Determination of polycyclic aromatic hydrocarbons in edible cattle hides in Enugu State, Nigeria

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ABSTRACT

INTRODUCTION Polycyclic aromatic hydrocarbons (PAHs) constitute public health risks among exposed individuals. Data on the concentrations of these compounds in singed hides meant for consumption in Enugu and Nsukka slaughterhouses, Enugu State, Nigeria, are available in the literature.

METHODS The study was a cross-sectional survey conducted during the dry and wet seasons at Enugu and Nsukka slaughterhouses, Enugu State, Nigeria, between June 2020 and July 2021. A total of 480 samples were collected using systematic sampling [160 each of unsinged hides (USHs), singed hides (SHs) and singed-washed hides (SWHs) in both slaughterhouses]. The hides samples were transported in air tight bags containing ice to the laboratory. The samples were pretreated by grinding with sodium sulphate, PAHS were extracted with Soxhlet extractor and cleaned up with magnesium silicate.

RESULTS The PAHs residues recorded in Enugu and Nsukka were significantly higher ($p<0.05$) in SHs than USHs and SWHs. PAHs concentrations (mg/kg) recorded in dry season and wet season were of benzo(b)fluoranthene (0.5773 ± 0.1207 and 0.1848 ± 0.0511, respectively) and were fluorene (0.0246 ± 0.0100 and 0.0450 ± 0.0119, respectively). The PAHs concentrations were significantly higher ($p<0.05$) in dry than wet season. PAHs residues in the samples were all <0.5 mg/kg except with benzo(b)fluoranthene occurring highest in SHs in Enugu and Nsukka slaughterhouses, Enugu State, Nigeria, respectively (0.9080 ± 0.2283 and 0.5882 ± 0.1680).

CONCLUSIONS The study found that SHs had total PAHs at higher concentration than USHs and SWHs. However, PAHs levels in this study were far below the European Union recommended levels of 5 mg/kg in hides.

INTRODUCTION

In Nigeria, hides of livestock are valued as meat. However, the risk of polycyclic aromatic hydrocarbons (PAHs) contamination of meat is a food safety concern. PAHs are known for their mutagenic and carcinogenic effects, and animal products from livestock reared on contaminated pasture or feed are good sources of exposure[1]. In addition, indiscriminate dumping of waste materials on land, and methods of processing slaughtered cattle have been incriminated in contamination of animal products with these substances[2-4]. One of the major routes of human exposure to PAHs in non-smoking people is food. PAHs are also found in foods as a result of certain industrial food processing methods such as smoke curing, broiling, roasting and grilling over open fires or charcoal, which permits the direct contact between food and combustion products[5]. Singeing of slaughtered cattle hides with other materials such as scrap tires, plastic and rubber could introduce high levels of polycyclic aromatic hydrocarbons (PAHs) in the hide and meat due to high temperatures, oxidation, and incomplete combustion of organic compounds contained in these materials[6].

However, the maximum residual limit (MRL) of PAHs recommended by the European Commission is set at 5 mg/

kg in hides[7]. Several analyses of charcoal roasted/grilled common food items have proven the presence of PAHs such as benzo[a]pyrene, anthracene, chrysene, benzo[a] anthracene, and indeno[1,2,3-c,d]pyrene[1,7-10]. Most of these PAHs have been found to be carcinogenic while some are not[11-15]. There is little information on the levels of these PAHs in hides in Enugu State.

The aim of the study was to detect the presence of PAH residues in hides of cattle and to determine any seasonal variations in the concentration of PAH residues in these samples.

METHODS

Study design

The survey was cross-sectional and was conducted during dry and wet seasons in the study area to assess the concentration PAHs in the hides of cattle slaughtered at two major government approved slaughterhouses at Nsukka and Enugu. The cattle hide hairs were removed by shaving with a razor blade (unsinged USH), removed with flame (SH) and removed with flame and washed (SWH). Method of systematic random sampling was used to select one in three slaughtered cattle at the selected slaughterhouses, twice a week for 12 months. About 5 g of hides of cattle were randomly selected and cut out for PAH residue analysis.

A total of 480 fresh samples of singed, unsigned and singed-washed hides from 160 slaughtered cattle were collected between July 2020 and June 2021. The sample size in both seasons was equal (n=240). All the hide samples were placed in air tight bags, placed in an ice container and transported to the Springboard research laboratory, Awka Anambra State, for PAH analysis.

Study area

The study was conducted in Enugu metropolis and Nsukka urban area in Enugu State, Nigeria (Supplementary file Figure 1). Enugu State is made up of 17 Local Government Areas, which are grouped into three Senatorial zones. According to the National Population Commission in 2006, the State is estimated to have a population of about 3.3 million[16]. It has two seasons which are the wet season (April to October) and the dry season (November to March). Enugu and Nsukka are the major towns in the state[16].

Laboratory analysis pretreatment for hide samples

Chemical drying of the hide samples was performed by grinding with sodium sulphate (NaSO4), which is a drying agent, until the samples were reduced to a fine consistency, so as to increase the surface interaction of solvent and matrix. This increased the homogeneity of the samples in order to increase the extractability of the analytes in the samples[17].

Extraction (Soxhlet extraction method) of hide samples

Extraction of the samples was done using the Soxhlet extraction method. All the glass apparatus were rinsed with petroleum ether and dried in the oven at 102°C and placed in a desiccator. About 5 g of grounded and dried sample was weighed and placed in the thimble. The thimble was placed in the Soxhlet extractor. A clean 150 mL round bottom flask was filled with 90 mL petroleum ether. The setting was placed on a heating mantle and the petroleum ether was allowed to boil for 8 hours, the sample was allowed to cool and the solvent was collected after distillation and the sample was weighed[17].

Clean up (Flormisil clean up)

Flormisil (magnesium silicate) was heated in an oven at 130°C overnight and transferred into a 250 mL size beaker and placed in a desiccator. About 0.5 g of anhydrous sodium sulphate (NaSO4) was added to 1.0 g of activated flormisil (60–100 mesh) on an 8 mL column plugged with glass wool. The packed column was filled with 5 mL n-hexane for conditioning. The stop cock was opened to allow n-hexane to run out until it reached the top of sodium sulphate into a receiving vessel whilst tapping gently on the top of the column until the flormisil settled well in the column. The extract was transferred into the column with a disposable Pasteur pipette from the evaporating flask. The crude extract was eluted on the column with the wide opening of the stopcock and inserted into an evaporating flask and rotary-evaporated to dryness. The dry elute was dissolved in 1 mL n-hexane for gas chromatographic analysis[17].

The dry elute was analyzed for naphthalene, acenaphthylene, benzo[b]fluoranthene, phenanthrene, dibenzo[a,h]anthracene, benzo[a]pyrene, acenaphthene, benzo[k]fluoranthene, fluorene, pyrene, xylene, anthracene, fluoranthene, 1-2 benzanthracene, and benzo[g,h,i]perylene. Corresponding results were obtained using GC (Agilent 5890N, Hewlett-Packard HP-5890 Series II, USA) with Flame Ionization Detection (FID). The limit of detection of all the PAHs ranged 0.0001–0.0007 mg/kg[17]. The GC was programmed as follows: initial temperature of 60°C for 2 min and ramped at 25°C/min to 300°C for 5 min, and allowed to stay for 15 min giving a total run time of 22 min. A 2 L volume splitless injection mode was used and the injection port temperature was set at 250°C, while 300°C was maintained for the injection port of the FID detector[17]. A standard mixture of 15 priority PAHs, including naphthalene, acenaphthylene, benzo[b]fluoranthene, phenanthrene, dibenzo[a,h]anthracene, benzo[a]pyrene, acenaphthene, benzo[k]fluoranthene, fluorene, pyrene, xylene, anthracene, fluoranthene, 1-2 benzanthracene, and benzo[g,h,i]perylene was obtained and used for the analysis. Compounds were identified by comparing the retention time of standards with that obtained from the extracts while the individual analysis of PAHs were used for quantification. Naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene were assessed as non-carcinogenic PAHs, while benzo[a] anthracene, benzo [k] fluoranthene, benzo[a]pyrene, benzo[b]fluoranthene, 1-2 benzanthracene, dibenzo [a,h] anthracene, and benzo [g,h,i] perylene were the determined as carcinogenic PAHs[17].

Data processing and analysis

The data generated from the study were statistically analyzed using IBM SPSS Statistics, version 20. Descriptive statistics was used to analyze the data generated which were converted to percentages, and are presented in the tables. Chi-squared analysis was used to determine the association between the occurrence of PAHs during the dry and wet seasons. The concentrations of the PAHs in singed and unsinged cattle meat were compared using Student's t-test. Analysis of variance and *post hoc* test were performed to determine if there was a statistically significant difference in the mean concentration of singed, unsinged and singed-washed hides, respectively. A $p<0.05$ was considered to be significant.

RESULTS

The results from Enugu slaughterhouse recorded prevalence rates of 78.3% for acenaphthylene, 35% naphthalene, 68.3% fluoranthene, 60% phenanthrene, 38.3% dibenzyl(a-h) anthracene, 43.3% anthracene and 90% 1-2 benzanthracene (Supplementary file Table 1).

Similarly in Nsukka slaughterhouse, prevalence rates observed were 73.3% acenaphthylene, 35% naphthalene, 83.3% fluoranthene, 73.3% phenanthrene, 61.7% dibenzyl(a-h)anthracene, 53.3% anthracene and 95% 1-2 benzanthracene (Supplementary file Table 2).

Concentrations of polycyclic aromatic hydrocarbons (PAHs) of slaughtered cattle in Enugu and Nsukka slaughterhouses

Concentrations of acenaphthylene, fluoranthene, benzo(b) fluoranthene, pyrene, benzo(a)pyrene, benzo(k)fluoranthene and1-2benzanthracene were found to be significantly higher ($p<0.05$) in the SHs and SWHs compared to USHs (Table 1). For Nsukka slaughterhouse, concentrations of acenaphthene were significantly higher ($p<0.05$) in the SHs and SWHs compared to USHs (Table 2).

Seasonal distribution of polycyclic aromatic hydrocarbons (PAHs) concentrations in samples of cattle slaughtered in Enugu slaughterhouse

Concentrations of anthracene, acenaphthene, benzo(b) fluoranthene and fluorene in the dry season were significantly higher ($p<0.05$) compared with the concentrations in the wet season in Enugu slaughterhouse (Table 3). Results from the Nsukka slaughterhouse revealed significantly higher ($p<0.05$) concentrations of acenaphthylene, naphthalene, fluoranthene, anthracene, 1-2 benzanthracene, acenaphthene, benzo(a)pyrene, xylene, and benzo(b)fluoranthene in the hides tested during the dry season compared with those of the wet season (Table 4).

Table 1. Concentration (mg/kg) of polycyclic aromatic hydrocarbons (PAHs) in hides of slaughtered cattle in Enugu slaughterhouse

PAHs	Unsinged hide Mean ± SEM	Singed hide Mean ± SEM	Singed washed hide Mean ± SEM
Acenaphthylene	0.0633 ± 0.0120^{a}	0.1555 ± 0.0335^{b}	0.1061 ± 0.0228^{ab}
Naphthalene	0.0231 ± 0.0092^{a}	0.0631 ± 0.0203^{a}	0.0331 ± 0.0113^{a}
Fluoranthene	0.0621 ± 0.0127^{a}	0.1132 ± 0.0212^{b}	0.0868 ± 0.0157^{ab}
Phenanthrene	0.0673 ± 0.0161^{a}	0.1124 ± 0.0296^{a}	0.0844 ± 0.0228^{a}
Dibenzyl(a-h)Anthracene	0.0243 ± 0.0089^{a}	0.0414 ± 0.0162^{a}	0.0328 ± 0.0126^{a}
Anthracene	0.0701 ± 0.0515^{a}	0.1549 ± 0.1100^{a}	0.0778 ± 0.0518^{a}
1-2 Benzanthracene	0.0877 ± 0.0099^{a}	0.2433 ± 0.0561^{b}	0.1869 ± 0.0500^{ab}
Acenaphthene	0.0736 ± 0.0115^{a}	0.1664 ± 0.0729^{a}	0.1123 ± 0.0341^{a}
Benzo(k)Fluoranthene	0.0958 ± 0.0227^{a}	0.2376 ± 0.0463^{b}	0.1657 ± 0.0376^{ab}
Benzo(a)Pyrene	0.0756 ± 0.0141^{a}	0.1288 ± 0.0236^{b}	0.1018 ± 0.0163^{ab}
Xylene	0.0653 ± 0.0260^{a}	0.1455 ± 0.0378^{a}	0.1068 ± 0.0326^{a}
Pyrene	0.0430 ± 0.0100^{a}	0.0957 ± 0.0235^{b}	0.0553 ± 0.0113^{ab}
Benzo(g-h-I)Perylene	0.0880 ± 0.0174^{a}	0.1350 ± 0.0240^{a}	0.1165 ± 0.0205^{a}
Benzo(b)Fluoranthene	0.3818 ± 0.0990^{a}	0.9080 ± 0.2283^{b}	0.6490 ± 0.1603^{ab}
Fluorene	0.0190 ± 0.0084^{a}	0.0629 ± 0.0218^{a}	0.0400 ± 0.0158^{a}

SEM: standard error in mean. Values within the row with different superscript letters are statistical different ($p<0.05$).

Table 2. Concentration (mg/kg) of polycyclic aromatic hydrocarbons (PAHs) in hides of slaughtered cattle in Nsukka slaughterhouse

PAHs	Unsinged hide Mean ± SEM	Singed hide Mean ± SEM	Singed washed hide Mean ± SEM
Acenaphthylene	0.0617 ± 0.0145[a]	0.1147 ± 0.0271[a]	0.1066 ± 0.0398[a]
Naphthalene	0.0182 ± 0.0076[a]	0.0335 ± 0.0117[a]	0.0434 ± 0.0178[a]
Fluoranthene	0.1028 ± 0.0193[a]	0.1782 ± 0.0598[a]	0.1398 ± 0.0443[a]
Phenanthrene	0.1126 ± 0.0351[a]	0.1855 ± 0.0540[a]	0.1712 ± 0.0492[a]
Dibenzyl(a-h)Anthracene	0.0391 ± 0.0096[a]	0.0655 ± 0.0204[a]	0.0445 ± 0.0104[a]
Anthracene	0.0905 ± 0.0257[a]	0.2552 ± 0.1064[a]	0.1046 ± 0.0369[a]
1-2 Benzanthracene	0.1360 ± 0.0348[a]	0.3475 ± 0.1051[a]	0.2916 ± 0.0797[a]
Acenaphthene	0.0705 ± 0.0124[a]	0.2075 ± 0.0652[b]	0.1089 ± 0.0315[ab]
Benzo(k)Fluoranthene	0.1544 ± 0.0354[a]	0.2688 ± 0.0580[a]	0.1921 ± 0.0415[a]
Benzo(a)Pyrene	0.0702 ± 0.0169[a]	0.0949 ± 0.0223[a]	0.0767 ± 0.0157[a]
Xylene	0.1187 ± 0.0400[a]	0.1746 ± 0.0421[a]	0.1226 ± 0.0368[a]
Pyrene	0.0770 ± 0.0195[a]	0.1098 ± 0.0245[a]	0.0809 ± 0.0200[a]
Benzo(g-h-I)Perylene	0.0865 ± 0.0180[a]	0.1139 ± 0.0240[a]	0.0767 ± 0.0164[a]
Benzo(b)Fluoranthene	0.2849 ± 0.0860[a]	0.5882 ± 0.1680[a]	0.2701 ± 0.0798[a]
Fluorene	0.0234 ± 0.0099[a]	0.0483 ± 0.0176[a]	0.0326 ± 0.0120[a]

SEM: standard error in mean. Values within the row with different superscript letters are statistical different ($p<0.05$).

Table 3. Seasonal distribution of polycyclic aromatic hydrocarbons (PAHs) concentration (mg/kg) in samples of cattle slaughtered in Enugu slaughterhouse

PAHs	Dry season November–March (N=240)	Wet season April–October (N=240)	
	Mean ± SEM	Mean ± SEM	p
Acenaphthylene	0.1400 ± 0.0244[a]	0.0767 ± 0.0146[a]	0.086
Naphthalene	0.0367 ± 0.0095[a]	0.0428 ± 0.0142[a]	0.127
Fluoranthene	0.0962 ± 0.0142[a]	0.0785 ± 0.0141[a]	0.940
Phenanthrene	0.1054 ± 0.0227[a]	0.0708 ± 0.0145[a]	0.274
Dibenzyl(a-h)Anthracene	0.0358 ± 0.0084[a]	0.0298 ± 0.0123[a]	0.604
Anthracene	0.0368 ± 0.0126[a]	0.1650 ± 0.0853[b]	0.006
1-2 Benzanthracene	0.1270 ± 0.0158[a]	0.2182 ± 0.0490[a]	0.055
Acenaphthene	0.1044 ± 0.0092[a]	0.1304 ± 0.0538[b]	0.041
Benzo(k)Fluoranthene	0.1566 ± 0.0317 [a]	0.1762 ± 0.0317[a]	0.553
Benzo(a)Pyrene	0.1014 ± 0.0173[a]	0.1027 ± 0.0134[a]	0.325
Xylene	0.1077 ± 0.0308[a]	0.1041 ± 0.0223[a]	0.090
Pyrene	0.0744 ± 0.0134[a]	0.0549 ± 0.0138[a]	0.790
Benzo(g-h-I)Perylene	0.1427 ± 0.0180[a]	0.0836 ± 0.0144[a]	0.389
Benzo(b)Fluoranthene	0.8022 ± 0.1748[a]	0.4904 ± 0.0961[b]	0.006
Fluorene	0.0247 ± 0.0099[a]	0.0565 ± 0.0159[b]	0.013

SEM: standard error in mean. Values within the row with different superscript letters are statistical different ($p<0.05$). N: number of samples.

Table 4. Seasonal distribution of polycyclic aromatic hydrocarbons (PAHs) concentration (mg/kg) in samples of cattle slaughtered in Nsukka slaughterhouse

PAHs	Dry season November–March (N=240)	Wet season April–October (N=240)	
	Mean ± SEM	Mean ± SEM	p
Acenaphthylene	0.1364 ± 0.0293[a]	0.0522 ± 0.0127[b]	0.033
Naphthalene	0.0472 ± 0.0132[a]	0.0162 ± 0.0064[b]	0.014
Fluoranthene	0.1288 ± 0.0088[a]	0.1518 ± 0.0506[b]	0.004
Phenanthrene	0.1439 ± 0.0242[a]	0.1689 ± 0.0484[a]	0.065
Dibenzyl(a-h)Anthracene	0.0502 ± 0.0081[a]	0.0493 ± 0.0146[a]	0.079
Anthracene	0.0800 ± 0.0155[a]	0.2203 ± 0.0750[b]	0.001
1-2 Benzanthracene	0.1239 ± 0.0117[a]	0.3930 ± 0.0854[b]	0
Acenaphthene	0.0938 ± 0.0088[a]	0.1642 ± 0.0493[b]	0.001
Benzo(k)Fluoranthene	0.2748 ± 0.0324[a]	0.1355 ± 0.0392[a]	0.672
Benzo(a)Pyrene	0.0824 ± 0.0106[a]	0.0787 ± 0.0185[b]	0.029
Xylene	0.2058 ± 0.0392[a]	0.0714 ± 0.0163[b]	0
Pyrene	0.1382 ± 0.0169[a]	0.0403 ± 0.0129[a]	0.068
Benzo(g-h-I)Perylene	0.1420 ± 0.0153[a]	0.0428 ± 0.0110[a]	0.435
Benzo(b)Fluoranthene	0.5773 ± 0.1207[a]	0.1848 ± 0.0511[b]	0
Fluorene	0.0246 ± 0.0100[a]	0.0450 ± 0.0119[a]	0.081

SEM: standard error in mean. Values within the row with different superscript letters are statistical different ($p<0.05$). N: number of samples.

DISCUSSION

This study found a higher prevalence rate of PAHs in cattle hides in Enugu State. This higher prevalence is in agreement with the work of Nwude et al.[18] in South Eastern Nigeria. High concentrations of PAHs were also reported in smoked fish[19], and other meat products[20-23].

The findings of the present study differ from the lower prevalence results by Ogbonna and Nwaocha[24] in Umuahia, Abia State, Nigeria[24]. The sample source, sample size, as well as the level of environmental contamination, may be responsible for the rates of PAH components detected in the different studies. A high prevalence rate of PAHs in SH was recorded in the Nsukka slaughterhouse. This could be attributed to singeing methods used in the slaughterhouse. Most butchers in the slaughterhouse make use of vehicle tires for singeing hides as earlier reported[25]. Tires are known to deposit PAHs on hides because they are produced with 'extender oil' known to contain PAHs in appreciable quantities[26]. The work of Obiri-Danso et al.[6] noted that although adverse effects are associated with the use of scrapped tires for singeing, preference for their use by butchers stems from the fact that they are cheap and produce more flame with less heat, thereby burning the hairs without damaging the hides[6]. The results of the study revealed statistically significantly higher occurrence of PAHs in the SHs and SWHs compared to USHs. The increase in concentration of PAHs after singeing was also reported by other studies[5,19-23]. Singeing is known to deposit PAHs on hides because these substances are usually produced by direct contact with a flame, incomplete combustion, and the type of material used to produce the flame utilized for singeing[27].

Higher levels of PAH concentrations were recorded in the Enugu slaughterhouse compared with those at the Nsukka slaughterhouse. This finding differs from the results indicated by Ogbonna and Nwaocha[24] in Umuahia, Abia State, Nigeria, where low levels of PAHs were reported in singed cow hides. The finding was, however, in agreement with the work of Ofomata et al.[23], in Eastern Nigeria, who observed an appreciable amount of PAHs in raw hides and skin including benzo[a]pyrene, benz[a]anthracene, benzo[b]fluoranthene, chrysene, and xylene. However, mean values for PAHs in all the hide samples were below the European Commission and WHO recommended maximum permissible levels of 5 mg/kg in hides[7,26]. The low level of PAH concentrations in the Nsukka slaughterhouse may be due to lower industrial activities in the town compared with Enugu town where many industries may lead to higher contamination of the environment with industrial waste such as empty battery cases, engine oil, exhaust from vehicles or industries. The concentration of PAHs in the unsinged hides in the present study may be attributed to accidental or unintentional exposure to PAHs during grazing of the animals or industrial exposure due to air pollution[23].

Higher concentrations of PAHs in SHs and SWHs could be attributed to materials or methods (fueling of wood with kerosene, fuel, plastics, and tires) used in singeing the slaughtered cattle at Nsukka slaughterhouse and the source of water used for washing singed hides[25]. In addition, burning of bush and waste, which is common practice in Nigeria, releases smoke into the atmosphere which precipitates as dew in the morning. Given that livestock are rarely housed but left over night in the open field in Nigeria, the dew falls on the body of the animals with the resultant penetration of PAHs into their skin[28]. According to Erema and Adaobi[29], PAHs can enter the body through inhalation, ingestion, contact and singeing methods. This may explain the presence of PAHs in USH.

The concentrations of PAHs demonstrate a unique seasonal pattern, with higher concentrations of PAHs during the dry than the wet season. The results from Enugu slaughterhouse showed statistically higher amounts of anthracene, acenaphthene, benzo(b)fluoranthene and fluorene in the dry season than in the wet season. Similarly, findings from Nsukka slaughterhouse showed statistically significant higher concentrations of acenaphthylene, naphthalene, fluoranthene, anthracene, 1-2 benzanthracene, acenaphthene, benzo(a)pyrene, xylene, and benzo(b) fluoranthene during the dry season than the wet season. The higher concentrations during the dry season may be attributed to increased risk of exposure to PAHs from chemicals and contaminated water as animals scavenge for feed and water[29], which are usually scarce during the dry season.

Limitations

Given that food and water are among the routes of exposure of cattle to PAHs, the concentrations recorded may have been affected by the fact that the animals sampled were sourced from different areas and, therefore, may not have had an equal rate of exposure. In addition, due to the study design, there is a lack of causal inference.

CONCLUSIONS

The present study showed that hides from slaughtered cattle sourced from Enugu and Nsukka slaughterhouses contained different concentrations of PAHs. Although the known carcinogenic PAHs in the samples studied were below the maximum permissible level, they are of public health concern due to the health risk associated with cumulative exposure via the dietary consumption of such hides. It could also be concluded that the presence of PAH concentrations in slaughtered cattle in the present study were a result of environmental factors, singeing methods and materials. Furthermore, the concentrations of PAHs were generally higher in the dry season than in the wet season. It should be noted that although the hides from slaughtered cattle at Enugu and Nsukka slaughterhouses, Enugu State, Nigeria, seem to be safe for consumption considering that the level of concentrations of PAHs were below the international recommended level, long-term consumption could result in bioaccumulation of these compounds. Therefore, butchers in slaughterhouses need to be educated on the deleterious effects of using vehicle tires for singeing. In addition, consumers need to be educated on the risks involved in the consumption of singed hides.

REFERENCES

1. Akpan V, Lodovici M, Dolara P. Polycyclic aromatic hydrocarbons in fresh and smoked fish samples from three Nigerian cities. *Bull Environ Contam Toxicol*. 1994;53(2):246-253. doi:10.1007/BF00192040
2. Felix OC, Ekene E, Johnbosco UC, Anelon NJ. Assessment of cadmium (Cd) residues in organs and muscles of slaughtered pigs at Nsukka and environs in Enugu State, Nigeria. *J. Vet. Med. Anim. Health.* 2016;8(11):199-206. doi:10.5897/JVMAH2016.0514
3. Felix OC, John NA, Ekene EV. Assessment of lead (Pb) residues in organs and muscles of slaughtered pigs at Nsukka and Environs in Enugu state, Nigeria. Journal of Advanced Veterinary and Animal Research. 2016;3(4):392-398. doi:10.5455/javar.2016.c178
4. Obioha, Felix Chidiebere, Nwanta, Anelon J, Anaga AO. Survey of heavy metals residues in muscle and internal organs of slaughtered cattle in Enugu State, Nigeria. Journal of Agriculture and Veterinary Science (IOSR-JAVS). 2023;15(12):31-38. doi:10.9790/2380-1512013138
5. Guillén MD, Sopelana P, Partearroyo MA. Food as a source of polycyclic aromatic carcinogens. *Rev Environ Health*. 1997;12(3):133-146. doi:10.1515/reveh.1997.12.3.133
6. Obiri-Danso K, Hogarh JN, Antwi-Agyei P. Assessment of contamination of singed hides from cattle and goats by heavy metals in Ghana. *African Journal of Environmental science and Technology.* 2008;2(8):217-221.
7. Ogbadu GH, Ogbadu LJ. Levels of benzo(a)pyrene in some smoked ready-to-eat Nigerian foods. *Lebensmittel-Wissenschaft und Technologie.* 1989;22(5):313-314.
8. Duke O, Albert IO. Polynuclear aromatic hydrocarbons concentrations in charbroiled meat suya. Journal of Applied Sciences. 2007;7:1873-1879. doi:10.3923/jas.2007.1873.1879
9. Linda MN, Carboo PD, Yeboah PO, et al. Characterization of Polycyclic Aromatic Hydrocarbons (PAHs) present in smoked fish from Ghana. Adv. J. Food Sci. Technol. 2011;3(5):332-338.
10. Akpambang VO, Purcaro G, Lajide L, Amoo IA, Conte LS, Moret S. Determination of polycyclic aromatic hydrocarbons (PAHs) in commonly consumed Nigerian smoked/grilled fish and meat. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess.* 2009;26(7):1096-1103. doi:10.1080/02652030902855406
11. Bababunmi EA, Emerole GO, Uwaifo AO, Thabrew MI. The

role of aflatoxins and other aromatic hydrocarbons in human carcinogenesis. *IARC Sci Publ*. 1982;(39):395-403.

12. Alonge DO. Carcinogenic Polycyclic Aromatic Hydrocarbons (PAH) determined in Nigerian Kundi(smoke-dried meat). Journal of the Science of Food and Agriculture. 1988;43:167-172. doi:10.1002/jsfa.2740430207
13. Lijinsky W. The formation and occurrence of polynuclear aromatic hydrocarbons associated with food. *Mutat Res*. 1991;259(3-4):251-261. doi:10.1016/0165-1218(91)90121-2
14. Fritz W, Soós K. Smoked food and cancer. *Bibl Nutr Dieta*. 1980;(29):57-64. doi:10.1159/000387467
15. Borokovcova I, Dofkova M, Rehurkova I, Ruprich J. Polycyclic aromatic Hydrocarbons in the Czech Foodstuffs in the Year 2004. Chem. Listy. 2005;99:268-270.
16. National Population Commission of Nigeria. Population and housing census. Priority table. Population distribution by age & sex. State & Local Government Area. National Bureau of Statistsics; 2011.
17. United States Environmental Protection Agency. The Clean Air Act Amendments of 1990 List of Hazardous Air Pollutants. EPA; 2016. Accessed June 9, 2024. https://www3.epa.gov/airtoxics/orig189.html
18. Nwude DO, Okoye PAC, Babayemi JO. Heavy metal level in animal muscle tissue. A case study of Nigeria raised cattle. *Res. J. Appl. Sci.* 2010;5:146-150. doi:10.3923/IJDS.2010.264.270
19. Chen Y, Shen G, Su S, et al. Contamination and distribution of parent, nitrated, and oxygenated polycyclic aromatic hydrocarbons in smoked meat. *Environ Sci Pollut Res Int*. 2014;21(19):11521-11530. doi:10.1007/s11356-014-3129-8
20. Nisha AR, Dinesh-kumar V, Arivudainambi S, Umer M, Khan MS. Polycyclic aromatic hydrocarbons in processed meats: a toxicological perspective. *Research Journal of Chemistry and Environmen.* 2015;19:72-76.
21. Singh L, Varshney JG, Agarwal T. Polycyclic aromatic hydrocarbons' formation and occurrence in processed food. *Food Chem*. 2016;199:768-781. doi:10.1016/j.foodchem.2015.12.074
22. Li J, Dong H, Li X, Han B, Zhu C, Zhang D. Quantitatively assessing the health risk of exposure to PAHs from intake of smoked meats. *Ecotoxicol Environ Saf*. 2016;124:91-95. doi:10.1016/j.ecoenv.2015.10.007
23. Ofomata I, Obodoechi LO, Obidike RI, Nwanta JA. Presence and levels of concentration of polycyclic aromatic hydrocarbons (PAHs) in smoked fish, hides and skin of slaughter cattle and goats in Awka urban, Nigeria. International Journal of Current Pharmaceutical Research. 2019;11:14-17. doi:10.22159/ijpps.2019v11i2.33014
24. Ogbonna ILP, Nwaocha KB Determination of levels of polycyclic aromatic hydrocarbons on singed cow hide (Punmo) and charcoal grilled meat (Suya). *Archives of Applied Science Research*. 2015;7:1-6.
25. Ekenma K, Nwanta JA, Anaga AO. Determination of the presence and concentration of heavy metal in cattle hides singed in Nsukka abattoir. *Journal of Veterinary Medicine and Animal Health.* 2015;7(1):9-17 doi:10.5897/JVMAH2014.0283
26. European Commission. Commission Regulation (EU) No 835/2011 amending regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs. 2011;215:8. Accessed June 9, 2024. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:215:0004:0008:En:PDF
27. Nnaji JC, Madu ES, Chukwuemeka-okorie HO. Polycy-clic aromatic hydrocarbons (PAHs) content in cattle hides and meat singed with scrap rubber tyres. *Journal of Applied Science and Environmental Management*. 2017;21:1105-1110. doi:10.4314/jasem.v21i6.19
28. Okonkwo FO, Ejike CECC, Berger U, Schmaling C, Schierl R, Radon K. Workplace exposure to polycyclic aromatic hydrocarbons (PAHs): a review and discussion of regulatory imperatives for Nigeria. *Research Journal of Environmental Toxicology.* 2014;8:98-109. doi:10.3923/rjet.2014.98.109
29. Erema RD, Adaobi PU. Polycyclic aromatic hydrocarbons in sediment and tissues of the crab Callinectes pallidus from the azuabie creek of the upper bonny estuary in the Niger Delta. *Research Journal of Applied Science, Engineering and Technology,* 2013;6:2594-2600. doi:10.19026/rjaset.6.3744

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