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MUTAGENIC AND/OR CARCINOGENIC COMPOUNDS IN MEAT AND MEAT PRODUCTS: POLYCYCLIC AROMATIC HYDROCARBONS PERSPECTIVE

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Abstract
Polycyclic aromatic hydrocarbons (PAHs) are widespread environmental contaminants posing a great risk to human health due to their mutagenic and/or carcinogenic properties. They are produced from incomplete combustion of a heat source, pyrolysis of organic components, and fat-induced flame formation. Meat and meat products are one of the major sources of PAH exposure. Since PAH intake increases the risk of cancer, understanding the factors affecting PAH formation in meat and meat products is very important within the scope of PAH exposure reduction strategies. In this study, the features and formation of PAHs, the factors affecting the formation of PAH compounds and their reduction/inhibition pathways were reviewed in order to provide a perspective on the presence of PAHs in meat and meat products.

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Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a large group of chemicals that contain 2–7 aromatic rings. PAHs are non-polar compounds of lipophilic nature [1,2,3]. They are formed through incomplete combustion or pyrolysis of organic matter [4]. Epidemiological studies have shown that PAH compounds can negatively affect the organism by interfering with the normal functioning of the cellular membrane and the enzyme system [5]. Storelli et al. [6] reported that PAHs bind to DNA and cause mutations that initiate the carcinogenic process. PAHs are considered common environmental pollutants due to their long-range transport and bioaccumulation [7]. Industrial emissions, agricultural resources, air, water, soil and foodstuffs are the main sources of PAHs [5]. However, it is reported that the most important PAH exposure source for humans is foodstuffs [7] and foodstuffs are responsible for approximately 88–98% of PAH pollution [8].

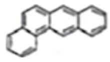
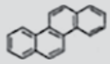
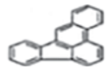
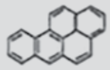
Early studies of PAHs focused on the analysis of industrial sources of PAHs. However, further studies have shown that environmental PAHs can be transferred to food such as fruits and vegetables, seafood, oils, etc [9,10]. On the other hand, food production processes based on high temperature application such as baking, frying and smoking also cause high levels of PAH formation [11,12]. Pyrolysis and oxidation of fat, protein and carbohydrates are induced during high temperature application, which can result in the production of high levels of PAHs. In addition, fat dripping onto the flame and returning to the meat as smoke can also lead to PAH production [2]. Considering that meat with its rich protein and fat content is cooked by various methods before consumption, it is understood that cooked meat and meat products play an important role in PAH exposure through food. Especially, thermal processes such as smoking, grilling, barbecue, frying, roasting can cause high levels of PAH formation in meat due to high temperature, pyrolysis and intense smoke generation [8]. Indeed, it has been reported that meat and meat products contain high concentrations of PAH and are important sources for PAH exposure through foodstuffs [13,14].

Therefore, it is essential to understand the properties and occurrence of PAHs and the factors that influence PAH formation in order to develop strategies reducing exposure to PAHs, which have adverse health effects. The present review focuses on the features and formation of PAHs, the factors affecting the formation of PAH compounds in cooked meat and meat products and their reduction/inhibition pathways.

The structure, toxicity and health hazards of PAHs

PAH compounds exhibit toxic, mutagenic, and carcinogenic effects on humans [15]. They are easily absorbed by the body and can participate in metabolism due to their lipophilic nature [16]. In addition, PAHs can cause toxicity to organisms by interfering with the normal function of biological cell membranes and membrane-associated enzyme systems [17,18]. To date, approximately 160 different PAH compounds have been identified in nature and authorities such as the European Commission Scientific Committee on Food and the United States Environmental

Table 1. Some characteristics of individual PAHs used as markers in the assessment of PAH contamination

Compound name	Abbreviation	Molecule structure	Chemical formula	Molecular weight	LARC classification*	Genotoxity
Benz(a)anthracene	BaA		$C_{18}H_{12}$	228.3	2B	Positive
Chrysene	Chry		$C_{18}H_{12}$	228.3	2B	Positive
Benzo(b)fluoranthene	BbF		$C_{20}H_{12}$	252.3	2B	Positive
Benzo(a)pyrene	BaP		$C_{20}H_{12}$	252.3	1	Positive

*** Carcinogenic; 2B: Possibly carcinogenic**

Protection Agency have determined 16 of these compounds as priority contaminants, considering their mutagenic and carcinogenic properties [3,14]. Benzo[a]pyrene (BaP) is classified as a Group 1 carcinogen, while the majority of other high molecular weight PAHs are largely classified in Group 2A (probably carcinogenic to humans) or Group 2B (possibly carcinogenic to humans) [19] (Table 1).

Laboratory studies have revealed that prolonged exposure to PAH compounds causes lung cancer by inhalation, gastric cancer by ingestion with food, and skin cancer by contact, in animals [20,21]. Daniel et al. [22] declared that the risk of renal cell carcinoma increases with grilled meat consumption. Alomirah et al. [23] reported that the cancer risk associated with consumption of foods of animal origin by children/adolescents and adults is $2.63/10^7$ and $9.3/10^7$ BaP equivalents, respectively.

Several regulations have been declared to protect consumers against PAH intake from diet due to the negative effects of PAHs on health [24]. In this context, Benzo(a) pyrene (BaP) and ∑PAH4 [BaP, Chrysene (Chry), Benz[a] anthracene (BaA) and Benzo[b]fluoranthene (BbF)] have been used as markers for the PAH contamination in food [25]. The legal limits of BaP and ∑PAH4 were determined as 5 µg/kg and 30µg/kg for heat treated meat products, respectively [26].

Factors affecting the formation of PAH compounds in meat and meat products

Many factors such as cooking method, cooking duration and distance, heat source and fuel type, direct/indirect heat application, pre-cooking processes and fat content of meat affect the formation of PAH compounds in meat and meat products (Figure 1).

Frying, grilling, baking, smoking, steaming are techniques commonly used in cooking of meat and meat products [2,24]. There is a strong correlation between PAH formation in meat and cooking methods. On the other hand, the level of PAHs formed varies widely depending on the cooking method [27,28,29,30]. In a study examining the effects of different cooking methods on PAH formation in beef, it was reported that the BaP and ∑PAH4 content were lower in pan-fried samples compared to barbecue-cooked samples [31]. Chung et al. [28] reported that among beef and pork samples cooked by grilling and roasting methods, the highest BaP and ∑PAH4 content was observed in the grilled samples. In addition, the researchers stated that this may be related to the pyrolysis of meat fat dripping onto the charcoal during grilling. In another study examining the effects of different cooking processes (smoking, grilling and boiling) on PAH formation in different meat products, the highest BaP content was found in the smoked samples while the lowest BaP content was detected in boiled samples [29]. As a result of the studies examining the effect of different cooking methods on the level of PAH formed in meat and meat products, it was reported that meat samples cooked by grilling, smoking and roasting methods carry a high health risk due to their high PAH content [28].

Another factor affecting the PAH level formed during the cooking of meat; is the practice of cooking by direct or indirect method. While the direct method is based on the principle of direct contact of meat with a thermal agent, in the indirect method, a thermal agent does not affect the cooked meat through direct contact. Many studies confirm that direct contact with heat source increases PAH formation and that food retains PAH compounds through adsorption and absorption [32]. In [33], the ∑PAH16 content

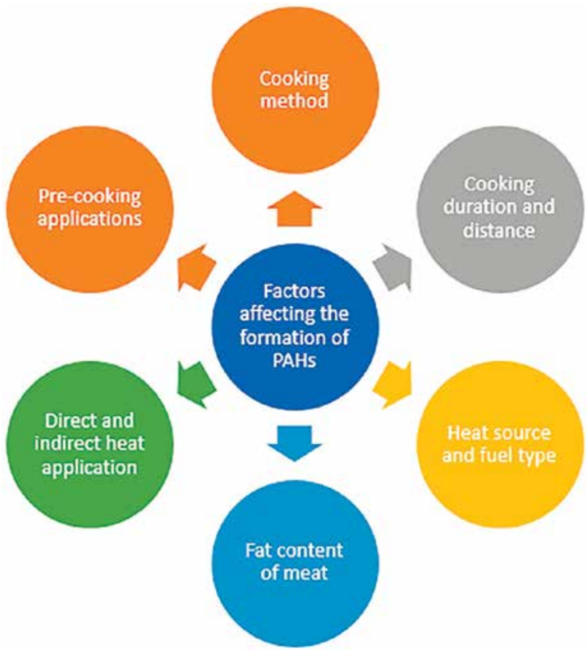


Figure 1. Factors affecting the formation of PAH compounds

of beef cooked with the electric oven grill, which is an indirect cooking technique, was determined as 2.01 μg/kg, while this value was reported to be 17.88 μg/kg in the samples cooked with the charcoal grill method, a direct cooking technique. El-Badry [34] found that direct contact with the gas flame promoted the formation of PAH in the chicken. The author [34] also reported that cooking chicken meat with the direct gas grill cooking technique should be avoided. Wretling et al. [35] stated that the BaP and ∑PAH15 content of the various meat samples smoked by the traditional "sauna" method, in which the samples are exposed directly to the hot smoke from a burning fire, were above the legal limits. Akpambang et al. [36] reported that the use of the indirect smoking technique instead of the direct smoking method is quite effective in reducing PAH formation in smoked meat products.

Free radicals formed when high temperatures are applied to foods undergo recombination to form light PAHs. Heavy PAHs that migrate to the hydrophobic portions of the food following this formation eventually attach to the fat-rich food portions [32]. In this context, the level of PAH formation and accumulation in meat may vary depending on the lipid level of meat. Wegrzyn et al. [37] reported that the fat content is an important parameter that can affect the safety of meat in terms of PAH compounds. Particularly, in meat and meat products where grill and barbecue cooking methods are applied, PAH compounds can be formed that are carried back to the meat surface as a result of the pyrolysis of meat fat or dripping into the flame [13]. The fat content of meat is an important factor influencing the level of PAH formed when this type of cooking method is used. In a study examining the effect of fat content on PAH formation in various grilled meat samples, it was determined that the BaP content of lamb steak, which had the highest fat content, was higher than that of beef steak, pork chop and ham. It has been reported that this result may be related to the formation of more lipid oxidation and degradation products in lamb steak with the high fat content [38]. Pöhlmann et al. [39] conducted a study to determine an effect of the fat content on PAH formation in smoked frankfurter sausages and found that the ∑PAH4 level of sausages with different fat contents (10, 20, 30 and 39%) increased with an increase in the fat content. They also reported that PAH formation in smoked frankfurter sausages could be reduced by reducing the fat content in the sausage formulation. In addition to an amount of fat, a type of fat can also affect the formation of PAH. As a matter of fact, Chen and Chen [40] examined the PAH level of smoke formed as a result of heat treatment of soybean oil, canola and sunflower oils and determined that the highest total PAH amount was in soybean oil. Researchers reported that this result was related to the higher levels of linolenic acid in soybean oil compared to canola and sunflower oils. Similarly, in a study examining the PAH level of meatballs cooked in barbecue using different types of fat (meat fat, sheep tail fat and a mixture of meat fat and tail fat), it was determined that the highest total PAH8 level belonged to the meatballs formulated with tail fat, which had the highest linolenic acid content [3].

The cooking process, including temperature and time, and a distance between meat and a heat source are the factors affecting the PAH formation. Literature data indicate that the level of PAH formed in meat increases in parallel with an increase in cooking temperature and time. According to Kao et al. [41] reported that high temperature and long cooking time cause more fat loss from the meat surface, which may cause a heat source to produce more PAH. In a study, in which an effect of cooking time on the PAH content of grilled pork was determined, the BaP contents of the samples cooked for 2, 3 and 4 minutes were found to be 2.4 μg/kg, 4.5 μg/kg and 10.2 μg/kg, respectively. In addition, it has been reported that the BaP level formed as a result of cooking for 4 minutes has reached the legal limit specified by the European Commission [42]. Oz and Yuzer [30] found that the total PAH8 content of well-done and very well-done beef samples in wire barbecue was 0.8 and 0.9 mg/kg, respectively, while they could not detect any of the individual PAH compounds that make up PAH8 in rare and medium cooked beef. In another study examining the PAH level of a traditional Malaysian beef product, cooking was done at different temperatures (150 °C, 200 °C, 250 °C, 300 °C and 350 °C). As a result of the research, it was reported that the lowest ∑PAH15 level was detected in the samples grilled at 150 °C and an increase in the ∑PAH15 level was observed as the temperature increased [43]. Szterk [44] reported that PAH formation increased as a result of high temperature application due to the pyrolysis of nitrogen-containing organic compounds such as amino acids and protein. In a study examining an effect of smoking time on PAH formation in meat products, it was found that both BaP and ∑PAH4 amounts were higher in meat samples with high smoking time [45]. On the other hand, studies on a distance between food and a heat source, which is another factor affecting PAH formation, show that there is a negative correlation between distance and PAH formation in general. Roseiro et al. [46] examined an effect of smoking distance on PAH formation in sausages and reported that as the distance decreased PAH penetrated into the central point of the sausages. In [11] Rose et al. determined that the ∑PAH4 content of beef burgers cooked at a distance of 9 cm from the heat source was 75% of the ∑PAH4 content of the samples cooked at a distance of 4 cm from the heat source. This relationship between distance and PAH formation is probably related to an increase in the rate of PAH formation and penetration into the sample that comes into contact with hot and intense heat more quickly in short distance.

PAH formation occurs due to the acetylene addition mechanism (HACA) with the release of hydrogen during the combustion of the fuel used in the thermal process. On the other hand, the level of PAH formed may vary depending on a type of fuel used [10]. In the report published by the Codex Alimentarius Commission in 2009, it was recommended not to use resinous or chemically treated woods, waste or diesel oils as fuel in cooking process [47]. In [48] Viegas et al. examined an effect of fuel type on the PAH level of grilled salmon and reported that the samples grilled with coconut shell charcoal produced less PAH than the samples grilled with usual wood charcoal. The authors stated that this result is related to the ability of coconut charcoal to absorb dripping oil without creating smoke, since it is flameless and smokeless [48]. Oz [12] found that amounts of ∑PAH8 were higher in fish samples barbecued with charcoal briquette compared to those barbecued with wood charcoal, and suggested the use of wood charcoal in barbecuing. In another study examining the PAH levels of chicken meat cooked using charcoal and electric grill, it was determined that the average ∑PAH16 level of chicken meat cooked with charcoal and electric grill was 1.6 μg/kg, and 0.038 μg/kg, respectively [49]. Similarly, it was determined that the BaP content of doner kebabs cooked on charcoal and gas grills was 24.2 μg/kg and 5.7 μg/kg, respectively, and gas grilling caused less BaP formation [50]. Oz [2] reported that a type of smoke flavoring wood chips affected the level of PAH formation in barbecued salmon fillets, and bourbon-soaked oak, cherry and hickory wood chips were the wood chips types that could reduce the content of PAHs in barbecued salmon fillets. Stumpe-Viksna et al. [51] reported that a type of sawdust is a critical parameter to be controlled in the smoking process, and that softwood shavings cause higher PAH formation than hardwood shavings, possibly due to the high resin content they contain.

Pre-cooking is one of the strategies applied to reduce PAH formation in cooked meat. Ohmic heating is a widely used technique in recent years due to its advantages such as short processing time, high efficiency and preservation of the nutritional value compared to conventional heating methods [52]. Sengun et al. studied an effect of ohmic preheating on the PAH level of half-cooked meatballs and found that the PAH levels of the meatballs were within acceptable limits, and therefore the ohmic cooking method was safe in terms of PAH formation [53]. In [54] Kendirci et al. determined an effect of ohmic preheating before infrared cooking on PAH formation in beef patties. They reported that the BaP and ∑PAH4 contents formed as a result of the combination of preheating and infrared cooking did not exceed the legal limits [54]. Farhadian et al. [55] investigated an effect of preheating processes (steam and microwave) on PAH levels in grilled chicken and beef. They established that preheating processes applied to the samples strongly affected PAH levels and BaP could not be detected in pretreated samples. The authors stated that this situation may be related to a decrease in the pyrolysis rate as a result of preheating and less penetration of the smoke components into the meat surface and suggested to expand the use of preheating processes in homes and restaurants in order to reduce PAH exposure [55].

Marinating is a technique commonly used to improve the sensory properties of meat products such as texture, color and flavor. Studies on the effect of the marination on the formation of PAH in meat reveal that the effect varies depending on a type of marinade used. Farhadian et al. [56] reported that the PAH content in grilled beef marinated with basic marinades varied between 45.19–56.09 μg/kg, while this value varied between 74.0–80.6 μg/kg in the unmarinated control samples. On the other hand, researchers mentioned that adding 40 mL of oil into basic marination increased the PAH content of grilled beef meat (98.9–109 μg/kg). Similarly, it has been shown in some studies that oil and fatty components are major precursors of PAHs and that cooking oils can be contaminated with PAHs during various preparation processes [57,58]. In a study examining the level of PAH in grilled chicken, the ∑PAH16 amount of unmarinated, palm oil-marinated and sunflower oil-marinated samples was determined as 190.1μg/kg, 457.6 μg/kg and 376.6 μg/kg, respectively. In addition, it has been reported that an increase in the PAH content observed as a result of marinating with oil is related to the fact that oils are the main precursors of PAH components [59]. In [31] Büyükkurt et al. used sage and thyme extracts prepared at 0.5–2.0 °Brix concentration as a marination agent and reported that these marinades showed a reducing effect on PAH formation in barbecued beef. Viegas et al. [60] determined that marinating with different types of beer reduced the amount of ∑PAH8 formed in grilled pork by 13–53%, depending on a type of beer used. They also reported that the greatest decrease in the PAH content was observed in dark beer marinated samples, which had the highest antiradical activity. Janoszka [61] found that the use of onion (30/100 g meat) caused a 60% reduction in the total PAH content of pan-fired meat, while the use of garlic (15/100 g meat) resulted in a 54% reduction. It has been declared that the PAH-lowering effect of onion and garlic may be caused by components with sulfhydryl groups, and polyphenols responsible for the antioxidant activity [61,62]. In a study examining an effect of using a spice mixture containing cumin, coriander, black pepper, rosemary and garlic on the formation of carcinogenic PAHs in chicken meat, it was determined that the spice mixture caused a significant decrease in the level of carcinogenic PAHs. In addition, it has been suggested to use the specified mixture before cooking chicken meat in order to reduce the level of PAHs [34].

Conclusion

PAHs are a large group of environmental pollutants with mutagenic and/or carcinogenic properties. Foodstuffs are the main sources of PAH exposure. Among food groups, meat and meat products being rich in protein and fat contribute significantly to PAH exposure due to the frequent use of thermal processes and increased risk depending on consumption habits. Many factors such as cooking method, thermal process duration, fuel/wood type, pre-cooking applications, marination, additives and fat content of meat affect the level of PAH in meat and meat products. In this context, in order to reduce the amount of PAH formed in meat, it can be recommended to apply moderate and indirect heat processes in cooking, to use non-smoke fuel types, to add antioxidants and to reduce the fat content of meat.

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Completely prepared the manuscript and is responsible for plagiarism.

The author declare no conflict of interest.