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Fine particulate matter in the indoor air of barbeque restaurants: Elemental compositions, sources and health risks

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HIGHLIGHTS

- Particulate emissions from charcoal combustion in the BBQ restaurants were studied.
- Vanadium, Se, Zn, Cr and As were found as high concentrations in $PM_{2.5}$.
- Charcoal combustion and indoor activities were the primary sources of the fine particles.
- The ELCR of As and Cr(VI) exceeded the accepted limits in $PM_{2.5}$.
- The highest HQ and ELCR were found in $PM_{1.0-0.5}$ in BBQ restaurants.

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ABSTRACT

Cooking is a significant source of indoor particulate matter that can cause adverse health effects. In this study, a 5-stage cascade impactor was used to collect particulate matter from 14 restaurants that cooked with charcoal in Kocaeli, the second largest city in Turkey. A total of 24 elements were quantified using ICP-MS. All of the element contents except for Mn were higher for fine particles ($PM_{2.5}$) than coarse particles ($PM_{>2.5}$), and the major trace elements identified in the $PM_{2.5}$ included V, Se, Zn, Cr, As, Cu, Ni, and Pb. Principle component analysis (PCA) and enrichment factor (EF) calculations were used to determine the sources of $PM_{2.5}$. Four factors that explained over 77% of the total variance were identified by the PCA. These factors included charcoal combustion, indoor activities, crustal components, and road dust. The Se, As, Cd, and V contents in the $PM_{2.5}$ were highly enriched ($EF > 100$). The health risks posed by the individual metals were calculated to assess the potential health risks associated with inhaling the fine particles released during charcoal cooking. The total hazard quotient (total HQ) for a $PM_{2.5}$ of 4.09 was four times greater than the acceptable limit (i.e., 1.0). In addition, the excess lifetime cancer risk (total ELCR) for $PM_{2.5}$ was 1.57×10^{-4}, which is higher than the acceptable limit of 1.0×10^{-6}. Among all of the carcinogenic elements present in the $PM_{2.5}$, the cancer risks resulting from Cr(VI) and As exposure were the highest (i.e., 1.16×10^{-4} and 3.89×10^{-5}, respectively). Overall, these results indicate that the lifetime cancer risk associated with As and Cr(VI) exposure is significant at selected restaurants, which is of concern for restaurant workers.

1. Introduction

Nowadays, many people are aware that outdoor air pollution can negatively impact human health, but most are unaware that indoor air pollution can be harmful as well. Studies conducted by the Environmental Protection Agency (EPA) in the US investigated human exposure to air pollution and found that indoor pollution levels are often 2 to 5 times and occasionally 100 times greater than outdoor pollution levels (Zimmerman, 1999).

According to many previous studies, significant sources of particulate matter that contribute to indoor pollution include smoking, cooking, kerosene heating, wood burning, operation of humidifiers and electric motors, pets and humans themselves (He et al., 2004). In addition, the particle total exposure assessment methodology (PTEAM) study by the EPA showed that cooking is the second most significant source of indoor particles (Lai and Ho, 2008). Estimates indicate that 25% of indoor particles come from cooking inside the home (Abt et al., 2000).

Several heating sources are used for cooking throughout the world, including biomass (e.g., wood or charcoal), coal, kerosene, natural gas, liquefied petroleum gas (LPG), and electrical energy (İşler and Karaosmanoğlu, 2008). Most fire-based cooking is based on the combustion of fuel types that can increase overall health risks. Indeed, cooking fuels are one of the most important sources of indoor air pollution, particularly in developing countries (Kima et al., 2011). For example, Turkey is a large developing country, and traditional biomass

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is routinely burned for heat in food preparation throughout the country. Charcoal is used for cooking at grillroom restaurants in Turkey and is also used extensively for barbecuing in households and restaurants worldwide. Charcoal contains many different types of hydrocarbons, sulfur compounds, organic and inorganic chemicals, water, a small amount of oxygen, and other trace elements (Kabir et al., 2011; Susaya et al., 2010). The combustion processes that occur during cooking are the main source of particulate matter found in the air, most of which is in the submicrometer range; therefore, people who are near the combustion charcoals (e.g., both customers and restaurant employees) can be exposed to inhalable pollutants, such as respirable suspended particles and carbon monoxide (Chao and Wong, 2002). Charcoal combustion creates a considerable amount of airborne toxic elements. Nonetheless, barbecuing with charcoal is not typically considered as an important source of airborne pollution in comparison to other well known pollution sources (e.g., motor vehicles, industries, and power plants) (Kabir et al., 2011).

Numerous studies have identified the relationships between the properties of airborne particulate matter and human health (Atkinson et al., 2001; Franck et al., 2011; Langkulsen et al., 2006). For example, a number of epidemiological studies have associated negative health impacts with particle mass concentration, which included concentrations of particles smaller than 2.5 μm ($PM_{2.5}$) and particles smaller than 10 μm (PM_{10}) (Hauck et al., 2004; Pope, 2000; Samet et al., 2000). A scientific study found that increasing the mass concentration of PM_{10} by 10 μg/m^3 increased the mortality rate by approximately 0.5% (Samet et al., 2000). In another study that looked at fine particles (i.e., $PM_{2.5}$), a daily increase of 10 μg/m^3 increased the mortality rate by 8 to 18% (Polichetti et al., 2009). The adverse health effects associated with particulate matter (PM) depend on the physical properties (e.g., particle size and number, total surface area, and electrostatic properties) and the chemical and biological compositions of the PM (Gemenetzis et al., 2006; Oeder et al., 2012). Although the underlying mechanisms that contribute to these adverse health effects are still not clear (Cheng et al., 2011), various studies have indicated that chemical composition and particle size of the PM are relevant to these mechanisms (Oeder et al., 2012). Moreover, despite the fact that the elemental mass fraction of the PM is small, trace elements, such as Pb, As, Se, Cd, and Hg, may pose serious threats to human health; more specifically, they may cause inflammation, lung and heart diseases, or DNA damage because toxins, including heavy metals, are absorbed onto the large surface area of the $PM_{2.5}$ (Gemenetzis et al., 2006; Senlin et al., 2008). Additionally, particles in the $PM_{1.0}$ size fraction (i.e., with an aerodynamic diameter of less than 1.0 μm) are more dangerous to human health because they adversely impact the human respiratory, circulatory, and cardiovascular systems (Caggiano et al., 2010; Cheng et al., 2011).

To date, few research studies have been conducted to assess the elemental composition of indoor PM in grillroom restaurants. The objectives of this study are to determine the elemental composition of five different particle fractions in restaurants that use charcoal cooking and to identify the possible sources and health risks associated with these particle fractions.

2. Material and methods

2.1. Sampling site

In this study, indoor PM sampling was conducted in 14 different non-smoking restaurants in Kocaeli, Turkey, in May of 2011. Questionnaires were developed to collect data on certain characteristics of each restaurant, and the results from those questionnaires are presented in Table 1. Charcoal was used as the cooking fuel in all of the participating restaurants, and it was also the predominant pollutant source in the selected restaurants. Electricity, natural gas, and wood were also used as other forms of cooking fuel in some of the participating restaurants (Table 1). Charcoal cook stoves are located in the dining area of the

Table 1
Characteristics of the participating restaurants.

Sampling area	Indoor area, m^2	Building age, year	Personnel number	Max. customer capacity	Building location	Ventilation	Fuel used	Space heating
R1	25	20	3	25	50 m away from the main road	Chimney hood	Charcoal	None
R2	70	20	10	60	On the main road	Exhaust fan, air-conditioner	Charcoal	Natural gas, air-conditioner
R3	100	8	12	50	500 m away from the main road	Chimney hood	Charcoal, natural gas	Air-conditioner
R4	20	20	5	40	20 m away from the main road	Exhaust fan	Charcoal, electricity	Electrical heater
R5	110	40	32	90	50 m away from the main road	Exhaust fan	Charcoal	Air-conditioner
R6	120	10	14	50	50 m away from the main road	Exhaust fan	Charcoal	None
R7	20	11	9	60	50 m away from the main road	Exhaust fan	Charcoal, wood, electricity	None
R8	80	15	24	100	On the main road	Exhaust fan	Charcoal, wood	Wood burning stove
R9	100	3	5	50	On the main road	Chimney hood	Charcoal	None
R10	50	30	6	40	On the main road	Chimney hood	Charcoal, electricity, natural gas	Electrical heater
R11	20	7	4	15	On the main road	Exhaust fan	Charcoal	Electrical heater
R12	15	50	4	20	20 m away from the main road	Chimney hood, Natural ventilation	Charcoal, natural gas	None
R13	25	50	8	80	25 m away from the main road	Chimney hood, Exhaust fan	Charcoal	Air-conditioner, electrical heater
R14	75	18	10	80	On the main road	Chimney hood	Charcoal	None