Food Science and Technology
ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.60921

Polycyclic aromatic hydrocarbon in smoked meat sausages: effect of smoke generation source, smoking duration, and meat content

Mahtab ALSADAT MIRBOD[1], Milad HADIDI[2*], Elcin HUSEYN[3], Amin MOUSAVI KHANEGHAH[4*]

Abstract

The current study was conducted to evaluate the effects of three generation sources of smoke (poplar, haloxylon, and white paper), smoking duration (2 and 4 h) and meat contents (55 and 80%) on Polycyclic Aromatic Hydrocarbons (PAHs) levels of meat sausages. The results showed that there are a positive correlation between the lignin content of smoke generation sources and the PAHs level of smokes and smoked sausages. The total PAHs contents in both smoke and smoked sausages increased significantly as smoking duration increased from 2 to 4 h. The concentrations of total PAHs in the smoked sausage ranged from 6.35 to 20.04 µg/Kg. Furthermore, the benzo[a]pyrene (BaP) levels for the smoked sausages were 0.30 to 1.14 µg/Kg. However, the contents of BaP and PAH4 (benz[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[a]pyrene) were lower than the limit of detection (LOD) in all samples of the smoked sausages. The smoked sausage with 80% of meat content (less fat) processed by poplar and white paper for 2 h had the lowest level of PAHs.

Keywords: Polycyclic Aromatic Hydrocarbons (PAHs); smoked sausage; lignin; white paper; Haloxylon.

Practical Application: The poplar and white paper could be potentially utilized as a safe alternative to commercial woodchips for smoking meat sausages in the meat industry

1 Introduction

Considering the worldwide popularity of meat and meat products, concerns regarding food safety are increasing. Smoking is considered one the oldest methods of food protection and is still expansively in use in fish and meat processing. The bactericidal, antioxidant, and dehydration attribute of smoking lead to preserve the food in addition to adding a unique flavor, color, and aroma to the food (Cabral et al., 2021; Roseiro et al., 2012; Conde et al., 2005). However, concerns are raised about the consumption of smoked meat products mainly due to considerable amounts of PAH found in this type of food product (Silva et al., 2018; Babaoglu et al., 2017; Aghamohammadi et al., 2014; García-Falcón & Simal-Gándara, 2005; Wenzl et al., 2006).

PAH is a carcinogenic and mutagenic compound whose structure includes aromatic rings. Light PAHs contain two up to four rings which are less lipophilic, more volatile, and water-soluble than the heavy PAHs, which contain more than four benzene rings and they are more stable and more toxic than light ones (Farhadian et al., 2010; Škaljac, et al., 2014). 15+1 EUPAH compounds which are prioritized in food containing chrysene (CHR), benzo[b]fluoranthene (BbF), indeno [1,2,3- cd]pyrene (IcP), 5-methylchrysene (5MC), dibenzo[a,i]pyrene (DiP), dibenzo[a,l]pyrene (DlP), benzo[a]pyrene (BaP), dibenzo[a,e]pyrene(DeP), benzo[j]fluoranthene (BjF), benzo[c]fluorene (BcL), dibenzo[a,h]anthracene (DhA), dibenzo[a,h]pyrene (DhP), benzo[k]fluoranthene (BkF), cyclopenta [c,d]pyrene (CPP), benzo[a]anthracene (BaA) and benzo[ghi]perylene (BgP) and they are recommended analyzing by the EU (European Commission, 2002).

The level of BaP is significant due to more probability of carcinogenicity in humans. As the Scientific Committee on Food (European Commission, 2002) has published, BaP is applied to signify incident and carcinogenic effects in food. In smoked meat and its products, the maximum admissible BaP level is 2.0 µg/kg (wet weight) since 2014 (European Union Commission Regulation No. 835/2011). Then EFSA presented that BaP is not a valuable marker for the incident of PAHs in food and suggested that PAH4 (benz[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[a]pyrene) has more validation and competence for indicator (European Food Safety Authority, 2008). The admissible sum of PAH4 in these foods is 12.0 µg/kg^{-1} in wet weight since September 1, 2014 (Ledesma et al., 2015). The USFDA determines hazardous amounts in food but has not set standards for controlling the PAH level in foodstuffs yet (Agency for Toxic Substances and Disease Registry, 2009) as the same in Iran.

The main compositions of wood cells consist of cellulose and hemicelluloses, which generate carbonyls when burnt and responsible for color and flavor (McGee, 2004; Rowell, 2012). Lignin attaches to the wood cells' which is comprised of organized phenolic molecules producing an amount of specific

Received 03 July, 2021
Accepted 22 July, 2021
[1] *Department of Food Science and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran*
[2] *Department of Organic Chemistry, Faculty of Chemical Sciences and Technologies, University of Castilla-La Mancha, Ciudad Real, Spain*
[3] *Research Laboratory of Intelligent Control and Decision-Making Systems in Industry and Economics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan*
[4] *Department of Food Science and Nutrition, Faculty of Food Engineering, University of Campinas, Campinas, São Paulo, Brasil*
*Corresponding author: milad.hadidi@gmail.com, mousavi@unicamp.br; mousavi.amin@gmail.com

aromatic compound when burnt that lead to creat PAHs, guaiacol, phenols, and syringol (Hui et al., 2001; McGee, 2004; Klemm et al., 2005; Garcia-Perez et al., 2008). Various kinds of wood smoke can cause different flavors to smoked sausage. Nakamura et al. (2008) reported that with comparing softwood and hardwood higher, PAHs were observed when softwood burnt at temperatures above 400 °C due to its high amount of lignin. Therefore, the generation of PAH during smoking depends on the wood's type and component (European Commission, 2002). Some research shows that various types of smoked sausages and meat products have different organoleptic characteristics and PAHs. In addition, it is crucial to assess the formulation of the products (Djinovic et al., 2008). Similar to the mentioned factor, smoking duration is also considered in different studies on PAH content in smoked meat products (Gomes et al., 2013; Stumpe-Vīksna et al., 2008). This study aimed to establish the effect of meat's percentage in sausages that effects on the fat and oil contents as a precursor of PAHs and smoke sources such as sawdust of poplar, haloxylon, and white paper, which have a different amount of lignin as well as the duration of smoking on the PAHs formation. We also evaluated the type and the amount of compounds derived from pyrolysis of wood and paper and their changes after absorption on the product's surface and the reaction with the treatment components. Sausages were chosen based on what is used most in Iran and for reducing PAHs content, utilized white paper due to low lignin content and compared it with Haloxylon that abundant in Iran and poplar for its common usage.

2 Material and methods

2.1 Chemical reagents

Poplar, haloxylon, and white paper were obtained from the local market have been used for the experiments. Ethanol, acetone, nitric acid, sulphuric acid, sodium hydroxide, boric acid, hydrogen chloride, petroleum ether, and dimethylsulfoxide were purchased from Merck (Darmstadt, Germany). A mixture of 15 PAH standards (5MC, BbF, CPP, DaeP, DalP, IcdP, DaiP, DahP, CHR, BjF, BaA, BkF, BaP, BghiP, DahA was provided from GmbH company.

2.2 Smoke generation sources

Smoke generated from poplar, haloxylon, and white paper was used for the smoking process due to their availability in Iran. The organization of agriculture Jahad Isfahan-Iran provided these woods. Poplar was chosen due to the tree's fast-growing and abundance and the fact that it can produce smoke at low temperatures, and it is also classified as hardwoods. Haloxylon, with the scientific name *Haloxylon ammodendron*, is a good fuel source and produces suitable and stable smoke. Because of an inconsiderable amount of lignin in the white paper, this can be considered an effective way to reduce polycyclic aromatic hydrocarbons. Extractives and lignin were isolated according to the standard methods TAPPI T 204 om-88 and TAPPI T 222 om-88 respectively, as determined by the Technical Association of the Pulp and Paper Industry (TAPPI). The T 17m-55 TAPPI standard also established cellulose.

2.3 Sausage preparation

Sausage samples with a meat content of 55% and 80% were produced. They differ in meat, oil, water, and ice content. They were prepared following the formulation of meat products Kalleh factory in Tehran, Iran. The basic formulation in a 5 L bowl chopper (Food Machines Muller, Germany) was 55% lean meat of bovine, 1.95% isolated soy protein, 12% oil, 1.9% frozen garlic, 21.5% water and ice, 1.5% salt, 0.3% STPP 900, 0.2% sodium nitrite acid, and spices (from India). The other formulation used was 80% lean meat of bovine, 1.95% isolated soy protein, 3% oil, frozen garlic 1%, 8.5% water and ice, 1.4% salt, 0.4% STPP 900, 0.01% sodium nitrite acid. These sausages were stuffed into a Fibrous casing. For each test, about 3 Kg sample was made (Maia et al., 2020).

2.4 Smoking experiments

Samples were placed in a chamber was designed in the Kalleh factory that is popularly used in IRAN for smoking in traditional hot smoking method with 3 different smoke sources of populous, haloxylon, and white paper. The temperature was set at 40 °C that was controlled with a ventilator and temperature regulator. After 2 hours of smoking, the first group (2 hours smoking) was removed, and the second group (4 hours smoking) was kept in the chamber for 2 additional hours. After smoking, the temperature in the cooking chamber was increased to 75 °C using steam for 70 minutes. After cooking, the product was cooled down to 20 °C and then kept dark at – 18 °C.

2.5 Smoke sampling

In order to evaluate the composition of smoke, sampling was done by a syringe. So, the adsorption of organic materials on solid particles with high absorption for both polar and nonpolar materials was used. The adsorbent substance was Tenax-TA which includes 2,6-diphenyl-P-phenylen oxide polymer. 4 grams were added to the glass tube. This polymer is a granule with a 200 μM diameter, and it is thermal resistance to 400 °C and oxidation resistance. It has 80 to 100 mesh, 200 nm diameter, and average absorption is 32 m^2/g, and a density is 0.25 g/cm^2. In the industry, this glass tube is connected to the sampling pump impinger on one side, which directs the gas into the tube at a rate of 250 ml/min. In this study, instead of this pump, the syringe was used, and after the creation of a vacuum in a glass tube, a gas injection with a syringe was performed (Dettmer & Engewald, 2002).

2.6 Determination of PAHs

The samples were injected into the GC–MS system (Agilent 6890N gas chromatograph equipped with a 5973N mass spectrometer). Separation was achieved on a HP-5 MS (5% phenylmethylpolysiloxane, 30 m, 0.25 mm i.d., 0.1 μM film thickness; J & W Scientific, Folsom) column. As oven temperature program we used the following operative conditions: 5 min at 60 °C then increase up to 220 °C with a gradient of 4 °C/min, then increase up to 280 °C at 4 °C/min, held for 15 min. The temperature of injector and detector was 280 °C; the carrier gas was helium (He) with a flow rate of 1 mL min^{-1} and using a split ratio of 1:50. Samples preparation, extraction procedure of PAHs, and chromatographic conditions were carried out according to the Siddique et al. (2020) method.

2.7 Statistical analysis

In this study, data were assessed by analyzing variance using one-way ANOVA (completely randomized design). The comparison of the means was performed by Duncan test at a 1% level of significance using SPSS 22.0 software (Hadidi et al., 2020).

3 Results and discussion

3.1 Chemical composition of smoke sources

Chemical components of the smoke generation sources are presented in Table 1. Haloxylon had the highest lignin content with 37.9%, and white paper had the lowest lignin content with 7.5%. Considering the amount of lignin, the composition of PAHs in the sausages can be different. As Nakamura et al. (2008) stated, wood with a high amount of lignin would cause high contents of PAHs.

3.2 PAHs of smokes

Table 2 illustrates the composition of smoke from different sources of smoke in two hours and four hours, which were extracted by gas chromatography with a mass spectrometer.

Table 1. Chemical component of smoke sources.

Components	Paper	Haloxylon	Poplar
Cellulose	60.5%	32%	40.38%
Lignin	7.5%	37.9%	23%
Extractive Component	5.06%	4.7%	7.6%
Hemicellulose	26.93%	25.4%	29.02%

From polycyclic aromatic compounds identified by the European Standard for examination, there were only cyclopenta (c) pyran (CPP) and chromium (CHR) in smoke samples, and they were not detectable in smoke from paper.

Table 3 also contains polycyclic aromatic hydrocarbons with a low molecular weight ring that is unstable and less risky, including pyran, floronate (FA), naphthalene (NA), anthracene acyne (AN). The total amount of these light-weight compounds in haloxylon and white paper smoke was 35.9 and 34 µg/L DSMO, respectively, and the lowest amount was 29.6 µg/L DSMO in poplar smoke, and high molecular weight compounds were not detectable in any of the smoke samples. Therefore, from the point of view of time, it can be concluded that increasing the production time of smoke led to an increase in all compounds in the smoke. The table also shows that total PAH4 in the smoke from haloxylon after 4 hours was the highest and 19.7 µg/L DSMO, and its amount was not detectable in the paper smoke, and the poplar smoke after 4 hours was 8.8 µg/L DSMO. Also, the sum of 13 PAH in white paper smoke is the lowest in the range of 1.8 to 3.2 µg/L DSMO, and in haloxylon smoke, the highest amount was in the range of 22.1 to 39.8 µg/L DSMO, and its amount in poplar smoke was between 8.1 to 12.7 µg/L DSMO. These differences were the level of the chemical composition of smoke sources that was measured as Alén et al. (1996) concluded cellulose hemicelluloses and lignin substances dominated the pyrolytic degradation of wood. Likewise, in this study, the insignificant amounts of paper lignin after pyrolysis resulted in producing a small content of polycyclic aromatic hydrocarbons compared to haloxylon, with the highest amount of lignin in total had the highest content of these PAHs.

3.3 PAHs in smoked meat sausage

The content of PAHs in the sausages was smoked with Haloxylon was the highest (Table 4). Overall, in this study, BaP

Table 2. Polycyclic aromatic hydrocarbons (PAHs) in µg/l DSMO of smoke sources.

Smoking time	2 hour			4 hour		
Smoking Source	paper	Haloxylon	Poplar	paper	Haloxylon	Poplar
Chrysene (CHR)	n.d.	10.40	5.50	n.d.	19.70	8.80
Cyclopentapyrene	1.80	11.70	2.60	3.20	20.10	3.90
Pyrene	12.50	9.90	7.10	19.60	20.60	15.20
Fluranthene	1.70	1.90	1.40	2.20	1.50	1.80
Naphthalene	4.50	6.30	n.d.	7.60	8.90	n.d.
Acenaphthene	n.d.	n.d.	n.d.	n.d.	2.20	3.10
Anthracene	3.30	2.10	6.90	4.60	2.70	9.50

n.d = value was not detected.

Table 3. Polycyclic aromatic hydrocarbon (PAH) (µg/l) DSMO of smoke sources.

Smoking time	2 hour			4 hour		
Smoking source	paper	Haloxylon	Poplar	Paper	Haloxylon	Poplar
PAH4	n.d.	10.40	5.50	n.d.	19.70	8.80
15+1 EU-PAH	1.80	22.10	8.10	3.20	39.80	12.70
Light PAHs	22	20.20	15.40	34	35.90	29.60
Heavy PAHs	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d = value was not detected.

Table 4. Polycyclic aromatic hydrocarbon (PAH) in μg/kg (dry weight) of smoked sausage.

Smoking time			2 hour			4 hour		
PAH	Meat %	control	paper	Haloxylon	Poplar	paper	Haloxylon	Poplar
BaA	55%	3.8 ± 0.2	6.4 ± 0.4	7.2 ± 0.3	3.6 ± 0.5	5.5 ± 0.5	7.9 ± 0.4	4.5 ± 0.3
	80%	3.9 ± 0.4	5.2 ± 0.5	7.5 ± 0.4	2.6 ± 0.3	8.3 ± 0.3	8.3 ± 0.5	4.9 ± 0.4
CHR	55%	n.d.	n.d.	5.7 ± 0.4	1.8 ± 0.14	n.d.	6.5 ± 0.4	2.3 ± 0.3
	80%	n.d.	n.d.	5.3 ± 0.2	1.3 ± 0.1	n.d.	7.3 ± 0.4	2.4 ± 0.2
BbF	55%	0.8 ± 0.1	0.41 ± 0.11	1.3 ± 0.1	n.d.	0.7 ± 0.1	2.1 ± 0.2	n.d.
	80%	0.5 ± 0.1	0.6 ± 0.1	1.6 ± 0.2	n.d.	0.7 ± 0.1	2.3 ± 0.1	n.d.
BaP	55%	0.4 ± 0.1	n.d.	0.6 ± 0.1	0.4 ± 0.04	0.3 ± 0.1	0.9 ± 0.1	0.6 ± 0.1
	80%	0.4 ± 0.05	n.d.	0.7 ± 0.1	0.3 ± 0.06	0.5 ± 0.1	1.1 ± 0.1	0.7 ± 0.1
BcL	55%	n.d.	n.d.	n.d.	0.4 ± 0.08	n.d.	n.d.	0.6 ± 0.09
	80%	n.d.	n.d.	n.d.	0.5 ± 0.02	n.d.	n.d.	0.9 ± 0.1
5MC	55%	0.7 ± 0.1	n.d.	0.7 ± 0.1	0.8 ± 0.1	n.d.	0.8 ± 0.1	0.6 ± 0.0
	80%	0.66 ± 0.1	n.d.	0.8 ± 0.1	0.9 ± 0.1	n.d.	1.1 ± 0.1	0.5 ± 0.0
DiP	55%	n.d.	n.d.	0.5 ± 0.05	n.d.	n.d.	0.9 ± 0.1	n.d.
	80%	n.d.	n.d.	0.7 ± 0.0	n.d.	n.d.	1.2 ± 0.1	n.d.
DhA	55%	0.7 ± 0.1	0.6 ± 0.1	0.4 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.07	0.8 ± 0.1
	80%	0.610.1	5.88 ± 0.6	0.5 ± 0.05	0.7 ± 0.1	0.4 ± 0.1	0.8 ± 0.08	1.1 ± 0.1

n.d = value was not detected.

Table 5. Some polycyclic aromatic hydrocarbons groups (PAHs) μg/kg (dry weight) of smoked sausage.

Smoking time		Control	2 hour			4 hour		
PAHs groups	Meat %		Paper	Haloxylon	Poplar	Paper	Haloxylon	Poplar
PAH4	55%	5.1 ± 0.3ij	6.8 ± 0.4gh	14.9 ± 0.3c	5.9 ± 0.6h	10.9 ± 0.5d	17.5 ± 0.2b	7.4 ± 0.5fg
	80%	4.8 ± 0.3ij	5.8 ± 0.6h	15.3 ± 0.4c	4.3 ± 0.4i	9.6 ± 0.3e	19.1 ± 0.7a	8.1 ± 0.8f
15P+1EU-PAH	55%	6.5 ± 0.4fg	7.4 ± 0.5fg	16.6 ± 0.2 c	7.9 ± 0.8f	11.5 ± 0.6d	20 ± 0.8b	9.5 ± 0.5e
	80%	6.1 ± 0.3g	6.3 ± 0.5g	17.4 ± 0.5c	6.5 ± 0.5fg	10 ± 0.4de	22.3 ± 1a	10.9 ± 1.1de
Light PAHs	55%	5.3 ± 0.5h	18.5 ± 0.4f	24.1 ± 1.2d	17 ± 1.1f	26.7 ± 0.1bc	28.1 ± 1.1b	21.5 ± 0.5e
	80%	5.1 ± 0.3h	18.4 ± 0.6f	25.3 ± 0.8cd	14.7 ± 0.4g	26.6 ± 0.6bc	31.6 ± 0.8a	24.2 ± 1.2d
Heavy PAHs	55%	1.9 ± 0.1e	1 ± 0.2fg	2.4 ± 0.1d	1 ± 0.1fg	1.6 ± 0.1e	3.7 ± 0.1b	1.4 ± 0.1ef
	80%	1.5 ± 0.1e	1 ± 0.1fg	2.9 ± 0.4c	1.1 ± 0.2fg	1.7 ± 0.1e	4.6 ± 0.2a	1.9 ± 0.2e

n.d: value was not detected; Results are represented as means ± SD, n = 3 and values within each column with the same letters are not significantly different (P > 0.05).

in all samples was below the latest allowable limits of 2 μg/Kg in dry weight. BaP in all samples was in the range of 0.3 to 1.14 μg/Kg. García-Falcón & Simal-Gándara (2005) reported with traditional smoking, the amounts of BaP in chorizo meat were around 1–2μg/kg. Smoked samples with haloxylon had the highest values of PAH4, ranging from 14.98 to 19.15 μg/Kg. Sausages smoked with poplar and control samples had the lowest PAH4 ranging from 4.87 to 10.9 μg/Kg presented in Table 5. Significant differences in the amount of PAH4 ($p < 0.01$) were observed in all samples except for the control samples, where the PAH4 ranges from 6.35 to 11.74 μg/Kg. The highest content of 13 PAH was found in smoked sausages with haloxylon, ranging from 16.68 to 22.38 μg/Kg. This was significantly different from other samples ($p < 0.01$). Essumang et al., (2013) also reported that smoked fish with sugarcane bagasse due to low lignin led to low PAH levels compared to the Acacia and mangroves. According to Gomes et al. (2009) and Santos et al. (2011), the content of low molecular weight compounds was more than heavyweights. As shown by Aurore et al. (2000), Guillén et al. (2000), and Stumpe-Vīksna et al. (2008), the presence of light PAHs can be related to the smoke composition itself. This is independent of the wood used in combustion and smoking procedure (direct/indirect). However, in this study, the highest amount of low molecular weight compounds was found in smoked sausages with Haloxylon, which was in the range of 24.15 to 31.67 μg/Kg. Samples smoked with poplar had the lowest molecular weight compound level ranging from 14.71 to 24.21 μg/Kg. The content of low molecular weight compounds in the smoked sausages with the white paper was in the range of 18.48 to 26.72 μg/Kg, as well. This difference between samples ($p < 0.01$) was statistically significant. In addition, the amount of these compounds increased significantly with an increase in the smoking time. Gomes et al. (2013) reported that products with less fat led to a decrease in PAHs, and this study also for the 80% meat sausages smoked with poplar, white paper, and a control sample compared to the 55% meat samples (more fat content) less PAHs content was observed. It can be concluded here that sausage smoked with Haloxylon had the highest content of high molecular weight compounds, where the sausage smoked with the white paper had the least. Only the results obtained for samples smoked with Haloxylon showed statistically significant differences. In general, the amount of meat used in the formula did not have any statistically significant difference in the level of 13 PAH ($p > 0.01$). Gomes et al. (2013) also found that the fat and smoking method did not affect the total PAH. However, a significant increase in these compounds was observed ($p < 0.01$) with an increase in smoking time, as stated by Essumang et al. (2013).

By comparison of the smoke composition table with the compounds in smoke treatments were observed that compositions of smoke after adsorption on the surface of the product and the reaction with the protein, including the reaction of carbonyls with amino acids in the Maillard, have been altered and, due to the type of smoke and product formulation and sometimes hazardous compounds were produced (Hadidi et al., 2021). For example, polycyclic aromatic hydrocarbons with high molecular weight, which were carcinogenic, were not found in smoke samples, while there were compounds such as benzo (b) fluoranthene and benzo (a, h) anthracene in smoked treatments. García-Falcón & Simal-Gándara (2005) tried to find the relation between the wood of smoking and the formation of PAH8 and transfer them into a kind of Spanish sausages with different casings. They stated that different traditional smoking conditions are important to consider in creating PAHs among the smoke materials from qualitative aspects. Nevertheless, it is not practical to prepare broadly acceptable guidelines for selecting wood species or other plant materials. So, they should be assessed in relevance to PAH formation before use in smoking processes. This shows that the main parameter causing the generation of PAHs is the chemical components of wood, cellulose, hemicellulose, and particularly lignin.

4 Conclusions

The highest content of BaP, 13PAH, and PAH4 was found in smoked sausages with haloxylon for 4 hours. This can be related to the high levels of lignin in haloxylon wood. PAH levels of sausage decreased with increasing meat content in formulation from 55 to 80%. The amount of BaP as an indicator of carcinogen in all samples was less than the legal limit (2 μg/Kg). PAH4 concentration in smoked sausages with poplar was the lowest among the samples. Smoking process with white paper caused a reduction in BaP, and 13 PAH and poplar reduced the PAH4 level. This is due to the high amount of BaA in samples smoked with white paper. PAH4 exceeded the new European limits of 12 μg/Kg only in sausages smoked with haloxylon. Therefore, less smoking time (2 hours), the formulation with more meat content (less fat and oil), and smoked sausages with sources that have lower lignin content (white paper and poplar) are more desired and contain less PAHs.

References

Agency for Toxic Substances and Disease Registry – ATSDR. (2009) *Case Studies in Environmental Medicine Toxicity of Polycyclic Aromatic Hydrocarbons (PAHs)*. Washington: US Department of Health and Human Services Public Health Service. Retrieved from: http://www.atsdr.cdc.gov/csem/pah/docs/pah.pdf

Aghamohammadi, B., Morshedi, A., Moayedi, G., Akbarian, M., Akbarian, A., & Hadidi, M. (2014). Effect of high pressure processing of food characteristics: a review of quality aspect. *International Journal of Biosciences*, 10, 193-205.

Alén, R., Kuoppala, E., & Oesch, P. (1996). Formation of the main degradation compound groups from wood and its components during pyrolysis. *Journal of Analytical and Applied Pyrolysis*, 36(2), 137-148. http://dx.doi.org/10.1016/0165-2370(96)00932-1.

Babaoglu, A. S., Karakaya, M., & Öz, F. (2017). Formation of polycyclic aromatic hydrocarbons in beef and lamb kokorec: effects of different animal fats. *International Journal of Food Properties*, 20(9), 1960-1970. http://dx.doi.org/10.1080/10942912.2016.1225761.

Cabral, N. O., Oliveira, R. F., Henry, F. C., Oliveira, D. B., Santos, A. C. Jr., Maia, J. A. Jr., & Martins, M. L. L. (2021). Effect of the fruit aqueous extract of balloon pepper (*Capsicum baccatum* var. Pendulum) on lipid oxidation, microbiological quality and consumer acceptance of fresh pork sausage and smoked. *Food Science and Technology* [Ahead of print].

Conde, F. J., Ayala, J. H., Afonso, A. M., & González, V. (2005). Polycyclic aromatic hydrocarbons in smoke used to smoke cheese produced by the combustion of rock rose (Cistus monspeliensis) and tree heather (Erica arborea) wood. *Journal of Agricultural and Food Chemistry*, 53(1), 176-182. http://dx.doi.org/10.1021/jf0492013. PMid:15631526.

Dettmer, K., & Engewald, W. (2002). Adsorbent materials commonly used in air analysis for adsorptive enrichment and thermal desorption of volatile organic compounds. *Analytical and Bioanalytical Chemistry*, 373(6), 490-500.

Djinovic, J., Popovic, A., & Jira, W. (2008). Polycyclic aromatic hydrocarbons (PAHs) in different types of smoked meat products from Serbia. *Meat Science*, 80(2), 449-456. http://dx.doi.org/10.1016/j.meatsci.2008.01.008. PMid:22063352.

Essumang, D. K., Dodoo, D. K., & Adjei, J. K. (2013). Effect of smoke generation sources and smoke curing duration on the levels of polycyclic aromatic hydrocarbon (PAH) in different suites of fish. *Food and Chemical Toxicology*, 58, 86-94. http://dx.doi.org/10.1016/j.fct.2013.04.014. PMid:23603007.

European Commission – EC. (2002). *Opinion of the Scientific Committee on Food on the risk to human health of polycyclic aromatic hydrocarbons in food. SCF/CS/CNTM/PAH/29 Final.* Brussels: EC.

European Food Safety Authority – EFSA. (2008). Scientific opinion of the panel on contaminants in the food chain on a request from European Commission on polycyclic aromatic hydrocarbons in food. *EFSA Journal*, 724, 1-114.

Farhadian, A., Jinap, S., Abas, F., & Sakar, Z. I. (2010). Determination of polycyclic aromatic hydrocarbons in grilled meat. *Food Control*, 21(5), 606-610. http://dx.doi.org/10.1016/j.foodcont.2009.09.002.

Garcia-Perez, M., Wang, X. S., Shen, J., Rhodes, M. J., Tian, F., Lee, W. J., Wu, H., & Li, C. Z. (2008). Fast pyrolysis of oil mallee woody biomass: effect of temperature on the yield and quality of pyrolysis products. *Industrial & Engineering Chemistry Research*, 47(6), 1846-1854.

García-Falcón, M. S., & Simal-Gándara, J. (2005). Polycyclic aromatic hydrocarbons in smoke from different woods and their transfer during traditional smoking into chorizo sausages with collagen and tripe casings. *Food Additives and Contaminants*, 22(1), 1-8. http://dx.doi.org/10.1080/02652030400023119. PMid:15895605.

Gomes, A., Roseiro, C., & Santos, C. (2009). Determination of polycyclic aromatic hydrocarbons profile in Portuguese traditional dry fermented sausage. In International Life Sciences Institute Europe, World Health Organization & Food and Agriculture Organization of the United Nations (Orgs.), *V Food Safety European Symposium,* Berlin, Germany: IAFP.

Gomes, A., Santos, C., Almeida, J., Elias, M., & Roseiro, L. C. (2013). Effect of fat content, casing type and smoking procedures on PAHs contents of Portuguese traditional dry fermented sausages. *Food and Chemical Toxicology*, 58, 369-374. http://dx.doi.org/10.1016/j.fct.2013.05.015. PMid:23692922.

Guillén, M. D., Sopelana, P., & Partearroyo, M. A. (2000). Polycyclic aromatic hydrocarbons in liquid smoke flavorings obtained from different types of wood. Effect of storage in polyethylene flasks on their concentrations. *Journal of Agricultural and Food Chemistry*, 48(10), 5083-5087. http://dx.doi.org/10.1021/jf000371z. PMid:11052782.

Hadidi, M., Amoli, P. I., Jelyani, A. Z., Hasiri, Z., Rouhafza, A., Ibarz, A., Khaksar, F. B., & Tabrizi, S. T. (2020). Polysaccharides from pineapple core as a canning by-product: extraction optimization, chemical structure, antioxidant and functional properties. *International Journal of Biological Macromolecules*, 163, 2357-2364. http://dx.doi.org/10.1016/j.ijbiomac.2020.09.092. PMid:32949627.

Hadidi, M., Motamedzadegan, A., Jelyani, A. Z., & Khashadeh, S. (2021). Nanoencapsulation of hyssop essential oil in chitosan-pea protein isolate nano-complex. *Lebensmittel-Wissenschaft+Technologie*, 144, 111254. http://dx.doi.org/10.1016/j.lwt.2021.111254.

Hui, Y. H., Hui, Y. H., Nip, W., & Rogers, R. (2001). *Meat science and applications*. New York: CRC Press. http://dx.doi.org/10.1201/9780203908082.

Klemm, D., Heublein, B., Fink, H. P., & Bohn, A. (2005). Cellulose: fascinating biopolymer and sustainable raw material. *Angewandte Chemie International Edition*, 44(22), 3358-3393. http://dx.doi.org/10.1002/anie.200460587. PMid:15861454.

Ledesma, E., Rendueles, M., & Díaz, M. (2015). Spanish smoked meat products: benzo (a) pyrene (BaP) contamination and moisture. *Journal of Food Composition and Analysis*, 37, 87-94. http://dx.doi.org/10.1016/j.jfca.2014.09.004.

Maia, J. A. Jr., Henry, F. C., Lucia, S. M. D., Santos, A. C. Jr., Cabral, N. O., Quirini, C. R., & Valle, F. R. A. F. (2020). Sensory attributes and Lipid oxidation of smoked lamb sausage formulated with passion fruit meal, potassium chloride and calcium chloride. *Food Science and Technology*, 40(2), 423-429. http://dx.doi.org/10.1590/fst.02419.

McGee, H. (2004). *On food and cooking: the Science and Lore of the Kitchen*. New York: Scribner.

Nakamura, T., Kawamoto, H., & Saka, S. (2008). Pyrolysis behavior of Japanese cedar wood lignin studied with various model dimers. *Journal of Analytical and Applied Pyrolysis*, 81(2), 173-182. http://dx.doi.org/10.1016/j.jaap.2007.11.002.

Roseiro, L. C., Gomes, A., Patarata, L., & Santos, C. (2012). Comparative survey of PAHs incidence in Portuguese traditional meat and blood sausages. *Food and Chemical Toxicology*, 50(6), 1891-1896. http://dx.doi.org/10.1016/j.fct.2012.03.054. PMid:22469922.

Rowell, R. M. (2012). *Handbook of wood chemistry and wood composites*. New York: CRC press. http://dx.doi.org/10.1201/b12487.

Santos, C., Gomes, A., & Roseiro, L. C. (2011). Polycyclic aromatic hydrocarbons incidence in Portuguese traditional smoked meat products. *Food and Chemical Toxicology*, 49(9), 2343-2347. http://dx.doi.org/10.1016/j.fct.2011.06.036. PMid:21722696.

Siddique, R., Zahoor, A. F., Ahmad, S., Ahmad, H., Mansha, A., Zahid, F. M., Faisal, S., & Aadil, R. M. (2020). GC-MS analysis of PAHs in charcoal grilled rabbit meat with and without additives. *Food Science and Technology* [Ahead of print]. http://dx.doi.org/10.1590/fst.34720.

Silva, S. L., Resende, O., Bessa, J. F. V., Bezerra, I. M. C., & Tfouni, S. A. V. (2018). Ozone in polycyclic aromatic hydrocarbon degradation. *Food Science and Technology*, 38(Suppl. 1), 184-189. http://dx.doi.org/10.1590/fst.06817.

Škaljac, S., Petrović, L., Tasić, T., Ikonić, P., Jokanović, M., Tomović, V., Džinić, N., Šojić, B., Tjapkin, A., & Škrbić, B. (2014). Influence of smoking in traditional and industrial conditions on polycyclic aromatic hydrocarbons content in dry fermented sausages (Petrovská klobása) from Serbia. *Food Control*, 40, 12-18.

Stumpe-Vīksna, I., Bartkevičs, V., Kukāre, A., & Morozovs, A. (2008). Polycyclic aromatic hydrocarbons in meat smoked with different types of wood. *Food Chemistry*, 110(3), 794-797. http://dx.doi.org/10.1016/j.foodchem.2008.03.004.

Wenzl, T., Simon, R., Anklam, E., & Kleiner, J. (2006). Analytical methods for polycyclic aromatic hydrocarbons (PAHs) in food and the environment needed for new food legislation in the European Union. *Trends in Analytical Chemistry*, 25(7), 716-725. http://dx.doi.org/10.1016/j.trac.2006.05.010.