days may exceed regulatory standards levels set by the United States Environmental Pollution Agency (J. Travers & Vogl, 2012). Although several studies have explored indoor air pollution at cooking sites, only a few studies have measured indoor air pollutants in large school cafeterias where students regularly work. These young workers could be more vulnerable to PM related respiratory illnesses and lung injuries (See & Balasubramanian, 2006). The objective of this research was to compare occupational exposures to PM from cooking during two work shifts, specifically the afternoon and evening shifts, at a large university dining commons kitchen.

METHODS

Study Site

This study was carried out at one of the two large dining commons in Georgia Southern University (GSU) campus, in Statesboro, Georgia, USA. The Georgia Southern University has two large dining commons where students, members of staff, and visitors go to get their meals. These dining locations include the Lakeside View dining commons and a larger dining common where more students prefer to eat. This study was carried out at the larger dining commons which is located across from the University's store and the bus park. It offers the most variety of any of the school's Eagle Dining Service's dining locations, with nine different servers and a wide range of cuisine choices from all across the globe (Dining Commons, Eagle Dining Services, Georgia Southern University, 2019). The stations in the dining commons include the breakfast club, no whey, signatures, traditions, DC Grill, sweet shop, today's brews, and smoothies, rotisserie, and southern gourmet. The table below shows a summary of some of the foods served at the four major dining stations (Table 1).

According to the Director of Residential Dining Dr. Greg Crawford, the dining commons has about 150 employees, most of which are students at the school, and it serves a total number of 35,000 guests per week, with about 4500 students per day. However, this number reduced to 18,000 guests per week as a result of the modifications made to accommodate the COVID-19 pandemic. It operates for about 10.5 hours on weekdays and 13 hours on weekends (University, 2021). With employees working spontaneously for four to six hours during the three major work shifts, the morning, afternoon, and evening shifts.

Experimental Design

An email was sent to the Director of Residential Dining, Georgia Southern University to seek approval to carry out this study for the duration of the study period. The study was approved and carried out three days a week for seven weeks, including weekdays and weekends between February to April 2021. Data on indoor air quality was collected during the afternoon and evening work shifts at the dining commons. These shifts were selected because more cooking activities are done during these shifts, with a greater number of students and staff, eating in, than during the morning shift.

Data were collected at three different sites in the dining commons, including the back kitchen, the DC grill, and the brick oven. The back kitchen is the central kitchen of the GSU dining commons where general cooking activities are done on a large scale. This cooking site has the greatest number of staff working there at a time and foods cooked there are supplied to other stations where cooking activities are not done in the dining commons. The DC grill is a station located within the dining commons where grilling and frying activities are carried out, including grilling of meat, and preparing of fires, and so on. Students easily walk up to this station to get their fried and grilled foods and they can serve themselves at that station. The brick oven is a station located inside the dining commons where pizza is being baked and pasta is made. At this station, there is a furnace, with the fire constantly burning during the repeated baking operations. This furnace has a ventilation control system above it to control combustion release at that station. Students also walk up to this station to get their food. Hence, diners and staff members are exposed to the air quality at that station. These three stations were selected for data collection because these stations have the most cooking activities carried out repeatedly, and so are suspected to have high levels of indoor air pollutants. Images of the three cooking stations are shown in figures 1, 2, and 3 below.

Table 1

Summary of foods served at the four major stations in the dining commons.

Dining Stations	Food Served at the Stations
Brick Oven	Spaghetti & Meatballs, Chicken Florentine, Buffalo Chicken Pasta, Italian Mac n' Cheese, Shrimp Primavera, Asiago Garlic Alfredo Pasta, Cheesesteak Casserole, Cajun Chicken Bake, Taco Mac Casserole, Jambalaya Skillet, Cheesy Beef Goulash, Pepperoni Pizza, Sausage Gravy Breakfast Pizza, Margherita Pizza, Spinach and Artichoke Dip Pizza
DC Grill	Hamburger, Turkey Burger, Breaded Chicken (Chicken Patty), Popcorn Shrimp, Hotdogs, Hamburger Buns, Hotdog Buns, French Fries, Grilled Chicken, Buffalo Chicken, Pastrami, Buffalo Chicken, Chicken Parm
Signatures	Wheat Wrap, Wheat Bread, Rye Bread, Texas Toast, Vidalia Onion Peppercorn, Apple Cider Vinaigrette, Soba Noodles, Kohlrabi, Hard Boiled Eggs, Buffalo Chicken Salad, Pasta Salad, Chickpeas, Spinach
Central Station	Red Drum, Shrimp, Sword Fish, Tuna, Barbacoa, Mexican Chicken, Ground Turkey, Taco Beef, Shrimp, White Rice, Spanish Rice, Refried Beans, Black Beans, Pinto Beans, Mexi Ranch Bean, Mushroom, Tzatziki Sauce, Cucumbers, Tomato, Olives, Goat Cheese, Mozzarella Cheese

Source:https://auxiliary.georgiasouthern.edu/eagledining/hours-and-locations/diningcommons/dining-commons-menus/

Figure 1

The DC Grill station inside the dining commons

Figure 2

The Brick Oven station in the dining commons

Figure 3A

Images of the back kitchen at the dining commons

Figure 3B

Images of the back kitchen at the dining commons

Data Collection and Analysis

Particle number concentrations (particles/m^3) of varying aerodynamic sizes (1, 2.5, 5, and 10 µm) were measured using the six-channel CEM DT-9881 air monitor, pulling air at 2.83L/min flow rate at 15 seconds intervals 5 times at respirable heights in each of the selected cooking sites during the afternoon and evening work shifts at the GSU dining commons kitchen. This particle counter operates based on light refraction by detecting the light scattered by individual particle sizes, revealing their number concentrations measured with a particle counter (Heim et al., 2008).

PM_1, $PM_{2.5}$, and PM_{10} Mass concentrations were measured using the DustTrak™ Aerosol Monitor 8532 (TSI Inc., Shoreview, MN) aerosol monitor. The device was used to collect data 5 times at 2 minutes intervals in the selected cooking stations during each work shift. The DustTrack is an aerosol monitor photometer that provides a real-time mass reading of particles (DustTrak II Aerosol Monitor 8532, 2021). It makes use of a sheath air system that separates the aerosol in the optics chamber to ensure clean optics for enhanced reliability and low maintenance (DustTrak II Aerosol Monitor 8532, 2021). This device has a TrakPro™ data analysis software that stores and analyzes data collected on the device. Mass concentrations of particulate matter were measured to compare the levels of particulate matter to the US EPA regulatory standards. Both measuring devices were fixed at respirable levels at each collection station. Number concentrations of particles are also essential for confirming the result from the mass concentration of particles. The air quality parameters measured are also essential for monitoring indoor and outdoor air quality in occupational and other settings (Adeoye et al., 2021). Data analysis was carried out using Microsoft Excel 2016 version. The normal distributions of data in different locations were checked by Q-Q (quantile-quantile) plots and we found that data were not normally distributed in some cases. Therefore, we conducted Mann-Whitney U tests to compare a pair of data sets and Kruskal-Wallis tests when we have more than two sets of data to compare. The results are presented below.

RESULTS

A total number of 120 data samples of PM mass concentrations were collected from the three cooking stations during both working shifts. Table 2 below shows the comparison of five particles categories between the afternoon and evening shifts, at the three sampling locations. At a significance level of 0.05, all particles except PM_1 show a statistically significant difference in their concentrations during the afternoon and the evening shifts. This is because PM_1 are very small particles and do not settle easily, and as a result, they stay in the air for a long period. These particles can also be present in the air from other sources of indoor air pollutants because the filters used in housing systems do not filter them out. The total particles also show a statistically significant difference between the afternoon and the evening shifts because the mass concentrations of individual particles are computed in the data analysis.

In table 3 below, the levels of the three particle categories ($PM_{2.5}$, PM_{10} and total particles) show a statistically significant difference ($P < 0.05$) between the afternoon and the evening shifts. A possible explanation for this finding is the different cooking activities carried out at different locations during these shifts generating different sizes and levels of particles. Larger particles do not move around easily, and as a result affect more local cooking areas. On the contrary, smaller particles disperse quickly and do not settle quickly, hence, they affect the whole kitchen area.

To further understand the difference between the levels of PM at specific locations, Table 4 below reveals the non-parametric post hoc analysis of the dining shifts in Table 3 above that showed statistically significant difference in PM concentrations. In total, seven shifts (three afternoon shifts and four evening shifts), showed varying concentrations of PM at specific locations. During the evening shift, the PM levels at the back kitchen do not show any statistically significant difference from the PM levels at the DC grill. This may be because there are similar cooking activities which involve grilling, frying, and roasting at the back kitchen and the DC grill during the evening.

Figure 4 below shows the variations of PM_1, $PM_{2.5}$, and PM_{10} mass concentrations at the Back Kitchen. The levels of PM_1, $PM_{2.5}$, and PM_{10} at the Back Kitchen during the afternoon shift were higher when compared to the evening shift. The highest mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} measured in the afternoon shifts were 32µg/m^3, 72µg/m^3, and 315µg/m^3, respectively. The highest levels of PM_1, $PM_{2.5}$, and PM_{10} measured in the evening shifts were 11µg/m^3, 19µg/m^3, and 91µg/m^3, respectively. $PM_{2.5}$ mass concentrations at the back kitchen during the afternoon shift was 72µg/m^3, which exceeds the US EPA 24-hours National Ambient Air Quality (NAAQ) regulatory standards (35µg/m^3) for $PM_{2.5}$ (EPA, 2020; J. Travers & Vogl, 2012).

Figure 5 shows the variations in mass-PM concentrations at the Brick Oven. The levels of PM_1, $PM_{2.5}$, and PM_{10} at the Brick Oven during the afternoon shift were higher when compared to the levels during the evening shift. The highest mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} measured in the afternoon shifts were 28µg/m^3, 35µg/m^3, and 295µg/m^3, respectively. The highest levels of PM_1, $PM_{2.5}$, and PM_{10} measured in the evening shifts were 14µg/m3, 19µg/m3, and 123µg/m^3, respectively. PM_{10} mass concentrations at the brick oven during the afternoon shift was 295µg/m^3, which exceeds the US EPA 24-hours National Ambient Air Quality (NAAQ) regulatory standards (150µg/m^3) for PM_{10} (EPA, 2020; J. Travers & Vogl, 2012) and 6 and the World Health Organization 24-hours mean standards (50µg/m^3) (WHO, 2021).

Table 2

Statistical significance values (p) when comparing afternoon versus evening PM concentrations for five PM size categories at three sampling locations in the dining commons by using Independent Sample Mann-Whitney U tests.

Location	PM_1	$PM_{2.5}$	Respirable particles	PM_{10}	Total particles
Back kitchen	0.07	0.001*	0.001*	0.001*	0.02*
Brick oven	0.091	0.014*	0.002*	0.002*	0.002*
DC grill	0.056	0.001*	<0.001*	<0.001*	<0.001*

Note: The significance level is 0.05; * indicates a significant difference between afternoon and evening levels.

Table 3

Statistical significance values (p) when comparing afternoon versus evening PM concentrations for five PM size categories combining all three sampling locations in the dining commons by using Independent Sample Kruskal-Wallis tests.

Dining Shifts	PM_1	$PM_{2.5}$	Respirable particles	PM_{10}	Total particles
Afternoon	0.266	0.277	0.050*	<0.001*	<0.001*
Evening	0.092	0.022*	0.008*	<0.001*	<0.001*

Note: The significance level is 0.05; * indicates a significant difference between afternoon and evening levels.

Table 4

Statistical significance values (p) when location and time-specific PM datasets were compared by using Independent Sample Mann-Whitney U tests to determine which specific locations have significantly higher concentrations of particle levels than other two.

Locations	Respirable particles - afternoon	PM_{10} - afternoon	Total particles - afternoon	$PM_{2.5}$ - evening	Respirable particles - evening	PM_{10} - evening	Total particles - evening
Back kitchen vs. Brick oven	0.028*	0.001*	0.001*	0.007*	0.004*	<0.001*	<0.001*
Back kitchen vs. DC grill	0.201	0.026*	0.004*	0.478	0.512	0.583	0.659
Brick oven vs. DC grill	0.108	0.002*	0.001*	0.038*	0.012*	<0.001*	<0.001*

Note: The significance level is 0.05; * indicates a significant difference between locations.

Figure 4 below shows the variations of PM_1, $PM_{2.5}$, and PM_{10} mass concentrations at the Back Kitchen. The levels of PM_1, $PM_{2.5}$, and PM_{10} at the Back Kitchen during the afternoon shift were higher when compared to the evening shift. The highest mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} measured in the afternoon shifts were 32µg/m^3, 72µg/m^3, and 315µg/m^3, respectively. The highest levels of PM^1, $PM^{2.5}$, and PM^{10} measured in the evening shifts were 11µg/m^3, 19µg/m^3, and 91µg/m^3, respectively. $PM_{2.5}$ mass concentrations at the back kitchen during the afternoon shift was 72µg/m^3, which exceeds the US EPA 24-hours National Ambient Air Quality (NAAQ) regulatory standards (35µg/m^3) for $PM_{2.5}$ (EPA, 2020; J. Travers & Vogl, 2012).

Figure 5 shows the variations in mass-PM concentrations at the Brick Oven. The levels of PM_1, $PM_{2.5}$, and PM_{10} at the Brick Oven during the afternoon shift were higher when compared to the levels during the evening shift. The highest mass concentrations of PM_1, $PM_{2.5}$, and PM_{10} measured in the afternoon shifts were 28µg/m^3, 35µg/m^3, and 295µg/m^3, respectively. The highest levels of PM_1, $PM_{2.5}$, and PM_{10} measured in the evening shifts were 14µg/m^3, 19µg/m^3, and 123µg/m^3, respectively. PM_{10} mass concentrations at the brick oven during the afternoon shift was 295µg/m^3, which exceeds the US EPA 24-hours National Ambient Air Quality (NAAQ) regulatory standards (150µg/m^3) for PM_{10} (EPA, 2020; J. Travers & Vogl, 2012) and 6 and the World Health Organization 24-hours mean standards (50µg/m^3) (WHO, 2021).

Figure 6 shows the variations in mass-PM concentrations at the DC Grill. The levels of PM_1, $PM_{2.5}$, and PM_{10} at the DC Grill during the afternoon shift were higher when compared to the levels during the evening shift. The maximum levels of PM_1, $PM_{2.5}$, and PM_{10} measured in the afternoon shifts were 24µg/m^3, 30µg/m^3, and 56µg/m^3, respectively. The maximum levels of PM_1, $PM_{2.5}$, and PM_{10} measured in the evening shifts were 18µg/m^3, 22µg/m^3, and 29µg/m^3, respectively.

The mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} were highest at the Brick Oven when compared to the mean concentrations at the Back Kitchen and DC Grill during both the afternoon and evening shifts. The mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the Back Kitchen during the afternoon shift were 12.8± 8.70µg/m^3, 19.85± 9.57µg/m^3, and 83.65± 75.54µg/m^3, respectively (Table 5). The mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the Back Kitchen during the evening shift were 7.7±4.21µg/m^3, 12.15± 5.23µg/m^3, and 31.05± 25.34µg/m^3, respectively (Table 6). The lowest mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} were noticed at the DC Grill when compared to the mean concentrations at the Back Kitchen and Brick Oven during both the afternoon and evening shifts. The mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the DC Grill during the afternoon shift were 9.85± 7.56µg/m^3, 17.3± 7.39µg/m^3, and 30.1± 11.39µg/m^3, respectively (Table 5). The mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the DC Grill during the evening shift were 5.8± 5.33µg/m^3, 8.25± 6.33µg/m^3, and 13.05± 8.97µg/m^3, respectively (Table 6).

The results from the particle number concentrations also support the observed levels of PM mass concentrations. A higher concentration of PM was recorded in the afternoon shift than the evening shift. The mean concentrations of $PM_{2.5}$, PM_5, and PM_{10} during the afternoon shift were 1,335,783± 93,4438, 320,471± 217,802, and 87,915± 65,571, particles/m^3 respectively. The evening shift, the values were 207,020± 22,347, 23,745± 12,219, and 4,146± 2,295, particles/m^3 respectively (Table 7).

As earlier mentioned in the method section, the operation hours at the GSU dining commons were reduced to accommodate the COVID-19 regulatory guidelines. However, high levels of PM are still noticed from the results of the study. Therefore, there may have been higher levels of PM than what was found in our study, before the COVID-19 pandemic period, since more cooking activities were done back then, and the dining commons operated for longer hours. The findings from this study correspond to the results from a recent study by Chang et al. (2021), who also measured levels of $PM_{2.5}$ and PM_{10} in a restaurant during the period of the COVID-19 pandemic. Findings from their study revealed that levels of $PM_{2.5}$ and PM_{10} at cooking stations inside the restaurant exceeded the US EPA and even the WHO regulatory standards. This is an indication that indoor cooking inside can contribute to high concentrations of PM. This study also highlighted the importance of PM exposure as a risk factor for causing vulnerability to COVID-19 and exacerbating already existing breathing problems (Chang et al., 2021).

The results from this study also correspond with the findings from a similar study conducted, that evaluated the indoor air quality of restaurants in Savannah, Georgia (J. Travers & Vogl, 2012). Their study found the levels of $PM_{2.5}$ in 11 restaurants to be 195µg/m^3 and 16 times higher than the levels of fine particles outdoors. However, their study focused on measuring PM in restaurants that permitted indoor smoking before the 100% smoke-free law was passed (J. Travers & Vogl, 2012). Nonetheless, both studies also prove that there are still very high levels of PM in most restaurants and cafeterias, and cooking staff may be exposed to levels that are detrimental to their health.

Figure 4

Box plots showing variations of PM_1, $PM_{2.5}$, and PM_{10} at the Back Kitchen

Figure 5

Box plots showing variations of PM_1, $PM_{2.5}$, and PM_{10} at the Brick Oven

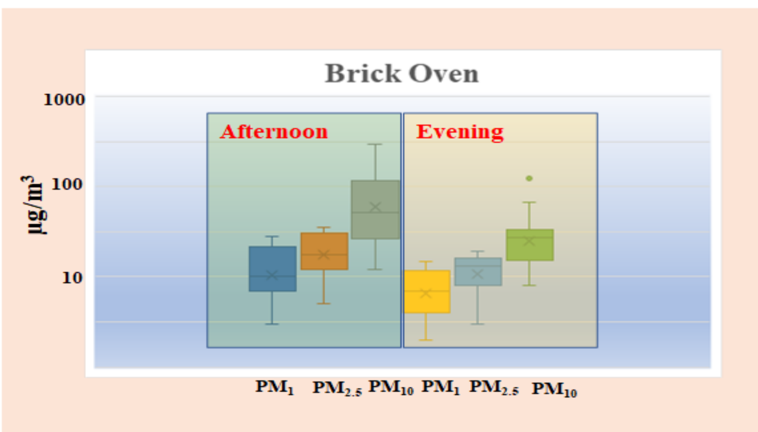

Figure 6

Box plots showing variations of PM_1, $PM_{2.5}$, and PM_{10} at the DC Grill

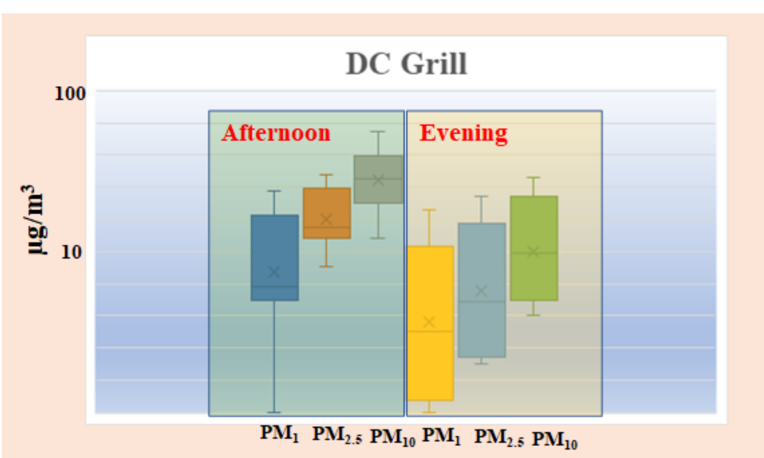

Table 5

Variations in the mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the three cooking stations during the afternoon shift

	Back Kitchen	Brick Oven	DC Grill
PM_1 (µg/m^3), Mean±SD	10.55 ± 7.59	12.8 ± 8.70	9.85 ± 7.56
$PM_{2.5}$ (µg/m^3), Mean±SD	18.45 ± 17.17	19.85 ± 9.57	17.3 ± 7.39
PM_{10} (µg/m^3), Mean±SD	44.5 ± 78.10	83.65 ± 75.54	30.1 ± 11.39

Table 6

Variations in the mean concentrations of PM_1, $PM_{2.5}$, and PM_{10} at the three cooking stations during the evening shift.

	Back Kitchen	Brick Oven	DC Grill
PM_1 (µg/m^3), Mean±SD	5.15 ± 2.37	7.7 ± 4.21	5.8 ± 5.33
$PM_{2.5}$ (µg/m^3), Mean±SD	7.85 ± 3.91	12.15 ± 5.23	8.25 ± 6.33
PM_{10} (µg/m^3), Mean±SD	15.35 ± 19.02	31.05 ± 25.34	13.05 ± 8.97

Table 7

Variations in particle number concentrations during the afternoon and evening shifts.

Work Shifts	$PM_{2.5}$ (Particles/m^3)	PM_5 (Particles/m^3)	PM_{10} (Particles/m^3)
Afternoon, (Mean±SD)	1,335,783 ± 93,4438	320,471 ± 217,802	87,915 ± 65,571
Evening, (Mean±SD)	207,020 ± 22,347	23,745 ± 12,219	4,146 ± 2,295

DISCUSSION

Our study revealed that high levels of $PM_{2.5}$ (fine particles) exceeding the US EPA NAAQs standard were observed in the Back Kitchen (Fig.4). These high levels may be due to many cooking activities at that station during the afternoon shift. These cooking activities involve boiling, frying, grilling, mincing, and so on, which can release fine particles into the air. The number of staff working routinely during the afternoon shift is increasing there. The back kitchen also makes use of mechanical and natural ventilation systems. However, our study proved that these ventilation systems might not be sufficient to reduce the levels of fine particles released at that station. A study conducted by Daly et al. (2010) which measured contributions of fine particulate matter sources to indoor exposure in bars, restaurants, and cafes, also found that natural ventilation is not sufficient to bring $PM_{2.5}$ to levels that are safe for kitchen staff workers. Previous studies (Akbar-Khanzadeh, 2003; Carrington et al., 2003; Dingle et al., 2002; Drope et al., 2004) have also implied that mechanical ventilation is not adequate to reduce exposure to fine particles. Taner et al. (2013) also found that exposure to high levels of fine particles from cooking activities can predispose cooking staff and other employees to a risk of developing cancer.

Our study also found that the highest levels of PM_{10} were observed from measurement at the Brick Oven (Table 5) and the levels of PM_{10} at that station exceeded the US EPA NAAQs 24-hr regulatory standards (Fig 6). As earlier described, this cooking station is where pizza baking was performed, and it contains a furnace with a ventilation system above it. However, our study revealed that even with the ventilation system above the stove, cooking staff at that station are still exposed to high levels of PM_{10}, resulting in possible long-term adverse respiratory effects. As described from the results of the back kitchen, the mechanical ventilation does still not impede the levels of PM workers at that station are exposed to. Our findings from this station are also similar to the findings of previous studies (Embiale et al., 2019; Embiale et al., 2020) which showed that baking could emit extremely high levels of PM_{10}. However, both studies measured PM_{10} levels emitted from baking done with traditional cooking stoves.

The low levels of PM observed at the DC Grill (Table 5) during both the afternoon and evening shift (Table 6), is in contrast to a study conducted by Sofuoglu et al. (2015), who found that deep-frying can result in high levels of PM. A possible reason for this would be that not many frying activities are done at the DC Grill compared to other cooking activities. Also, the study by Sofuoglu et al. (2015) measured levels of PM from a restaurant that made use of only margarine for deep-frying, and this may not be the case at the GSU dining commons. Their study also only measured levels of PM for a period of a week; therefore, their results may not be generalizable. The levels of PM at the DC Grill (Fig.6) did not also exceed the US EPA 24-hr regulatory standards, which is an indicator that kitchen workers at that station may be exposed to safe levels of PM. The observed high levels of particulate matter during the afternoon shift (Table 7), supports the findings of the mass concentration of PM at the three cooking stations. A possible explanation for this finding would be that the increased PM was as a result of the increased number of cooking activities taking place during the afternoon shift and the increased number of employees working during the afternoon shift because most staff members would prefer to work in the afternoon, as it is a more convenient time for them, and more cooking activities would demand more employees.

This study has a few limitations. First, other significant indoor air pollutants, including Volatile Organic Compounds (VOCs), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), Carbon dioxide (CO_2), and Polycyclic Aromatic Hydrocarbons (PAHs) that are released into the air from cooking, and could subject employees to adverse health effects like tightening of the chest, irritation of the respiratory tract and even cancer (Schauer et al., 2002), were not measured in this study. Secondly, the carbon monoxide levels were below the detection limits, which may be a result of sampling errors from the measurement instrument used or due to the mechanical ventilation at the cafeteria. Previous studies found that cooking could emit high levels of carbon monoxide (Adesalu & Kunrunmi, 2016; OJIMA, 2011). Further research involving measuring other indoor air pollutants from cooking is thus recommended.

CONCLUSION

In conclusion, $PM_{2.5}$ levels at the back kitchen and PM_{10} levels at the brick oven exceeded the 24h US-EPA NAAQ and WHO mean standards and workers at the dining commons, whether cooking staff or other employees, should adopt proper protective measures or engineering controls to reduce their exposure to PM from cooking activities. Mitigation measures may include wearing personal protective equipment like face masks. It is noteworthy that due to COVID-19 safety guidelines, employees of the GSU dining commons were mandated to put on their face masks while at work. However, these face masks may sag due to prolonged wearing hours and cooking activities, and in that way, the workers could still be exposed to some levels of PM. Furthermore, these masks may not be effective against PM generated from oil mists and droplets. Hence, the use of the P95 face mask is recommended to reduce workers' exposure to PM levels, as it filters at least 95% of airborne particles and is resistant to oil releases (CDC, 2021). Also, the administrative control approach can be directed towards reducing workers' exposures to PM by allocating staff with pre-existing health conditions to cooking stations where they would not be exposed to high levels of PM. Routine maintenance and change of air filters in the ventilation system and arrangement of adequate ventilation are also recommended to reduce exposures to levels of PM. The increased concentration of PM could be associated with increased cooking activities and the number of staff.

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