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PAHs CONTENT IN POLISH SMOKED MEAT PREPARED WITH TRADITIONAL METHOD

– Research paper –

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Abstract: Meat smoking is an old and efficient method of meat treatment, resulting in the preparation of meat with specific properties, improved taste, and modified the physical and chemical properties of treated meats. The aim of this study was to analyse the level of polycyclic aromatic hydrocarbons (PAHs) generated during meat smoking using traditional Polish methods. In particular, various meat products such as: Kornetka from Górno, Country sausage from Górno, Dry pork from Górno, Homemade ham, Steamed bacon, Pork kabanos were prepared. Within the treated meats, the following PAH compounds were determined: benzo(a)pyrene - BaP, chrysene - CHR, benzo(a)anthracene - BaA, benzo(b)fluoranthene - BbF, 5-methylchrysene - 5-MeCHR, benzo(c)fluorene - BcF, benzo(g, h,i)perylene - BghiP, benzo(j)fluoranthene - BjF, benzo(k)fluoranthene - BkF, dibenzo(a,e)pyrene - dBaeP, dibenzo(a,h)anthracene - dBahA, dibenzo(a,h) pyrene - dBahP, dibenzo(a,i)pyrene - dBaiP, dibenzo(a,l)pyrene - dBalP, indeno(c,d)pyrene - IcdP. After the smoking process, cold cuts samples were taken for chemical analysis to determine the presence of PAHs. Samples were taken 7 times, at 2-week intervals, in an amount of approximately 1.5 kg, immediately after heat treatment, cooling and packaging. The amount of polycyclic aromatic hydrocarbons was determined by liquid chromatography (HPLC). Research carried out shows that the lowest average PAH content was found in dry sausage and was 5.87µg/kg. In three of the meats tested, the total PAHs content assessed ranged from 10.78 to 16.62µg/kg The results of this study provide information on PAH levels in traditionally smoked meats and assess compliance of these levels with current health and safety regulations. This research is crucial to understand the possible health risks factors that could be associated with the consumption of traditionally smoked meat and to guide the development of safer smoking practices.

Keywords PAH, smoked sausage, smoked meat, sausage quality, food chemistry, food quality, food quality management

INTRODUCTION

Smoking is one of the oldest methods of preserving food, including meat and meat products, the essence of which is to saturate preserved products with smoke generated mainly during the combustion of wood. The process leads to the formation of ingredients such as phenol, formaldehyde, organic acids, and polycyclic aromatic hydrocarbons (PAHs), which settle mainly on the surface of smoked products (Toth, 1982; Ledesma et al., 2016; Paradowski, 2006; Tilgner et al., 1962; Vögel et al., 2005; Kostyra, 2005; Pan et al., 2000; Ghasemzadeh-Mohammadi et al., 2012; Migdał et al., 2016). The smoking method is a traditional procedure which action is based on the action of cold, warm, or hot wood smoke in presalted meat products or sausages to achieve results in the form of desirable sensory properties and aims to improve the stability of the products. Furthermore, smoking is expected to result in a reduction of microbial contamination and inhibit lipid oxidation. Smoke is composed of a variety of compounds, such as phenols, carbonyls, and acids (Bagnowska et al.,2011).

In addition to the storage effect, smoking improves the overall organoleptic profile of the product, giving a specific color, smell, and texture to smoked meats (Hitzel et al., 2012). At the same time, smoking has undesirable effects related to food contamination with toxic and carcinogenic compounds such as PAHs, N-nitrosamines, heterocyclic aromatic amines and β-carbolines (Ledesma et al., 2017).

According to numerous authors, smoking is the main source of food contamination with polycyclic aromatic hydrocarbons. (Ghasemzadeh-Mohammadi, 2012; Djinovic et al., 2008; Shrestha

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et al., 2015; Arias et al., 2010; Pongpiachan, 2015; Rey-Salguerio et al., 2009a; Rey-Salguerio et al., 2009b; Yebra-Pimentel et al., 2012; Yerba-Pimentel et al., 2014; Chen et al., 2022). The detection of PAHs in the environment and food is an undesirable signal due to their known carcinogenic, mutagenic, and teratogenic properties.

(Pei-Tjun Edna Hee, Zijian Liang, Pangzhen Zhang, Zhongxiang Fang 2024; Alomirah et al., 2010; Alomirah et al., 2011) aromatic hydrocarbons (PAHs) have been investigated in a number of food products due to their unique properties and complex effects that can cause carcinogen diseases (Singh et al.,2018). Except for occupational exposure or smokers, food is the primary source of PAHs ingestion for humans (Singh et al., 2020).

The risk of contamination of smoked products with PAHs means that the smoking process must be monitored to ensure consumer safety. These elements are mentioned by Ledesma et al. (Ledesma et al. 2015; Ledesma et al., 2014; Singh et al., 2018; Singh et al., 2020). Ledesma et al. pointed out that the most important factors that may affect the level of PAH contamination are the type of fuel, the time and temperature of wood pyrolysis, the smoke content of the chamber, the intensity of air flow, the design of the chamber, the type of smoking (direct or indirect), the distance between the product, the heat source, and sanitary and hygienic conditions of equipment and chamber (Rozentāle et al., 2015; Migdał, 2014; Migdał et al., 2015; Kołakowski at al., 2012).

It is known that the main cause of PAHs contamination of smoked meat products is traditional smoking conducted within smoking chambers in which the source of heat and smoke is combustion of wood originating from plants leaves characterised by specific moisture and the meat is kept some distance above the heat source where it undergoes smoking treatment.

Rozentāle et al., 2015; Migdał, 2014; Migdał et al., 2015; Kołakowski et al., 2012 and in earlier own research (Choroszy and Tereszkiewicz, 2020; 2021). It was concluded that PAHs are present in products smoked with the traditional method. Although strict control of wood pyrolisis within the smoking atmosphere, there are some amounts of properties that endanger consumers' health (Li et al., 2016; Lee et al., 2016; Fasano et al., 2016; Rozentāle et al., 2015).

Two groups are distinguished among 15 hydrocarbons. The first of them, called heavy PAHs, form compounds that contain five or more aromatic rings (Dutkiewicz, 1988; Kubiak, 2013). The group of light PAHs belongs to those that are made up of fewer than five aromatic rings. Heavy hydrocarbons are considered particularly toxic (Sapota, 2002; Kubiak, 2013; Bansal, Ki - Hyun, 2015). Among heavy PAH, the subject of special research interest is benzo(a)pyrene (Bansal, Ki-Hyun, 2015; Kubiak, 2013; Singh et al. 2016; Manda et al., 2012; Shen et al., 2014). It is an exemplary compound that determines the relative carcinogenic coefficient. It is included in the so-called sum of 4 PAH, which also includes benzo (b) fluoranthene and two "light" hydrocarbons, chrysene and benzo (a) anthracene.

The above means that to ensure the safety of consumers in the European Union, regulations were adopted and implemented on permissible PAH limits, including BAP and the sum of four PAH.

According to the updated regulation of the European Commission, the provisions on BAP limits and the sum of 4 PAH are determined differently for individual types of food products. According to the European Commission, the maximum limit for BaP is 2.0 µg/kg and 12 µg/kg for the sum of four PAH in smoked fish products (Duns et al., 2021).

In traditional smoked meat and meat products, the European Commission has established as a derogation from the provisions contained in the new Regulation No. 2023/915 of 25 April 2023 on the highest permissible levels of some pollution in food (Vranešević et al., 2022). On the basis of a deviation from art. 2 The following Member States may allow the marketing in their markets for the end consumer of the following traditionally smoked meats and meat products, smoked on their territory and showing levels higher than the levels specified in Annex I point 5.1.6, (smoked meat and smoked meat products 2.0µg/kg and 12.00µg/kg) unless these products contain more than 5.0 µg/kg benzo (a) pyrene and 30.0 µg/kg of sum benzo (a) pyrene, benzo (a) Anthracene, benzo (b) Fluoranthene and chrysene: Ireland, Croatia, Cyprus, Spain, Poland and Portugal: traditional smoked meats and meat products.

The purpose of the investigation was to determine the level of contamination of selected sausage products with compounds from the PAH group in relation to applicable European regulations.

MATERIALS AND METHODS

The material tested included cold cuts produced at one of the local meat processing plants operating in south-east Poland. The company specialises in the production of traditional meat products made from local raw materials obtained from the direct raw material resources of the plant within the existing cluster. From the range of products manufactured in the plant, products with the following trade names were selected for testing: Kornetka from Górno;Country sausage from Górno; Dry pork from Górno; Homemade ham; Steamed bacon; Pork kabanos.

The products were manufactured according to a company recipe covered by trade secrets. The selection of experimental material was guided by the principle that the common element of the entire technological process and, above all, the heat treatment used for each product was the use of the traditional smoking process in its technology. Smoking was carried out using the method of generating smoke in a fireplace approximately 50 cm away from the smoking chamber and connected to it by an inlet channel. The smoke generated within the furnace was produced by the pyrolysis process of air-dry chips and beech blocks, and then low-boiling substances containing a number of volatile compounds were directed into the smoking chamber. The combustion process in the chamber furnace was carried out using generated heat, which allowed the furnace temperature to be maintained at approximately 675 ° C. The wood pyrolysis temperature was controlled throughout the smoking process, taking readings at 15 minute intervals. The temperature in the furnace was checked using the LB-707 thermometer, hygrometer, and barometer set. The smoking time of the products selected for testing was:

- Kornetka of Górno smoking with wood chips at 60 ° C for 30 minutes;
- Górno country sausage - This sausage is smoked and dried at a temperature of 75°C for 2 hours and then smoked and baked at a temperature of 80÷85°C for 3÷4 hours;
- Górno dry sausage - dried at 65 ° C for 1.5 hours, smoking at 65 ° C (with wood chips smoke generated in an incandescent smoke generator);
- homemade ham - traditional smoking is carried out with the smoke from the burning of beech wood in two phases: drying at a temperature of 75-80 °C for 2-3 hours and proper smoking at a temperature of 80 °C for 30 minutes;
- Steamed bacon - dried in a smoking and cooking chamber at a temperature of 73 C for 2 hours and 15 minutes, then smoking with wood chips smoke at a temperature of 73 °C for 20 minutes;
- kabanos, dried at 50 °C for 1 hour and 45 minutes, smoking with wood chips smoke at 52 °C for 50 minutes.

After the smoking process, cold cuts samples were taken for chemical analysis to determine the presence of PAHs. Samples were taken 7 times, at 2-week intervals, in an amount of approximately 1.5 kg, immediately after heat treatment, cooling and packaging. When collecting, the principles specified in the Polish standard [PN-EN ISO 15753] were followed. Immediately after packaging, all samples were transported to the laboratory, where laboratory samples were prepared from them. For this purpose, they were homogenized three times in sieves with different widths of homogeniser holes, then packed in sterile glass packages, approximately 20g of samples from the entire homogenate and frozen at -25 °C to stop microbiological processes.

The content of polycyclic aromatic hydrocarbons was determined by liquid chromatography (HPLC). The level of contamination with 15 polycyclic aromatic hydrocarbons considered the most common in meat products was determined. The following were determined: benzo(a)pyrene - BaP, chrysene - CHR, benzo(a)anthracene - BaA, benzo(b)fluoranthene - BbF, 5-methylchrysene - 5-MeCHR, benzo(c)fluorene - BcF, benzo(g, h,i)perylene - BghiP, benzo(j)fluoranthene - BjF, benzo(k)fluoranthene - BkF, dibenzo(a,e)pyrene - dBaeP, dibenzo(a,h)anthracene - dBahA, dibenzo(a,h) pyrene - dBahP, dibenzo(a,i)pyrene - dBaiP, dibenzo(a,l)pyrene - dBalP, indeno(c,d)pyrene - IcdP.

The determination involved extracting the fat fraction from a previously prepared portion of the product using the Soxhlet method. The extraction was carried out in an apparatus with a capacity of 100 cm^3, using hexane + DCM solvent in a proportion of 3 + 1 (v/v) for 8 hours. The concentrated sample was purified by SEC/GPC size exclusion chromatography. The Bio-Beads SX-3 bed was placed in a column with dimensions of 50 cm x 1.5cm, the solvent was a mixture of cyclohexane and ethyl acetate in a 1:1 ratio (by volume), the flow was 2cm^3/min. The initial fraction with a volume of 60 cm^3 was discarded. Another fraction was collected with a volume of 60 cm^3 containing PAHs. After concentration, this sample was purified by solid phase extraction (SPE) using a 6 cm^3 SPE column containing 1000 mg of silica gel. The column was conditioned with a mixture of hexane and dichloromethane 1+1 (v/v),

and then a sample of 3 x 1 cm^3 was placed on the column and washed with 2 x 5 cm^3. The final fraction with a volume of 8 cm^3 was concentrated.
Qualitative and quantitative determination of polycyclic aromatic hydrocarbons was performed using a Waters Alliance 2695 high performance liquid chromatograph, equipped with an Agilent PAH 5 Pursuit C18 column, dimensions 250 x 4.6 mm and grain size 5 μm. 50μl of sample was dispensed; the column temperature was 30 ° C. The flow rate of the mobile phase was 1 cm^3/min. The gradient programme was as shown in Table 1. The analysis was carried out using AS-BbC internal standards, 05/05/15. The identification of polycyclic aromatic hydrocarbons was carried out using a fluorescence detector with programming of excitation and emission waves, presented in Table 2. Wavelengths: 286/408 correspond to the signal of benzo(a)anthracene, wavelength 380/406 - benzo(a)pyrene, wavelength 304/433 - benzo(b)fluoranthene, and wavelength 266/408 - chrysene.
The content of polycyclic aromatic hydrocarbons in μg/kg of the sample was determined using the 15 PAH2 programme.
The numerical material obtained from laboratory measurements was subjected to statistical analysis using a *Statistica package 12*

Table 1. Eluent gradient program (volume%)

Time [min]	Acetonitryl	Water	Ethyl acetate
0	75	25	0
15	75	25	0
55	93	7	0
56	100	0	0
60	100	0	0
75	50	0	50
80	100	0	0
85	75	25	0
90	75	25	0

Table 2. Fluorescence detector program - Waters 24752.

Time [min]	Canal A	Canal B	Canal C	Canal D
	Wave length: excitation/emission [nm]			
0,0	266/408	286/408	310/357	380/406
16,0	-	-	315/510	-
22,0	-	304/433	-	-
40,0	286/420	300/500	315/422	362/408
60,0	281/434	295/408	-	-

RESULTS AND DISCUSSION

The results obtained showed that of the selected polycyclic aromatic hydrocarbons, five were below the quantification limit (value 0), because the concentration was below the device sensitivity. They were as follows: dibenzo(a,e)pyrene, dibenzo(a,h)anthracene, dibenzo(a,h)pyrene, dibenzo(a,i)pyrene, dibenzo(a,l)pyrene. For these reasons, they were considered irrelevant in shaping the PAH profile in the tested meats and were omitted from further analysis.
The research carried out shows that the lowest average PAH content was found in dry sausage and was 5.87 μg/kg. In three of the meats tested, the total content of the PAH assessed ranged from 10.78 to 16.62 μg/kg. Further analysis of the results of our own research clearly shows that the traditional product with the highest concentration of PAHs was country sausage. The concentration of PAHs determined in the country sausage was on average 35.67 μg/kg, and the standard deviation value was high and amounted to ± 6.68 μg/kg.
The results of the analysis of ten polycyclic aromatic hydrocarbons that were divided into light and heavy, in the form of the results of subsequent repetitions (x_i) and mean value ($\bar{x}$**)** and standard deviation (s_d) - are summarized in Tables 1 and 2. The results of the evaluation of the content of light PAHs in the tested meats are presented in Table 3. Among these hydrocarbons, the presence of benzo(a)antarcene and chrysene was recorded in the tested meats. The highest average benzo(a)anthracene content of 8.07 μg/kg was recorded in the country sausage. The average concentration of BaA in country sausages significantly exceeded its concentration in the other cold cuts tested (homemade ham - 3.49 μg/kg; kabanos - 2.65 μg/kg, bacon - 2.22 μg/kg, kornetka - 1, 81 μg/kg, dry – 1.10 μg/kg).

It should be noted that the average concentration of BaA in country sausage was almost eight times higher in country sausage compared to dry sausage. Relatively approximate BaA levels were recorded in bacon, kornetka, and dry bacon. It was also found that the BaA concentration was characterised by the highest variability, as evidenced by the standard deviation index. The measurement results presented in Table 3 indicate differences in the concentration of benzo(a)anthracene in samples of individual cold cuts, for example: in two samples of dry sausage, the content of this hydrocarbon was very low and did not exceed 0.70 μg/kg, while one of the samples of country sausage contained as much as 10.90μg/kg BaA.

The data presented in Table 3 indicate significant differences in chrysene accumulation in individual meat samples. The average CHR content ranged from 2.35 μg/kg of dry sausage to 9.81 μg/kg of country sausage. Polish ham contained an average of 5.38μg/kg of chrysene. kornetka - 3.80 μg/kg. kabanos - 3.62 μg/kg. bacon - 3.46 μg/kg.

Table 3. Content of light polycyclic aromatic hydrocarbons in traditionally smoked meats tested

Cold cuts	**Hydrocarbon**					
	BaA			CHR		
	x_i	$\bar{x}$	s_d	x_i	$\bar{x}$	s_d
	μg/kg					
kornetka	1.51	1.81	0.48	3.83	3.80	0.86
	2.08			4.48		
	1.50			2.41		
	1.78			3.99		
	1.12			3.77		
	2.16			3.09		
	2.52			5.02		
country	9.19	8.07	1.71	11.53	9.81	1.58
	7.23			9.09		
	10.90			10.39		
	7.39			11.57		
	8.57			10.34		
	7.46			8.30		
	5.63			7.48		
dry	0.63	1.10	0.31	1.78	2.35	0.55
	1.26			2.40		
	1.21			2.44		
	1.44			2.85		
	1.21			2.43		
	0.69			1.49		
	1.26			3.03		
homemade	3.10	3.49	0.82	5.37	5.38	0.50
	3.30			5.96		
	5.13			5.08		
	2.91			4.57		
	3.17			5.72		
	3.34			5.57		
bacon	1.52	2.22	0.58	3.46	3.46	0.64
	2.20			3.30		
	1.36			2.30		
	2.78			4.26		
	2.66			4.00		
	2.26			3.18		
	2.75			3.71		
kabanos	2.18	2.65	0.31	2.71	3.62	0.53
	2.81			3.81		
	2.62			3.90		
	2.62			3.60		
	3.03			4.09		

In four samples. the CHR concentration in the country sausage was found to be greater than 10 μg / kg. with a maximum value of 11.57 μg/kg. and this was the highest value of chrysene concentration recorded in the studies. In turn, the lowest CHR value of 1.49 μg/kg was found in dry sausage. In the products: Dry, Homemade and kabanos, the concentration of chrysene was similar and had a low standard deviation of approximately 0.50 μg/kg.

Analyzing in detail the level of contamination of meat products tested with heavy hydrocarbons, it was found that 5-methylchrysene was a compound that accumulated at an average level below 1 μg/kg, with the exception of country sausage, which was 1.29 μg/kg. i.e. as much as 0.99 μg/kg more compared to homemade ham. The difference between the country sausage and the other meats tested in the 5-methylchrysene content was approximately 0.60 μg/kg (Table 4).

Table 4. Content of heavy polycyclic aromatic hydrocarbons in traditionally smoked meats tested

Cold cuts	Hydrocarbon											
	5-M			BaP			BbF			BcFI		
	x	$\bar{x}$	s_d	x_i	$\bar{x}$	s_d	x_i	$\bar{x}$	s_d	x_i	$\bar{x}$	s_d
	μg/kg											
kornetka	0.53	0.61	0.30	0.43	0.42	0.09	0.59	0.58	0.09	2.12	2.10	0.59
	0.70			0.40			0.57			1.75		
	0.44			0.31			0.70			1.39		
	1.23			0.30			0.40			1.69		
	0.27			0.42			0.58			2.08		
	0.48			0.53			0.64			2.51		
	0.61			0.52			0.56			3.16		
country	1.44	1.29	0.47	2.43	2.27	0.84	2.22	2.21	0.92	10.52	7.38	1.98
	1.68			1.92			1.80			6.17		
	1.29			4.01			4.25			5.6		
	2.03			2.10			1.86			7.63		
	1.05			2.33			1.99			8.86		
	0.73			1.65			1.86			8.03		
	0.78			1.46			1.51			4.85		
dry	0.15	0.71	0.37	0.16	0.14	0.10	0.20	0.19	0.29	0.25	0.64	0.45
	0.79			0.16			0.40			0.38		
	0.9			0.24			0.75			0.54		
	1.05			0.19			0			0.44		
	0.97			0			0			0.36		
	0.21			0			0			1.49		
	0.90			0.21			0			1.02		
Home made	0	0.30	0.37	1.12	0.97	0.20	1.20	1.20	0.29	2.98	2.80	0.43
	0.46			1.06			1.34			3.14		
	0			1.15			1.45			2.15		
	0.92			0.62			0.71			2.37		
	0.41			1.02			1.47			2.96		
	0			0.86			1.01			3.17		
bacon	0.47	0.57	0.51	0.48	0.48	0.11	0.57	0.57	0.19	2.36	2.36	1.29
	0.17			0.40			0.49			2.19		
	0.13			0.41			0.48			1.18		
	1.07			0.32			0.41			1.49		
	1.47			0.56			0.51			2.06		
	0.45			0.58			0.98			2.11		
	0.21			0.62			0.56			5.13		
kabanos	0.21	0.68	0.36	0.62	0.55	0.11	0.77	0.65	0.19	1.63	2.58	1.51
	0.47			0.41			0.49			1.67		
	1.16			0.51			0.41			1.90		
	0.78			0.50			0.81			2.48		
	0.77			0.69			0.78			5.21		

Table 4 continued. Content of heavy polycyclic aromatic hydrocarbons in traditionally smoked meats tested

	0.72			0.08			0.06			0.60		
	0.45			0.20			0.13			0.16		
	0.77			0.44			0.27			0.39		
kornetka	0.37	0.72	0.34	0.15	0.17	0.14	0.23	0.21	0.09	0.36	0.36	0.13
	0.92			0			0.19			0.36		
	1.34			0.22			0.30			0.33		
	0.49			0.13			0.30			0.33		
	1.21			1.34			1.06			0.93		
	0.97			0.98			0.80			0.66		
	2.10			3.76			2.10			1.47		
country	0.98	1.17	0.44	1.35	1.37	1.15	0.98	1.11	0.15	0.71	0.85	0.33
	1.22			1.30			1.10			1.03		
	0.97			0.87			0.86			0.67		
	0.72			0			0.86			0.46		
	0.26			0.09			0.01			0.11		
	0.33			0.08			0.06			0.11		
	0.56			0.46			0.32			0.45		
dry	0.44	0.38	0.11	0	0.14	0.18	0	0.10	0.15	0.20	0.12	0.16
	0.32			0			0			0		
	0.30			0.33			0.31			0		
	0.46			0			0			0		
	0.67			0.49			0.46			0.40		
	0.75			0.79			0.56			0.45		
Home	0.76			0.44			0.67			0.46		
made	0.46	0.66	0.11	0.40	0.58	0.17	0.36	0.53	0.11	0.38	0.42	0.04
	0.72			0.63			0.62			0.46		
	0.61			0.75			0.51			0.39		
	0.89			0.07			0.07			0.16		
	1.47			0.23			0.17			0.43		
	1.10			0.36			0.25			0.38		
bacon	0.43	0.89	0.45	0	0.23	0.21	0.26	0.26	0.11	0.20	0.30	0.11
	0.44			0.43			0.34			0.25		
	1.40			0.50			0.41			0.42		
	0.47			0			0.29			0.24		
	0.61			0.43			0.38			0.39		
	0.38			0.24			0.81			0.32		
kabanos	0.75	0.53	0.15	0	0.28	0.18	0.26	0.46	0.21	0.28	0.32	0.05
	0.40			0.43			0.35			0.25		
	0.53			0.32			0.35			0.35		

Benzo(c)fluorene accumulated in the meats tested with varying intensity. The least contaminated product was dry sausage (average 0.64 μg/kg). and the highest level was recorded in country sausage (average 7.38 μg/kg). The remaining products contained benzo (c) fluorene from 2.1 μg/kg (kornetka) to 2.80 μg/kg (homemade) of benzo(c)fluorene. One of the bacon samples tested contained as much as 5.13 μg/kg BcFl. An equally high concentration of benzo(c)fluorene was recorded in kabanos. However, a particularly high accumulation of BcFl was observed in one of the country sausage samples; also noteworthy is the very low level of benzo(c)fluorene. amounting to 0.2 5μg/kg and 0.36 μg/kg. respectively, in dry sausage samples (Table 4).

Analysis of the concentration of the next four determined heavy PAHs (continued: Table 4) shows that their average concentration in the individual products evaluated was quite diverse. Particularly high average concentrations. exceeding 1 g/kg of BghiP. BjF. BkF. were recorded in country sausage (Table 4). In turn, low concentrations in the group of these hydrocarbons were recorded in dry sausage for benzo(j)fluoranthene ($\bar{x}$=0.14 μg/kg). benzo(k)fluoranthene ($\bar{x}$=0.10 μg/kg) and indeno(c.d)pyrene ($\bar{x}$= 0.12 μg/kg). Furthermore, a low average BjF concentration of (0.17 μg/kg) was observed in the kornetka. It is also worth emphasising that some of the hydrocarbons discussed were characterized by unstable concentration levels in the meat products tested. A

particularly high minimum-maximum range was recorded for BghiP in bacon and IcdP in country sausage. High standard deviation values were calculated for BkF and BjF in dry sausage and BjF in kornetka and bacon. The high Sd value was determined by the fact that some of the tested samples contained the hydrocarbons in question at a level below the limit of quantification (Table 4).

The data in Table 5 indicate that two of the cold cuts tested. kornetka and dry, showed average contamination with the sum of four PAHs (benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, and chrysene) at a level below the maximum limit set by the European Union Commission. The average content of four PAHs in the kornetka and dry sausage was: 8.12 μg/kg and 4.22 μg/kg. respectively. Furthermore, it should be noted that none of the cold cuts samples tested was contaminated with the sum of four PAHs in an amount greater than 12 μg/kg (the maximum contamination of kornetka was 11.22μg/kg, and for dry it was 5.52μg/kg).

The research showed that the product in which the sum of four PAHs specified in the regulations of the European Union exceeded the ML (maximal level) was country sausage. The tested country sausage samples contained an average of 27.53 μg/kg (Sd=4.79 μg/kg), with a minimum-maximum determination range of determinations ranging from 19.42 μg/kg to 33.67 μg/kg (Table 5).

The results of the conducted experiment also showed that the average level of contamination with the sum of four PAHs in ham was higher than the limit of the European Union and amounted to 12.64 μg/kg. with a small dispersion of the results of individual tests. Detailed statistical analysis using a single-sample Student's t-test did not allow the rejection of the null hypothesis because there was no statistically significant difference between the mean sum of four PAHs in ham and ML.

The average value of the sum of four PAHs and its range for the remaining two types of cold cuts allow us to conclude that the value of this parameter in bacon and kabanos was at the level of 8.52 μg/kg and 9.40 μg/kg. and the standard deviation was 2.08 and 2.18 μg/kg. Verification of the hypothesis about the lack of difference between the arithmetic mean values describing the sum of four PAHs in bacon and sausage and the value of 12 μg/kg (ML) allowed the rejection of the assumed null hypothesis. Therefore, the level of contamination with four hydrocarbons in both bacon and sausage was found to be lower than the in limit set by the EU.

The tests showed that the content of benzo(a)pyrene in kornetka, dry, homemade, bacon, and kabanos did not exceed the maximum limit set by the EU (2.00 μg/kg). The arithmetic mean describing the content of this compound for the above-mentioned cold cuts was less than 1.00 μg/kg (Table 6).

Table 5. Results of the assessment of the sum of 4 PAHs in the traditionally smoked meats tested

Cold cuts	$\bar{x}$	S_d	Min	Max	**Results of the test „t”**
	μg/kg				
kornetka	8.12	1.68	5.61	11.22	-
country	27.53	4.79	19.42	33.67	-
dry	4.22	0.87	2.82	5.52	-
homemade	12.64	1.12	10.47	13.51	t = 1.391; p=0.223
bacon	8.52	2.08	5.25	12.21	t = 4.440*; p=0.004
kabanos	9.40	2.18	7.14	13.02	t = 2.971*; p=0..044

*The * symbol next to the value "t" means that the null hypothesis should be rejected (at α = 0.05)*

Table 6. Results of the assessment of the benzo(a)pyrene content in the tested traditionally smoked meats

Cold cuts	$\bar{x}$	S_d	Min.	Max	**Results of the test „t”**
	μg/kg				
kornetka	0.42	0.090	0.30	0.53	-
country	2.27	0.840	1.46	4.01	t=0.426; p=0.852
dry	0.14	0.100	0.00	0.24	-
homemade	0.97	0.200	0.62	1.15	-
bacon	0.48	0.110	0.32	0.62	-
kabanos	0.55	0.110	0.41	0.69	-

Exceeding the ML of BaP content was found only for country sausage. It was 2.27 μg/kg. In this case, the null hypothesis was verified using the Student's t test - H0: = 2.00. The test result (p>0.05) did not allow the rejection of this hypothesis. So it should be concluded that the benzo(a)pyrene content did not exceed the ML.

The principle applicable to the control of food products on the EU market is constant monitoring of threats that may have a significant impact on the health and safety of consumers.

Over the last 20 years. The importance of research on the contamination of meat products with polycyclic aromatic hydrocarbons has increased significantly (Zasadowski and Wysocki. 2002; Ciemniak. 2007; Lorenzo et al., 2010; Bansal and Kim. 2015; Purcaro et al., 2013; Lee et al., 2016).

This is due, on the one hand, to the interest of the European market in traditional and regional products, which leads to increased production and supply of these products (Bilska et al., 2017), and, on the other hand, to the problems of manufacturing plants in maintaining the appropriate chemical purity of products, which comes from traditional technologies, and above all smoking using the traditional method (Choroszy and Tereszkiewicz, 2021; Migdał, 2015).

Traditional smoking is based on the direct exposure of the product to smoke (Roda et al., 1999). Therefore, traditionally smoked products are characterised by a much higher level of contamination with PAH compared to products exposed to smoking on the industrial scale. Traditional smoking, as confirmed in numerous studies, may pose a significant risk of excessive contamination with polycyclic aromatic hydrocarbons due to the traditional design of the chamber and due to the course and nature of the smoking process. This often leads to exceeding the contamination limits set by EU quality standards (Mc Grath et al., 2003; Purcaro et al., 2013; Djinovic et al., 2008; Choroszy. and Tereszkiewicz, 2021). The results of several studies (Parol et al., 2014; Afolabi et al., 1983; Ciecierska and Obiedziński, 2007; Kubiak et al., 2013; Kubiak, 2012; Lee et al., 2016) showed that the content of polycyclic aromatic hydrocarbons in traditionally smoked products is several times higher than in industrially smoked products. in which these compounds are practically absent.

In turn. Traditional smoked meats accumulate fifteen PAHs at levels ranging from 5 to 35.00 μg/kg. The Italian authors obtained results in the range of 30 -35.00 μg/kg (Lorenzo et al., 2010). Kubiak reports very diverse levels of accumulation of fifteen PAHs. from 18.50 μg/kg in Silesian sausage to 77.10 μg/kg in dried hunting sausage (Kubiak, 2012c). Previous research also confirmed a significant exceedance of the permissible limits of PAHs in traditionally smoked products evaluated (Choroszy and Tereszkiewicz., 2020).

The results currently presented showed that the highest average benzo(a)anthracene content of 8.07μg/kg was recorded in country sausage. However, the average concentration of BaA in the country sausage significantly exceeded its concentration in the other cold cuts tested. Homemade ham contained 3.49 μg/kg; kabanos - 2.65 μg/kg. bacon - 2.22 μg/kg. kornatka - 1.81 μg/kg. dry - 1.10 μg/kg. Authors Lorenzo et al. (2010, 2011) they showed a lower concentration of BaA in the assessed products. and their smoking was carried out at low temperatures. In two products originated in Spain. 'Androlla' and 'Botillo'. The level of benzo (a) anthracene contamination detected was low – on average 0.67 μg/kg in the case of ("Androlla") and 0.51 μg/kg in the case of ("Botillo"). 'Androlla' was subjected to smoking procedure that lasted for 8-10 days. and 'Botillo' was treated with smoke for 7-15 days. Choroszy and Tereszkiewicz (2021) determined that the concentration of BaA in traditional Polish ham ranges from 1.52 μg/kg to 4.31 μg/kg and depends on the meteorological conditions under which smoking was carried out. The higher accumulation of BaA was favoured by conditions of low pressure and low air humidity.

The average CHR content ranged from 2.35 μg per kilogramme of dry sausage to as much as 9.81μg per kilogramme of country sausage. Polish ham contained an average of 5.3 9μg/kg of chrysene, kornetka - 3.79 μg/kg, kabanos - 3.62 μg/kg, bacon - 3.46 μg/kg. Their average content was many times higher than the content of other polycyclic aromatic hydrocarbons. reaching values close to 10.00μg/kg in some cold meats (country sausage. home sausage). Chrysene constituted on average 30% of all hydrocarbons. and benzo(a)anthracene - more than 20%.

According to Fasano et al. (2016) the contamination level of the samples subjected to analysis was found to be within the range of 21 and 649 μg/kg. Thus, it significantly exceeded the results of the authors own investigation. Similarly, Lorenzo et al. (2010) identified an elevated level of chrysene contamination in various samples subjected to analysis (for example. 12 μg/kg in "Chorizo de cebolla"). It is worth noting that the products subject to the authors' own research were most exposed to contamination with the light PAHs described above. benzo(a)anthracene and chrysene. Furthermore. it

should be emphasised that both analysed light PAHs belong to compounds with particular carcinogenicity.

The results obtained in our own research indicate that the contamination of the tested cold cuts with heavy hydrocarbons ranged from 1.00 μg/kg in dry sausages to 9.10 μg/kg in country sausages. The share of heavy hydrocarbons ranged from 18% to 27% of the PAH profile. It should be emphasised that the accumulation of benzo(b)fluoranthene, benzo(g, h, i)perylene, benzo(j)fluoranthene, benzo (k)fluoranthene and indeno(c.d)pyrene did not exceed 1.00μg/kg, while the concentrations of dibenzo(a,i)pyrene, dibenzo(a,l)pyrene, dibenzo(a,e)pyrene, dibenzo(a,h)anthracene and dibenzo(a,h)pyrene were undetectable at the sensitivity level used in the study apparatus.

In the smoked meats tested by Kubiak (2012), the heavy hydrocarbon content was 2.80 μg/kg, and the Silesian and dried hunting sausages evaluated in these studies were contaminated at the level of 5.60 μg/kg and 7.90 μg/kg, respectively.

The research showed that the average content of benzo(a)pyrene in the meat samples tested was relatively low (about 0.80μg/kg). Only in the case of country sausage, the accumulation of this hydrocarbon was approximately three times higher than in other cold meats. The share of benzo(a)pyrene in the profile of fifteen PAHs was on average more than 5%. These results are consistent with the information provided in the available literature. Djinovic et al. (2008) claimed that in the 15 PAH profile benzo(a)pyrene constituted 4.6%. In turn, research by Lorenzo et al. (2010) indicated that the content of benzo(a)pyrene did not exceed the level of 5.00μg/kg, which amounted for 1.3% of the 15 PAHs. According to Kubiak (2012) cold meat accumulated benzo(a)pyrene in the amount of 4.5μg/kg. and smoked meat in the amount of 2.80 to 4.50μg/kg. In the meats studied by Kao et al. (2014). The amount of benzo(a)pyrene did not exceed 5.80μg/kg. The BaP concentrations reported by the authors exceeded the permitted limits in smoked meat products specified in Regulation 2023/915. In the research presented. An exceedance of the permissible concentration of BaP was recorded in one product. which was country sausage.

The results obtained indicate the need to pay attention to the concentration of benzo(b)fluoranthene. This compound was another heavy PAH that occurred in particularly high concentrations in the meats tested. This phenomenon was observed especially in ham, where the concentration of BbF was on average 1.19μg/kg and in country sausage, where its concentration was on average 2.21μg/kg. As reported by Więk et al. (2013), the concentration of this PAH in meat products was very high. The author noted a particularly high concentration of BbF in bacon, where its concentration was the highest in the group of PAHs tested. In turn, benzo(c)fluorene accumulated in the meats tested with varying intensity. The least contaminated product was dry sausage (0.64μg/kg), while the highest level of BcFl was recorded in country sausage - 7.38μg/kg. The obtained results indicate that the concentration of four additional heavy PAHs in the individual products assessed was quite diverse. A high average concentration, exceeding 1.00μg/kg. concerned BghiP. BjF. BkF. and IcdP in country sausage. The BkF concentration above 1.00μg/kg was also characteristic of the kabanos sausages. In turn, low concentrations were recorded in the group of these hydrocarbons in dry sausage for benzo(j)fluoranthene ($\bar{x}$ = 0.14μg/kg) and benzo(k)fluoranthene ($\bar{x}$ = 0.10μg/kg), indeno(c.d)pyrene ($\bar{x}$ =0.12μg/kg).

Analysis of the results of their own research also included a comparison of the content of the sum of four PAHs with the maximum permissible levels in foodstuffs established by Commission Regulation (EC) No. 2023/915 of April 25. 2023 on the maximum permissible levels of certain contaminants in food (for benzo(a) pyrene - 2.00 μg/kg. and for the sum of 4 PAHs - 12.00 μg/kg).

Comparison of the concentration of benzene(a)pyrene in most of the meats tested showed that traditional smoking does not cause excessive concentrations that are dangerous to the consumer. the maximum permitted limit specified in the provisions in question. The only exception was country sausage, in which the accumulation of BaP was 0.27 μg/kg above the permitted limits.

In terms of contamination with the sum of four PAHs. the results of our own research do not allow for a clear summary. The content of four PAHs in kornetka and dry sausage is so low that traditional smoking does not pose a hygienic and toxicological problem. In turn. the contamination of the country sausage exceeded the level of 22.00μg/kg and was significantly above the maximum allowed limits specified in the regulation. The results obtained indicate that the method of smoking country sausages in traditional chambers poses a threat to the health of consumers. Regarding the other cold cuts tested. it should be noted that their traditional smoking may occasionally result in exceeding the limit set by the Regulation of the European Union Commission.

The results of the conducted research also confirm literature reports on the differences in the degree of contamination with polycyclic aromatic hydrocarbons that occur not only between different types of meat (e.g. pork and poultry), which results from the difference in the species of raw material and other parameters used for smoking. but also between different types of cold meat.

The results of our own research clearly show that the country sausage was more contaminated with the tested hydrocarbons. The content of three hydrocarbons deserves special attention: benzo(a)anthracene. benzo(c)fluorene and chrysene. It was on average: 8.07. 7.38 and 9.81μg/kg. This is more than twice as high as in domestic ham (3.49μg/kg), and more than three times as high as in kabanos sausage (2.65μg/kg) and other cold cuts. The content of benzo(a)pyrene in country sausage is high and is many times higher than in other products. It amounted to an average level of 2.3μg/kg.

The distinction of country sausage as the product most contaminated with ten polycyclic aromatic hydrocarbons results primarily from the thermal treatment method and the smoking time to which this sausage is subjected.

It seems that introducing certain modifications into the smoking process may contribute to reducing the concentration of the analyzed PAHs in the products. This was experimentally confirmed by systematically removing carbon deposits from the smokehouse chambers (Choroszy and Tereszkiewicz, 2020) and introducing smoking taking into account the meteorological conditions. On the basis of earlier conducted own research, an increase in relative humidity and in atmospheric pressure was observed, which in turn led to a reduction in PAH content in the examined product. Furthermore, it was concluded that traditional smoking conducted under conditions of high relative air humidity and high atmospheric pressure contributed to a decrease mainly in 5-methylchrysene, benzo(a)pyrene and benzo(g,h,i)perylene (Choroszy and Tereszkiewicz, 2021).

CONCLUSIONS

The results obtained indicate that PAHs were present in all tested products. The research carried out shows that the lowest average PAH content was found in dry sausage and was 5.87μg/kg. In three of the meats tested, the total content of the PAH assessed ranged from 10.78 to 16.62μg/kg. Particularly high accumulation, at the same time exceeding the permissible EU standards were recorded in the country sausage. The most notable results were for a total of four PAHs. It should be noted that none of the cold cuts samples tested was contaminated with the sum of four PAHs in an amount greater than 12μg/kg (the maximum contamination of kornetka was 11.22μg/kg, and for dry it was 5.52μg/kg).

There are certain technological possibilities to reduce the concentration of PAHs in meat products preserved by traditional smoking.

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