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Detection and control of polycyclic aromatic hydrocarbons in meat products

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ABSTRACT

Chemicals known as polycyclic aromatic hydrocarbons (PAHs) can be found in foods that have been grilled or barbecued, especially meats. One hundred and twenty samples of meat products represented by roasted kofta, roasted meat, charcoal grilled kofta and charcoal grilled meat (20 of each) were collected randomly from different markets at Kalyobia governorate, Egypt. The collected samples were examined for determination of Polycyclic Aromatic Hydrocarbons (PAHs). Natural oils as lauryl oil, garlic oil and lemon oil with concentration (0.5% -1% 1.5%) were used to reduce fat pyrolysis by minimizing the amount of meat drips. The recorded results revealed that mean values of PAH4 was 10.35±0.89, PAH8 was 14.53±1.17 and PAHs was 16.49±1.33, respectively in untreated samples of charcoal grilled meat. Meanwhile PAH4 residual concentrations in samples treated with lauryl oil of 0.5, 1.0 and 1.5% were 13.7±0.6, 10.3±0.4 and 7.2±0.3, and with reduction percentages of 26.4, 44.5 and 61.2 %, respectively. Samples treated with garlic oil of 0.5, 1.0 and 1.5% showed PAH4 residual concentrations ere 12.1±0.5, 8.9±0.4, 5.5±0.2, with reduction percentages of 34.9, 52.2 and 70.0%, respectively. However, samples treated with lemon oil in concentrations of 0.5, 1.0 and 1.5% revealed that PAH4 levels were10.3±0.5,6.8±0.4 and 3.9±0.2, with reduction percentages of 45.7, 65.6 and 79.1%, respectively. It could be concluded that charcoal-grilled meat treated with natural oils decrease the levels of PAH4 in the examined samples.

Introduction

Rapid urbanization and industrialization have spewed contaminants into the atmosphere, including polycyclic aromatic hydrocarbons, or PAHs (Mojiri *et al.*, 2019). PAHs are persistent pollutants with a broad range of biological toxicity due to their inherent properties, and their removal from the atmosphere has long been a source of worry. Furthermore, toasting, grilling, frying, baking, and roasting are processes used in both home and commercial food preparation that produce PAHs (Rose *et al.*, 2015). Three main factors contribute to the build-up of PAHs in charcoal beef steaks: the smoke from incomplete combustion of the heat source attached to the steak's surface, the pyrolysis of organic compounds (protein and fat) in the steak during cooking, and the heat source itself (Zelinkova and Wenzl, 2015).

Furthermore, the abrasive combustion of food molecules produces free radicals, which are the basic mechanism generating PAHs, and these byproducts eventually accumulate in food items (Singh *et al.*, 2016). because PAHs can mutate, cause cancer, and be cytotoxic. Consequently, the European Commission has established thresholds for the quantity of PAHs present food matrices. Meat that has been grilled by grilling or barbecuing is allowed to contain up to 5 ng g1 of benzo [a] pyrene (BaP) and 30 ng g1 of PAH4 (EC, 2023).

Countries are inconsistent with different food categories and limit values when it comes to PAH limit standards in food (Racovita *et al.*, 2021). The European Commission's Scientific Committee on Food (SCF) declared 15 PAHs to be genotoxic and carcinogenic, with Benzo[a]pyrene (BaP) identified as a food detection index. (Li *et al.*, 2021; Zhao *et al.*, 2014). As a result, the SCF added a PAH to the European Union (EU) standard called "15 + 1 EU priority PAHs" in 2005. However, the European Food Safety Authority (EFSA) questioned the logic of using BaP as the only PAH detection indicator in food. Therefore, EFSA, in 2008, proposed to use eight PAHs (PAH-8, including Benz[a]anthracene (BaA), Chrysene (CHR), Benzo[b]fluoranthene (BbF), Benzo[k]fluoranthene (BkF), BaP, Dibenz[a, h]anthracene (DhA), Benzo[g, h, i]perylene (BgP), and Indeno[1,2,3-c, d]pyrene (IcP)) or four (PAH-4, including BaA, CHR, BkF, and BaP) as the detection index of PAHs in food (EFSA, 2008). PAH-8 (BaP, CHR, BaA, BbF, BbF, DhA, BgP, and IcP) and PAH-4 (BaP, CHR, BaA, BbF) have since become widely used as PAH detection standards in food. Detection standards for PAHs in foods are still limited to only one BaP type in China (National Food Safety Standard, PR China, GB 2762-2017). So, in this study, natural methods were used to control PAHs levels in charcoal grilled meat and control the carcinogenic effects that cause.

Materials and methods

This study was carried out in the Center of Experimental Animal Research, Faculty of Veterinary Medicine, Benha University, Egypt, in accordance with ethical rules (NO BUFVTM 40-06-23).

Collection of samples

One hundred and twenty samples of meat products represented by roasted kofta, roasted meat, charcoal grilled kofta and charcoal grilled meat (30 of each) were collected randomly from different markets at Kalyobia governorate, Egypt. Each sample was separately wrapped in a plastic bag and transferred directly to the laboratory. The collected samples were examined for determination of Polycyclic Aromatic Hydrocarbons (PAHs) and Heterocyclic Aromatic Hydrocarbons (HAAs). Accordingly, the comparison of such dangerous residues in the examined meat products with the maximum residual limits stipulated by international regulations was applied to evaluate of their acceptability for human consumption. Further, certain trials using natural oils and antioxidants to control these residues to gain excess to meat products were performed.

Thus, this study provided an overview of important variables to reduce the amount of PAHs, particularly those that cause cancer, in grilled meat.

Determination of Polycyclic Aromatic Hydrocarbons (PAHS)

For the sample preparation cyclohexane (ECD tested), N,N-dimethylformamide, methanol (HPLC grade), sodium chloride (ACS), ethanol sodium-sulphate (ACS) potassium hydroxide were purchased El-Gomhurya, Al-Amirya, Egypt. Silica solid phase extraction (SPE) tubes (500 mg) and ultra-pure water was obtained with a MilliQ filter system. Mixture of 15 PAH standards were used (purchased from AccuStandard, CT06513, USA). The standard mix of PAHs consisted of a solution in acetonitrile with concentration 50 mg/l and the concentration of deuterated benzo[a]-pyrene-d12 dissolved in cyclohexane was 1000 ng/µl.

The tested meat product was thoroughly homogenized. The sample preparation procedure was elaborated according to Simko (2002) and Stumpe *et al*. (2008) with some modifications in order to adapt to the gas chromatography–mass spectrometry (GC–MS) detection method.

An Agilent 1200 HPLC system (Germany) consisting of a quaternary pump G1311A, a vacuum degasser G1322A, an automatic injector G1329A with sample tray G1330A, a column thermostat G1316A, a fluorescence detector G1321A, a multiple wave detector G1365B and integration software (Chem Station G2170AA and G2180AA) was used.

Twenty five grams of the sample were placed into round bottomed flask, 12 g of potassium hydroxide and 100 ml of ethanol were added. Accordingly, 25 µl of internal standard benzo[a]pyrene-d12 solution with concentration 10 ng/ µl and 125 µl of PAH mix with concentration 1 ng/ µl were added. Therefore, the mixture was subjected to an alkaline treatment with potassium hydroxide and ethanol by heating for 2 hours at 40°C under reflux and filtered. After cooling to room temperature, the solution was transferred to a 500 ml separating funnel, 100 ml of water and 100 ml of cyclohexane were added. The funnel was shaken, and the layers were allowed to separate.

The ethanol/water phase was transferred into a 250 ml separating funnel and shaked with another 50 ml of cyclohexane. The ethanol/water phase was discarded, and the cyclohexane phases were combined. Thus, the cyclohexane solution was washed successively with 50 ml water, 50 ml of methanol/water (4:1) and 50 ml of water. The cyclohexane extract was shaken with 50 ml of N, N-dimethylformamide/ water (9:1) solution. The layer of N, N-dimethylformamide/water solution was transferred into a 250 ml separating funnel, 50 ml of 1% NaCl solution were added, and PAH were extracted with 75 ml of cyclohexane. The cyclohexane phase was dried over anhydrous sodium sulphate and concentrated by rotary evaporator under reduced pressure (40°C, 235 mbar). The extract was applied to a silica SPE column previously conditioned with cyclohexane (5 ml). The flask was rinsed with cyclohexane (3 ml), and the PAH were eluted with 6 ml cyclohexane. The collected fraction was evaporated under a light stream of nitrogen at 40°C temperature, dissolved in 50 µl of cyclohexane.

An Agilent 1200 HPLC system (Germany) consisting of a quaternary pump G1311A, a vacuum degasser G1322A, an automatic injector G1329A with sample tray G1330A, a column thermostat G1316A, a fluorescence detector G1321A, a multiple wave detector G1365B and integration software (Chem Station G2170AA and G2180AA) was used. Varian Factor Four capillary column 30 m×0.25 mm with film thickness of 0.25 lm, helium carrier gas 1 cm3/min, injector and detector temperature 280°C, temperature program: 120°C (1 min), 120-250°C (15°C/ min), 250°C (13 min), 250-280°C (20°C/ min), 280°C (1 min), 280-300°C (35°C/ min), 300°C (20 min). Total run time was 48 minutes.

One microliter of the sample solution was injected into gas chromatograph. The data were acquired operating the MS in selected ion monitoring mode. Peak spectra were compared to the mass spectra of PAH standards and library supplied with the instrument. The results of recovery of PAHs from the different meat products under investigation were evaluated according to the technique adopted by Chantara and Sangchan (2009). Accurately, the recovery percentages were ranged from 91% to 103% for the various studied meat products. Thus, the average of triplicate analysis was calculated for each polycyclic aromatic hydrocarbon.

Experimental part

Accurately, 30 samples of meat fillets represented by untreated 3 samples (control), 9 samples treated with lauryl oil at concentrations of 0.5, 1 and 1.5% (3 of each), 9 samples treated with garlic oil at concentrations of 0.5, 1 and 1.5% and 9 samples treated with lemon oil at concentrations of 0.5 and 1.0%. All treated samples were sprayed for 15 min in the prepared natural oils (0.5, 1.0 and 1.5%) and cooked by ordinary charcoal grilling. Therefore, all charcoal grilled meat fillets were examined for determination of their contents of BaP, BaA, BpF and CHR Polycyclic Aromatic Hydrocarbons (PAH4). The reduction% of PAHs was calculated to study the effect of such treatments on these serious residues. (The source of essential oils is Food Analysis Center, Faculty of Veterinary Medicine, Benha University)

Statistical Analysis

The collected data were analyzed using one-way analysis of variance (ANOVA) with Duncan by SPSS® version 16.0 according to the methods recommended by Feldman *et al*. (2003).

Results

Results achieved in Table 1, showed the mean concentration of potentially carcinogenic PAHs, PAH4 was 21.92±1.48, PAH8 was 31.16±1.85 and PAHs was 36.97±2.32 µg/kg.

The recorded results in Table 1, showed that the mean concentration of the PAHs group in the examined samples of roasted meat (n=30), PAH4 was 17.05±1.32, PAH8 was 24.35±1.67and PAHs was 28.86±1.95 µg/kg.

The results in Table 1, revealed that PAH individual concentrations in the examined samples of charcoal grilled kofta (n=30), PAH4 was 13.91±1.14, PAH8 was 13.91±1.14 and PAHs was 22.75±1.62 µg/kg.

The results achieved in Table 1, showed the mean concentration of PAHs in the examined samples of charcoal grilled meat (n=30), PAH4 was 10.35±0.89, PAH8 was 14.53±1.17and PAHs was 16.49±1.33 µg/kg.

Additionally, the findings of the present investigation presented in Table 2, demonstrated the influence of lauryl oil in concentrations of 0.5, 1 and 1.5% on PAHs levels in the examined samples of charcoal grilled meat fillets (n=5). PAH4 was 13.7±0.6 with reduction percentage 26.4% for lauryl oil concentration 0.5%.

Concerning 1% lauryl oil concentration; PAH4 was 10.3±0.4 with reduction percentage 44.5%. The best concentration of lauryl oil to reduce the carcinogenic PAHs in fillets of charcoal-grilled meat fillets was 1.5%; PAH4 was 7.2±0.3 with reduction percentage 61.2 %.

Furthermore, results in Table 3, showed the Influence of garlic oil in concentrations of 0.5, 1, and 1.5% on PAHS levels in the examined samples of charcoal grilled meat fillets (n=5). PAH4 level was 12.1±0.5 with a reduction percentage of 34.9% for garlic oil concentration.

In contrast, for those with 1% garlic oil concentration; PAH4 level was 8.9±0.4 with a reduction percentage of 52.2%.

The optimal concentration of garlic oil to reduce the carcinogenic PAHs in fillets of charcoal-grilled meat (n=5) was 1.5%, with PAH4level of 5.5±0.2 and a reduction percentage of 70.4%.

The recorded results in Table 4, showed the influence of lemon oil in

Table 1. Analysis of PAHs levels (μg/kg) in the examined samples of roasted kofta, roasted meat, charcoal grilled kofta and charcoal grilled meat (n=30).

PAHs	Roasted kofta	Roasted meat	Charcoal grilled kofta	Charcoal grilled meat
Benzo[a]Pyrene (BaP)	10.69±0.73	8.19±0.41	7.02±0.36	4.93±0.28
Benz[a]anthracene (BaA)	8.07±0.61	6.37±0.29	4.89±0.22	3.76±0.19
Benzo(b)fluoranthene (Bbf)	1.35±0.04	0.96±0.08	0.74±0.05	0.61±0.04
Chrysene (CHR)	1.81±0.06	1.53±0.11	1.26±0.08	1.05±0.06
Sum PAH4	21.92±1.48	17.05±1.32	13.91±1.14	10.35±0.89
Benzo[k]fluoranthene (BkF)	2.13±0.15	1.88±0.10	1.51±0.12	1.18±0.07
Dibenz[a,h]anthracene (DahA)	0.52±0.03	0.45±0.02	0.36±0.01	0.25±0.02
Benzo[g,h,i] perylene (BghiP)	3.76±0.31	2.91±0.18	2.40±0.16	1.84±0.13
Indenol [1,2,3 cd] pyrene (IcdP)	2.83±0.26	2.06±0.14	1.25±0.11	0.91±0.06
Sum PAH8	31.16±1.85	24.35±1.67	19.43±1.45	14.53±1.17
Dibenzo[ae]pyrene (DaeP)	0.58±0.04	0.46±0.02	0.32±0.01	UDL
Dibenzo[al]pyrene (DalP)	0.93±0.07	0.78±0.05	0.59±0.04	0.41±0.03
Dibenzo[ah]pyrene (DahP)	0.41±0.02	0.33±0.02	0.26±0.01	0.16±0.01
Dibenzo[ai]pyrene (DaiP)	0.24±0.01	0.19±0.01	0.14±0.01	UDL
Cyclopenta(c,d)pyrene (CcdP)	2.89±0.15	2.27±0.13	1.63±0.09	1.18±0.07
Fluoranthene (Flt)	0.76±0.08	0.48±0.03	0.38±0.04	0.23±0.01
Sum PAHs	36.97±2.32	28.86±1.95	22.75±1.62	16.49±1.33

Data are expressed as Mean±SE. PAH4: BaP, BaA, Bbf & CHR; PAH4: BaP, BaA, Bbf, CHR, BkF, DahA, BghiP & Icd; UDL: Undetected limit

Table 2. Influence of lauryl oil on PAHS levels in the examined samples of charcoal grilled meat fillets (n=5).

PAHS / Treatment	Control	0.50% Lauryl oil		1% Lauryl oil		1.50% Lauryl oil	
	Average level	Mean	R %	Mean	R%	Mean	R%*
Benzo[a]Pyrene (BaP)	9.2±0.5^{A}	6.7±0.3^{B}	27.2	5.1±0.3^{C}	44.6	3.6±0.2^{D}	60.9
Benz[a]anthracene (BaA)	5.8±0.3^{A}	4.1±0.2^{B}	29.3	3.0±0.2^{C}	48.2	1.9±0.2^{D}	67.2
Benzo(b)fluoranthene (Bbf)	2.1±0.1^{A}	1.6±0.1^{B}	23.8	1.2±0.1^{C}	42.9	0.8±0.1^{D}	61.9
Chrysene (CHR)	1.5±0.1^{A}	1.3±0.1^{B}	13.3	1.0±0.1^{C}	33.3	0.9±0.1^{D}	40
Sum PAH4	18.6±0.9^{A}	13.7±0.6^{B}	26.4	10.3±0.4^{C}	44.5	7.2±0.3^{D}	61.2

Means with different superscripts in the same column are significantly different (P<0.05). R %= Reduction %

Table 3. Influence of garlic oil on PAHS levels in the examined samples of charcoal grilled meat fillets (n=5).

PAHS / Treatment	Control	0.50% Garlic oil		1% Garlic oil		1.50% Garlic oil	
	Average level	Mean	R %	Mean	R%	Mean	R%*
Benzo[a]Pyrene (BaP)	9.2±0.5^{A}	6.1±0.2^{B}	33.7	4.5±0.2^{C}	51.1	2.9±0.2^{D}	68.5
Benz[a]anthracene (BaA)	5.8±0.3^{A}	3.3±0.2^{B}	43.1	2.6±0.2^{C}	55.2	1.5±0.2^{D}	74.1
Benzo(b)fluoranthene (Bbf)	2.1±0.1^{A}	1.5±0.1^{B}	28.6	1.0±0.1^{C}	52.4	0.6±0.1^{D}	71.4
Chrysene (CHR)	1.5±0.1^{A}	1.2±0.1^{B}	20	0.8±0.1^{C}	46.7	0.5±0.1^{D}	66.7
Sum PAH4	18.6±0.9^{A}	12.1±0.5^{B}	34.9	8.9±0.4^{C}	52.2	5.5±0.2^{D}	70.4

Means with different superscripts in the same column are significantly different (P<0.05). R %= Reduction %

Table 4. Influence of lemon oil on PAHS levels in the examined samples of charcoal grilled meat fillets (n=5).

PAHS / Treatment	Control	0.50% Lemon oil		1% Lemon oil		1.50% Lemon oil	
	Average level	Mean	R %	Mean	R%	Mean	R%*
Benzo[a]Pyrene (BaP)	9.2±0.5^{A}	5.6±0.2^{B}	39.1	3.9±0.2^{C}	57.6	2.2±0.1^{D}	76.1
Benz[a]anthracene (BaA)	5.8±0.3^{A}	2.7±0.1^{B}	53.4	1.8±0.2^{C}	68.9	1.0±0.2^{D}	82.7
Benzo(b)fluoranthene (Bbf)	2.1±0.1^{A}	1.1±0.1^{B}	47.6	0.7±0.1^{C}	66.7	0.4±0.1^{D}	80.9
Chrysene (CHR)	1.5±0.1^{A}	0.9±0.1^{B}	40	0.4±0.1^{C}	73.3	0.3±0.1^{D}	80
Sum PAH4	18.6±0.9^{A}	10.3±0.5^{B}	45.7	6.8±0.4^{C}	65.6	3.9±0.2^{D}	79.1

Means with different superscripts in the same column are significantly different (P<0.05). R %= Reduction %

concentrations of 0.5, 1 and 1.5% on PAHS levels in the examined samples of charcoal grilled meat fillets.

PAH4 level was10.3±0.5 with a reduction percentage of 45.7% for 0.5% lemon oil concentration While for lemon oil concentration of 1.0%, PAH4 level was 6.8±0.4 with a reduction percentage of 65.6%.

The most efficient concentration of lemon oil for lowering the carcinogenic PAHs in charcoal grilled meat fillets was 1.5%, with PAH4 level of 3.9±0.2 and a reduction percentage of 79.1%.

Discussion

Charcoal grilling is a popular method in Egypt and other Arabian countries for improving the organoleptic quality, palatability, and digestibility of beef steaks. However, it can also lead to the creation of carcinogenic compounds, such as PAHs. As a result, the identification of these compounds offers details on possible health hazards associated with eating processed meat, knowledge that may be helpful for consumers' health management (IARC, 2018).

This study's primary focus was on BaP and PAH4 (the combined content of BaP, BaA, CHR, and BbF). Additionally, an analysis was done on the contents of DaeP, DalP, DahP, IcdP, DaiP, BghiP, CcdP, BaA, and DahA, which caused by fat-induced flame generation, incomplete combustion of the heat source, or organic compound pyrolysis.

In terms of their carcinogenicity, PAH4 and PAH8, which are internationally known indicators, had mean concentration values of 90.0±93.14 and 19.7±28.09 µg/kg-1, respectively. The results obtained are not likely to be the same as those reported by Eldaly *et al*. (2016), who found only benzo(a) pyrene and benzo(g,h,i) anthracene at maximum concentrations of 26.0±16.0 µg/kg and 33.2±4.0 µg/kg in the examined non-marinated charcoal grilled kofta samples.

The results in Table 1, showed greater levels of PAH4 and PAH8 than those seen in samples of beef cooked over charcoal (Darwish *et al*., 2019). The maximum allowable limits of PAHs in grilled meat and meat products established by the EC (2023) were surpassed by the discovered B[a] P, total PAH4, and PAH8 in this investigation.

The results obtained in Table 1 were greater than those reported by Alomira *et al*. (2011), who stated that the mean concentration of B[a]P was 1.33 $\mu g/kg^{-1}$, and lower than those recorded by Shawish *et al*. (2022), who found B[a]A, B[a]P, and CHR with mean values of 10.7, 9.7, and 2.3 $\mu g/kg^{-1}$, respectively. Furthermore, the study's detection of B[a]P, total PAH4, and PAH8 exceeded the maximum allowable levels for PAHs in grilled meat and meat products (EC, 2023). The quantity of fat content, the duration and distance of the grilling process, and the type of contact heat (direct or indirect) were found to be strongly associated with these changes in PAH concentration levels. These factors are what cause PAH development in meat.

On the other hand, Janoszka *et al*. (2004) found that cooked beef products in Poland had a lower concentration of BaP (0.11 to 3.93 µg/kg), and the overall PAH content ranged from 2.43 to 16.10 µg/kg. Additionally, Eldaly *et al*. (2016) found that only benzo(a)anthracene and benzo(a) pyrene, at maximum concentrations of 33.2±4.0 and 26.0±16.0 µg/kg, respectively, were detected in the analyzed non-marinated charcoal-grilled meat samples. They did not identify benzo[ghi]perylene. The amount of fat in the steak, the length of time it was grilled, and the high heat contact caused the fat to drip off onto the flames and produce smoke were all strongly linked to these differences in the concentration levels of PAHs or because of organic matter pyrolyzing, which produces free radicals that cause PAH production.

Regarding 1% lauryl oil concentration, Benzo[a]Pyrene (BaP), Benz[a] anthracene (BaA), Benzo(b)fluoranthene (Bbf), Chrysene (CHR) were 5.1±0.3, 3.0±0.2, 1.2±0.1 and 1.0±0.1 with reduction percentages of 44.6%, 48.2%, 42.9% and 33.3% respectively While PAH4 was 10.3±0.4 with a reduction percentage of 44.5%. The best concentration of lauryl oil to reduce the carcinogenic PAHs in fillets of charcoal-grilled meat fillets was 1.5%; Benzo[a]Pyrene (BaP), Benz[a]anthracene (BaA), Benzo(b) fluoranthene (Bbf), Chrysene (CHR) levels were 3.6±0.2, 1.9±0.2, 0.8±0.1 and 0.9±0.1 with reduction percentages of 60.9%, 67.2%, 61.9% and 40% respectively, While PAH4 level was 7.2±0.3 with a reduction percentage of 61.2%.

The type of wood used, the smoking technique, the temperature at which it burns, the smoke's composition, and the length of time that food is exposed to smoke all affect how much PAHs are carried by the smoke particles (Duedahl-Olesen *et al*. 2006). The amount of PAHs is further influenced by factors such as the fuel utilized, the length and kind of processing, the processing level, and the distance from a heat source. However, certain food products contain more PAHs due to operations like crushing, storing, recycling, and concentrating (Singh *et al*. 2016). The European Food Safety Authority (EFSA, 2008) states that benzo[a]pyrene (BaP) is considered a carcinogen to humans.

The carcinogenic PAHs in the charcoal beef steak were more successfully reduced by the altered marinade treatment. The addition of lemon juice tenderized the beef steak, facilitating faster protein digestion and retaining moisture so the meat did not dry out or become tough. This contributed to the reduced PAH levels in the beef steak treated with a modified marinade. These findings so concur with those published by Farhadian *et al*. (2012) in that they decrease the amount of time required to finish cooking.

It also keeps fat droplets from coming into touch with charcoal, which inhibits the production of smoke and the buildup of PAHs on the surface of beef steaks. Further, the addition of lemon juice to the essential marinade treatment had a positive effect on the concentration of PAHs. These oddities could be caused by differences in the acidity of the samples. Higher acidity may also have an impact on the kinetics and mechanism of nonenzymic browning (Maillard) processes. The reaction rate frequently increases when pH rises (Li *et al*., 2021).

PAHs are involved in the aroma products of Maillard reactions, according to studies on the kinetics and mechanism of PAH formation (Britt *et al*., 2004). But as Nursten (2005) points out, lemon juice contains organic compounds like sulfur dioxide, which are commonly used to stop the Maillard processes and may help reduce the amount of PAHs in the samples of beef steak.

Conclusion

Charcoal-grilled meat treated with natural oils decrease the levels of PAH4 in the examined samples. It is recommended that meat should be marinated prior grilling to minimize the hazards of PAHs on human health.

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Conflict of interest

The authors declare that they have no conflict of interest.

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