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Cooking Fume–Related Exposure to Polycyclic Aromatic Hydrocarbons among Kitchen Workers: A Review

Mutfak Çalışanları Arasında Pişirme Dumanına Bağlı Polisiklik Aromatik Hidrokarbon Maruziyeti: Bir Derleme

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Abstract

In food service systems, improper cooking processes create substances containing significant amounts of fine and ultra-fine particles. These substances contain organic substances such as polycyclic aromatic hydrocarbons and heterocyclic amines adsorbed on their surfaces. Polycyclic aromatic hydrocarbons consist of two or more fused aromatic rings of carbon and hydrogen atoms. These are harmful compounds that threaten human health due to their genotoxic and carcinogenic properties. Personnel working in commercial kitchens are at significant risk in terms of exposure to polycyclic aromatic hydrocarbons caused by high-temperature cooking methods and smoke. Benzo[a]pyrene is often used as an important indicator to assess the level of exposure to these compounds. The formation of polycyclic aromatic hydrocarbons increases especially during cooking methods such as barbecuing, frying and grilling. This situation increases the risk of employees experiencing serious health problems with long-term exposure. In order to reduce exposure, effective ventilation systems should be established in commercial kitchens, appropriate cooking methods should be applied, and employees should be made aware of the risks of polycyclic aromatic hydrocarbons by increasing the use of personal protective equipment.

Özet

Yiyecek hizmetleri yapılan kurumlarda uygun olmayan pişirme işlemleri önemli miktarda ince ve ultra ince partikülleri içeren maddeler oluşturmaktadır. Bu maddeler, yüzeylerine adsorplanmış polisiklik aromatik hidrokarbonlar ve heterosiklik aminler gibi organik maddeler içermektedir. Polisiklik aromatik hidrokarbonlar; karbon ve hidrojen atomlarının iki ya da daha fazla kaynaşmış aromatik halkasından oluşmaktadır. Bunlar, genotoksik ve kanserojen özellikleri nedeniyle insan sağlığını tehdit eden zararlı bileşiklerdir. Ticari mutfaklarda çalışan personel, yüksek sıcaklıkta pişirme yöntemleri ve dumanın neden olduğu polisiklik aromatik hidrokarbon maruziyeti açısından önemli bir risk altındadır. Bu bileşiklerin maruziyet seviyesini değerlendirmek amacıyla Benzo[a]piren sıklıkla önemli gösterge olarak kullanılmaktadır. Özellikle mangal, kızartma ve ızgara gibi pişirme yöntemleri sırasında polisiklik aromatik hidrokarbonların oluşumu artmaktadır. Bu durum, çalışanların uzun süreli maruziyetle ciddi sağlık sorunları yaşama riskini artırmaktadır. Maruziyeti azaltmak için ticari mutfaklarda etkin havalandırma sistemlerinin kurulması, uygun pişirme yöntemlerinin uygulanması ve çalışanların kişisel koruyucu ekipman kullanımı arttırılarak polisiklik aromatik hidrokarbon riskleri konusunda farkındalık kazanmaları sağlanmalıdır.

Introduction

The potential of work environments to pose health risks is an important area of assessment. Today, the increasing demand for food service systems has led to a continuous increase in the number of personnel employed in this sector. Kitchen and dining hall environments pose risks not only in terms of physical and chemical hazards, but also in terms of harmful emissions to which employees are exposed due to cooking fumes. However, it is observed that methods and measures aimed at protecting health are not sufficiently implemented in many mass catering systems (1, 2).

In addition to the physical and chemical hazards that may occur in the kitchen and dining hall environment, the formation of hazardous emissions originating from cooking fumes during the cooking process is observed. The main components of cooking fumes are grouped as particulate matter, volatile organic compounds, aromatic amines and polycyclic aromatic hydrocarbons (PAHs) (3). PAHs are carcinogenic compounds that have potentially serious effects on health. Although the formation of substances occurs in various ways, the factors affecting the emissions originating from cooking fumes include the cooking method, energy source, cooking temperature, equipment used, type of oil, additive and nutritional composition (4).

Despite extensive research on PAHs in various contexts, limited studies have comprehensively addressed their formation during cooking, the exposure routes specific to food service environments, and the associated occupational health outcomes among kitchen workers. The aim of this review was to summarize and evaluate existing research on PAHs formation during cooking processes, exposure routes in food service environments, and related occupational health outcomes, while also addressing the gap in the literature, raising awareness of occupational exposure to cooking-related PAHs, and highlighting potential preventive measures to offer an original contribution and a practical perspective to the field.

Material and Method

In this paper, a literature review was conducted to examine occupational exposure to PAHs originating from cooking fumes and the associated health risks among kitchen workers. The literature search was performed in PubMed, Scopus, Web of Science, and Google Scholar using the keywords (“polycyclic aromatic hydrocarbons” or “PAHs”) and (“cooking fumes” or “kitchen workers” or “food service” or “restaurant staff”). Publications were included if they focused on the measurement or discussion of PAH exposure or its health effects, cooking, kitchen, or food service environments, and were written in English or Turkish.

The selected studies were reviewed to extract information on PAH sources, exposure pathways, and health implications, and were synthesized to identify common findings, highlight existing knowledge gaps, and provide an overview of potential preventive strategies in this field.

Cooking Fume Composition

Indoor air pollution is estimated to account for approximately 2.7% of the global burden of disease (5). Among indoor environments, kitchens represent complex spaces where cooking emissions interact with various airflows and other indoor pollutants. Numerous studies have identified cooking as a major source of particulate matter generation in indoor settings (1, 2).

Cooking fumes are mixtures of gases, vapors, and particles formed through the chemical breakdown and evaporation of heat, oil, water, and organic compounds during food preparation. The smoke produced by cooking methods such as frying, grilling, boiling, and roasting, as well as the temperature applied during these processes, contains diverse chemical components (2, 3). The chemical composition of cooking emissions is influenced by several factors, including the type of raw ingredients, the nature of the cooking oil, the temperature used, and the specific cooking method employed (6).

Various studies have been conducted to measure the particle number and size distribution of particles generated during cooking and to better understand their properties (4, 7). Visible fumes produced during cooking generally result from submicron-sized particles consisting of oil droplets, combustion products, steam from the water content of food, and condensed organic pollutants. During the cooking process—particularly frying—significant amounts of particulate matter (PM), including fine and ultrafine particles, are formed. These are classified as particulate matter with an aerodynamic diameter of <10 µm (PM10, coarse particles), <2.5 µm (PM2.5, fine particles), and <0.1 µm (PM0.1, ultrafine particles, UFP) (8).

Currently, Sioutas Personal Cascade Impactor systems are commonly used for indoor PM measurements (9). Studies have demonstrated that cooking is the primary source of PM in indoor environments (10, 11). Cooking-related combustion processes generate ultrafine particles that are directly released into indoor air, representing a significant pathway for human exposure (8, 12, 13). One study reported that PM2.5 concentrations and particle emission rates measured during cooking were higher than those produced by smoking (14). Cooking fumes contain harmful and toxic substances such as PM10, PM2.5, UFPs, volatile organic compounds (VOCs), and PAHs (15). Among these, PAHs have been identified as major compounds contributing to indoor air pollution from cooking oil fumes (1, 16).

Polycyclic Aromatic Hydrocarbons

PAHs are organic compounds composed of multiple fused benzene rings containing only carbon and hydrogen atoms. Due to prolonged anthropogenic activities, PAHs have become globally prevalent environmental contaminants. Their chemical characteristics -such as stable aromatic ring structures, low water solubility, and high thermal stability- contribute to their environmental persistence and resistance to degradation (17).

PAHs are highly lipophilic and are therefore easily absorbed from the gastrointestinal tract of mammals, accumulate in adipose tissue, and are subsequently distributed to other organs. Their metabolism initially involves oxidation or hydroxylation via the mixed-function oxidase system mediated by cytochrome P450 (CYP), followed by conjugation to form end products such as glucuronic acid, sulfuric acid, or tetrols (18).

PAHs are formed through both natural and anthropogenic processes resulting from the incomplete combustion of organic materials. Natural formation is typically associated with forest fires and volcanic activity, while anthropogenic emissions originate from industrial activities, high-temperature cooking, motor vehicle exhaust, and tobacco smoke (19). Cooking and cooking oil fumes affect indoor

PAH levels in two main ways: first, PAHs volatilize from contaminated oils when exposed to high temperatures and enter the kitchen air; second, organic compounds partially decompose into unstable fragments at high temperatures, which subsequently recombine to form more stable PAHs (9, 20).

PAHs exhibit strong mutagenic, carcinogenic, teratogenic, and immunotoxic effects across various organisms (17). Due to their lipophilic nature, PAHs readily cross cell membranes by passive diffusion after inhalation. Once in pulmonary cells, these compounds act as procarcinogens that do not directly damage DNA but contribute to carcinogenesis after metabolic activation. Their biotransformation occurs primarily through the CYP1A1/1B1 and epoxide hydrolase pathway, the CYP peroxidase pathway, and the aldo-keto reductase (AKR) pathway (21, 22).

In the atmosphere, low–molecular weight PAHs (two or three rings) generally exist in the vapor phase, whereas those with five or more rings are predominantly particle-bound. Four-ring PAHs may exist in either phase, depending on ambient temperature. Particle-bound PAHs pose serious risks to human health. Benzo[a]pyrene (B[a]P) is commonly used as an indicator compound for assessing exposure levels, as elevated B[a]P concentrations correspond to higher overall carcinogenic potential (21, 23). According to one study, the health impacts attributed to PAHs range between 51% and 64% (24). Table 1 provides the formulas and aromatic structures of some polycyclic aromatic hydrocarbons associated with health risks.

PAH Exposure and Health Effects in Kitchen Workers

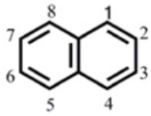
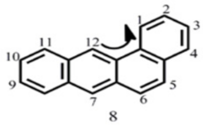
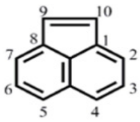
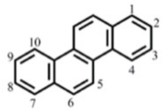
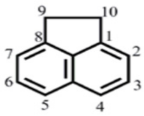
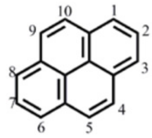
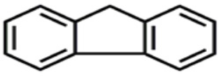
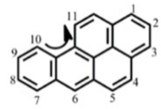
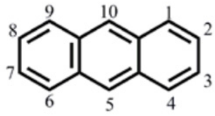
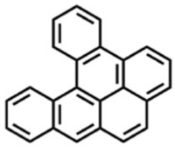
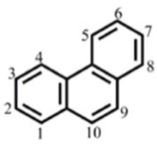
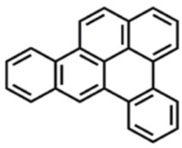
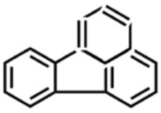
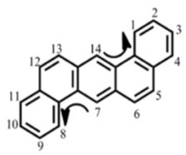
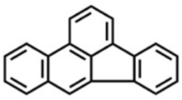
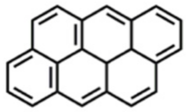
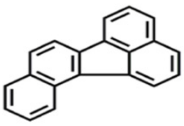
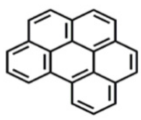
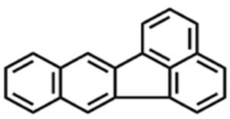
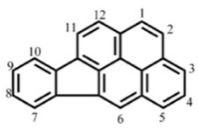
Human exposure to PAHs occurs through various routes. The main sources of exposure include inhalation of environmental elements such as air, soil, and dust; consumption of contaminated food or water; and dermal contact (23). For many individuals, primary exposure takes place in the workplace. Studies have reported that one of the most affected occupational groups is food industry workers, who are exposed mainly through inhalation and dermal absorption (1, 17).

Cooking processes generate large amounts of emissions, irritants, and carcinogenic compounds. Therefore, cooking methods used in commercial kitchens can pose significant health risks to kitchen workers, as they are a major source of airborne toxic substances (25). The formation of PAHs can occur during various domestic and industrial food preparation techniques, including grilling, roasting, frying, drying, and barbecuing (4). When vegetable or animal oils are overheated or reused repeatedly, the gases released during frying have been reported to increase and intensify PAH exposure in both kitchen air and fried foods (21, 25).

In a study examining the effects of cooking methods on particulate formation, analysis of various techniques—including steaming, boiling, sautéing, pan-frying, and deep-frying—revealed that the highest concentration of particulate matter measured at a distance of 20 cm from the stove occurred during deep-frying (190 mg/m^3), whereas the lowest concentration was observed during steaming (72 mg/m^3) (26). Studies comparing cooking practices in different countries have also shown that Asian-style cooking generates higher particulate matter emissions than Western-style cooking (21, 27).

PAHs are defined as carcinogenic compounds with multi-organ effects and are considered among the most hazardous environmental chemicals to human health. Due to their mutagenic and carcinogenic properties, PAHs are listed as priority environmental pollutants by both the European Union (EU) and the United States Environmental Protection Agency (USEPA) (23). The International Agency for Research on Cancer (IARC) classifies emissions produced during high-temperature frying as potentially carcinogenic to humans (Group 2A) (8). The carcinogenic potential of PAHs arises primarily from the multiple benzene rings in their molecular structure (28, 29). Specific PAH species such as benzo[a]pyrene, dibenz[a,h]anthracene, benzo[b]fluoranthene, and benzo[a]anthracene are

Table 1. Formula and structure of polycyclic aromatic hydrocarbon (17)

Name	Formula Structure	Name	Formula Structure
Naphthaline		Benz[*a*]anthracene	
Acenaphthylene		Chrysene	
Acenaphthene		Pyrene	
Fluorene		Benzo[*a*]pyrene	
Anthracene		Dibenzo[*a,l*]pyrene	
Phenanthrene		Dibenzo[*a,e*]pyrene	
Fluoranthene		Dibenzo[*a,h*]anthracene	
Benzo[*b*]fluoranthene		Anthanthrene	
Benzo[*j*]fluoranthene		Benzo[*g,h,i*]perylene	
Benzo[*k*]fluoranthene		Indeno[1,2,3-*cd*]pyrene	

recognized as carcinogenic by the USEPA and JECFA (FAO/WHO Expert Committee on Food Additives) (30).

PAHs tend to bioaccumulate in the soft tissues of living organisms. Their carcinogenic effects mainly result from their ability to interact with DNA, initiating biological processes that may lead to tumor formation. Structural features or molecular modifications that increase DNA binding are particularly associated with carcinogenicity (21, 24).

One study calculated cancer risks according to PAH exposure routes and reported that the highest risk was associated with ingestion (98.1–99.3%), followed by dermal contact (0.66–1.83%) and inhalation (0.03–0.04%). However, the toxic effects of PAHs may vary depending on age and other health conditions. Although ingestion accounts for the majority of PAH-related cancer risk in the general population, this distribution reflects combined exposure through diet, air, and soil (29). Kitchen workers, represent a distinct occupational group that experiences chronic inhalation and dermal exposure to cooking fumes containing PAHs. According to Eurostat data, the accommodation and food services sector employed approximately 10.9 million persons, representing 6.8% of total employment within the European Union's business economy in 2022 (30). In Türkiye, the catering industry comprised more than 4,800 companies, providing direct employment to over 400,000 people and indirect employment to around 1.5 million individuals (31). Therefore, even though inhalation- and dermal-related risks appear small at the population level, these routes constitute the primary exposure pathways in occupational kitchen environments, justifying the focus of this review on cooking fume–related PAH exposure among kitchen staff.

In another study, the toxic equivalent emission rate of benzo[a]pyrene (B[a]P) from cooking sources (675 kg/year) was found to be significantly higher than that from traffic sources (61.4 kg/year), suggesting that cooking may contribute more substantially to potential carcinogenic PAH emissions (33).

In occupational exposure studies, 1-hydroxypyrene, 2-hydroxyfluorene, and 3-hydroxyphenanthrene have been identified as suitable biomarkers of PAH exposure (34). A comparative study involving 94 male kitchen workers and 94 controls in Northern India showed significantly higher urinary 1-hydroxypyrene levels among kitchen workers, indicating occupational PAH exposure (1). Similarly, a study of 236 male kitchen workers across twelve restaurants found elevated airborne PAH concentrations and urinary 1-hydroxypyrene levels, confirming exposure to cooking oil fumes (35).

Figure 1 illustrates the exposure pathways and health impacts of PAHs among kitchen workers. Research indicates that biological contaminants commonly present in indoor environments may negatively affect respiratory health. Elevated mortality rates from respiratory conditions—such as asthma, emphysema, impaired lung function, and lung cancer—have been observed particularly among individuals employed in the hotel and restaurant sectors (1). Inhalation exposure to PAHs is generally associated with lung cancer, while dermal contact has been linked to non-melanoma skin cancer (21, 24, 28). A positive relationship has also been reported between PAH exposure and respiratory diseases as well as stomach cancer (1). Respiratory and allergic disorders are more prevalent among workers in food services systems (36).

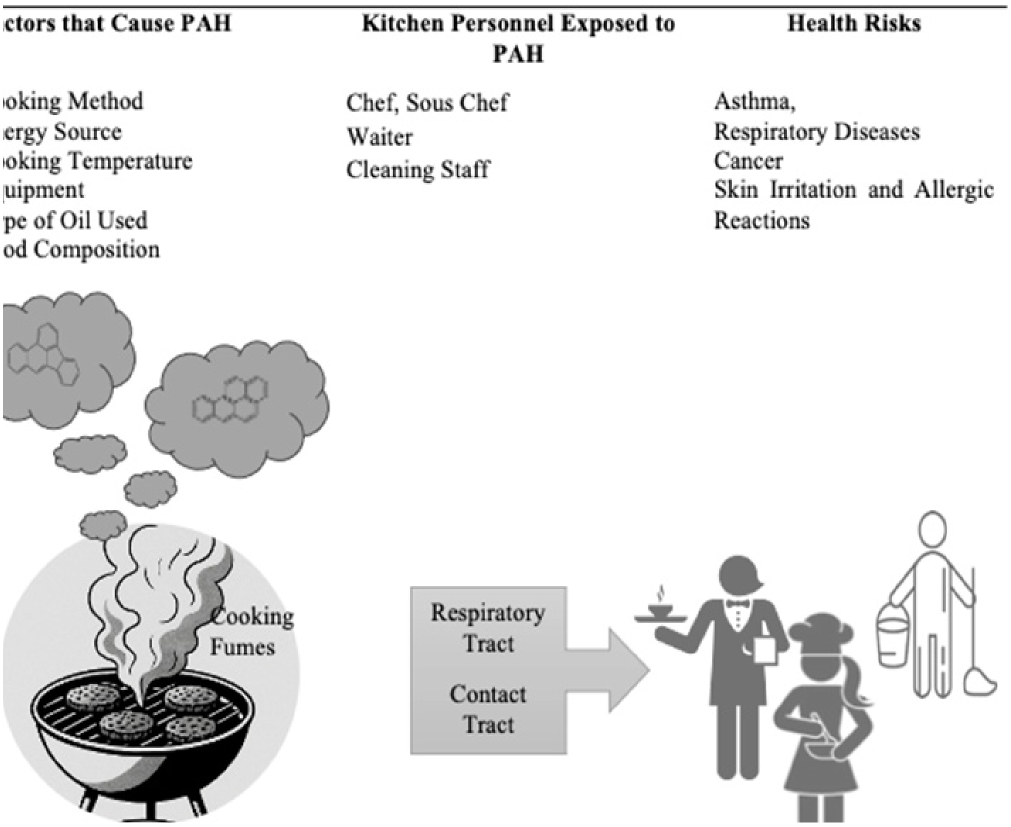


Figure 1. PAH exposure and health effects in kitchen workers (1, 4)

The presence of PAHs in commercial kitchens and the number of workers adversely affected by them are increasing each year. Factors such as enterprise size, raw materials used, cooking methods applied, personnel training level, indoor air quality, and the presence of control equipment influence the degree of exposure and health risks. Therefore, both enterprises and staff should maintain awareness and adopt preventive measures (37).

Recent studies on cooking fume–related exposure to PAHs have been reviewed, and their main findings are summarized in Table 2. The literature indicates that PAH exposure levels vary across cooking environments, being higher in poorly ventilated and high-temperature settings. Several studies also reported associations between PAH exposure and oxidative stress biomarkers among kitchen workers. Overall, the evidence emphasizes the need for improved ventilation, cleaner fuels, and safer cooking practices to reduce health risks.

Table 2. Summary of studies on cooking fume-related exposure to PAHs

Country	Aim	Results	Recommendations	Reference
Taiwan	To compare personal exposure levels of PAHs and aldehydes among workers in three types of commercial cooking workplaces-street food carts, Chinese cafeteria kitchens, and Western fast-food restaurants-and to estimate their associated cancer risks.	Comparative analysis revealed that street food vendors had significantly higher total PAH concentrations (geometric mean: 8790.2 ng/m³) than workers in Chinese cafeteria (3721.1 ng/m³) and Western fast-food kitchens (3171.0 ng/m³). Benzo(a)pyrene, the most potent carcinogen, was detected only at barbecue and popcorn chicken stands. Aldehydes contributed substantially to overall cancer risk, accounting for 74.9–99.7% of the total.	Installation and maintenance of efficient mechanical exhaust systems in street food environments are crucial to reducing exposure to PAHs and aldehydes and the associated carcinogenic risk.	(38)
Turkiye	To assess exposure to organic pollutants in cooking fumes and evaluate oxidative stress biomarkers among 88 kitchen workers (aged 18–65 years) employed in five different professional kitchens.	Concentrations of gas- and particle-phase PAHs and VOCs were analyzed in indoor air samples, and serum levels of MDA and SOD were used as indicators of oxidative stress among the cooks and waiters. Significant positive correlations were observed between serum MDA levels and indoor concentrations of chrysene, indeno(1,2,3-cd)pyrene, and total VOCs. Although the estimated carcinogenic risks were within acceptable limits, the hazard quotient for indoor benzene exceeded the safe threshold, suggesting a potential health risk, particularly for hot kitchen workers.	Implementation of effective ventilation strategies and worker training on hood operation are recommended. Moreover, substituting frying and grilling with safer cooking techniques could reduce occupational exposure to harmful organic pollutants.	(39)
Bangladesh	To evaluate the impact of cooking activities on indoor air quality in kitchens and living areas of four households located in Jashore city and surrounding rural areas in southwestern Bangladesh.	Continuous 24-hour monitoring showed that indoor $PM_{2.5}$, VOC, and CO_2 concentrations ranged from 18.52–207 μg/m³, 7.95–35.66 ppm, and 1061–2459 mg/m³, respectively, while outdoor cooking environments showed lower averages (20.63–23.72 μg/m³ $PM_{2.5}$, 11.18–12.36 ppm VOC, 1097–1747 mg/m³ CO_2). Cooking activities increased CO_2 levels by 5–77% relative to background levels. Toxicity potential values for $PM_{2.5}$ ranged between 0.8 and 8.3, exceeding standard limits in most cases.	Adoption of cleaner fuels and improvement of kitchen ventilation systems are essential for lowering indoor concentrations of $PM_{2.5}$, VOCs, and CO_2 and ensuring safer indoor air quality.	(40)
Iran	To determine urinary and blood biomarkers of PAH exposure among kitchen workers and residents living near restaurants and to assess associated non-carcinogenic and cumulative health risks.	The mean urinary concentration of PAH metabolites was highest among kitchen workers (2126.7 ng/g creatinine), compared to residents and control participants. 1-Hydroxypyrene showed the highest mean concentration, while 9-Phenanthrene showed the lowest. Significant positive correlations were identified between PAH metabolite levels and both MDA and TAC ($p < 0.05$), suggesting oxidative stress due to exposure.	Identification of PAH emission sources and reduction in their generation are key strategies to mitigate human exposure and related health effects in food preparation areas.	(41)
China	To investigate particulate matter and PAH concentrations generated during cooking in urban and rural Chinese kitchens and to assess associated health risks and economic implications.	$PM_{1.0}$, $PM_{2.5}$, and PM_{10} concentrations in rural kitchens were found to be 5.05, 3.39, and 3.78 times higher than those in urban kitchens, respectively. Similarly, total PAH concentrations were 4.79, 5.82, and 6.30 times higher in rural areas. Smaller PM fractions exhibited higher PAH adsorption capacities and carcinogenic potential compared to larger particles.	The use of clean energy sources and improvements in kitchen infrastructure are recommended to reduce particulate and PAH emissions and enhance occupational health.	(42)

PAHs: Polycyclic Aromatic Hydrocarbons, PM: Particulate Matter, $PM_{1.0}$ / $PM_{2.5}$ / PM_{10}-Particulate matter with aerodynamic diameters less than 1.0 μm / 2.5 μm / 10 μm, VOCs: Volatile Organic Compounds, CO_2: Carbon Dioxide, MDA: Malondialdehyde, SOD: Superoxide Dismutase, TAC: Total Antioxidant Capacity.

Conclusion

It is known that the work environment affects human health both psychologically and physiologically. Most kitchen workers have long working hours and spend an average of 60% of their time at their workplaces. These personnel are at risk for PAHs exposure due to high-temperature cooking methods and direct contact with smoke. This situation reveals the importance of studies to determine the relationship between cooking smoke exposure and health risks.

In order to reduce PAHs exposure, a strong ventilation system should be installed in kitchens, high-temperature cooking techniques such as frying, roasting and barbecuing should be limited, and alternative low-temperature methods such as boiling and steaming should be prioritized. Appropriate protective equipment such as smoke masks should be provided to employees and awareness of their use should be raised. Employees in this sector should be regularly informed about the health risks of PAHs and the precautions to be taken, and cooking areas, chimneys, hoods and equipment should be regularly cleaned and inspected. It is thought that these approaches will help to provide a safe working environment for kitchen personnel and to ensure compliance with health standards.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Conceptualization: AÖ; Literature search: AÖ; Formal analysis: AÖ; Research: AÖ; Supervision: AÖ; Visualization: AÖ; Writing review and editing: AÖ.

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