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Exposure assessment of polycyclic aromatic hydrocarbons from the consumption of processed cowhide (*Wele*), a West African delicacy

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ABSTRACT

This study describes the occurrence and profile of eight polycyclic aromatic hydrocarbons (PAHs) in fresh and cooked processed cowhide (*wele*) singed with different fuels. It also assessed the health risks associated with the consumption of this popular delicacy. The 8PAHs were all detected in the *wele* samples singed with scrap tires, whereas 5 and 3 carcinogenic PAHs were detected in the firewood and liquefied petroleum gas (LPG) singed *wele*, respectively. For each of the specific PAH detected, the contents in the *wele* samples were generally ranked as scrap tires > firewood > LPG. The average concentrations of benzo[a]pyrene for cooked *wele* samples were 2.75 ng g^{-1}(firewood) and 22.85 ng g^{-1}(scrap tires); exceeding the 2.0 ng g^{-1} European Commission regulation maximum levels (MLs) for smoked products. For the carcinogenic risk exposure assessment, the dietary intake based on benzo[a]pyrene equivalents was estimated as 777.06 ng g^{-1} day (scrap tires), 101.52 ng g^{-1} day (firewood) and 9.45 ng g^{-1} day (LPG). The probable cancer risk estimated considering the consumption frequency and quantity of *wele* for an average adult consumer was highest in the population exposed to *wele* singed with scrap tires (3.11×10^{-5}).

Introduction

Processed cowhide (w*ele*) is obtained by singeing the hide of cattle after slaughter, and it is a popular delicacy in many West African communities. Singeing has a long tradition and is still well accepted. However, the processing of *wele* is of grave concern because the fuel source for singeing the hide could introduce contaminants to the meat product and compromise its quality and safety. In processing the hide, the producers frequently use firewood and discarded (scrap) tires as

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sources of fuel [1,2]. Recently, some processors have used liquified petroleum gas (LPG) for singeing, but the majority have declined due to the exorbitant cost of LPG [3]. Food safety has become a significant issue in the food industry for consumers and health-based institutions in Ghana and the world at large [4].

Polycyclic aromatic hydrocarbons (PAHs) are a collection of organic compounds with two or more fused aromatic rings that emanate from the incomplete combustion of organic material or high-temperature pyrolysis of oils and fats [5,6]. PAHs occur in nature and through anthropogenic activities. Their occurrence in foods is mainly through food processing including smoking and drying but also cooking (frying, grilling, roasting, baking) [7,8]. PAH formation during processing depends on the type of fuel used, the distance between the food and heat source, the temperature of the heat source and the duration of processing [9]. Smoked foods are major contributors to PAH intake since these foods are part of our diet though eaten in smaller quantities [8]. PAHs have been extensively investigated for their carcinogenicity, mutagenicity and immunosuppression in animals and animal products [10,11]. PAHs are stable at room temperature and are classified based on their molecular weights: the low molecular weight PAHs (consists of two or three rings) and high molecular PAHs (consists of four or more rings) with the latter being more stable and hydrophobic [12,13]. The low molecular weight PAHs are volatile, and more soluble than the high molecular PAHs which bind strongly to soot, soil, or dust particles (German Federal Environment Agency [12,14]). PAHs have a high affinity for lipids and this affinity surges as the number of rings increases.

The current study aimed at determining the occurrence and levels of eight (8) PAHs in processed cowhide (*wele*) singed with different fuels (LPG, firewood, and scrap tires) and subsequently assessing the health risks associated with exposure to PAHs through consumption of processed cowhide. The study specifically focused on the 8PAHs rather than only benzo[a]pyrene (BaP) since they have been previously established as suitable indicators of the carcinogenic potency of PAHs in food (European Food Safety Authority [15]).

Materials and methods

Sample collection

Purposive sampling was used to obtain *wele* from three (3) producers based on the type of fuel (LPG, firewood, or scrap tire) they used in singeing the cowhide. Sampling was done twice and a total of two kilograms of raw *wele* was purchased from each producer and divided into four parts weighing approximately 500 g each. Thus, a total of twelve (12) sub-samples were obtained from the *wele* purchased. The singed *wele* samples were placed in labelled Ziploc bags and conveyed to the laboratory.

Sample preparation

Samples from each producer were further treated in the lab using processes typically practiced before consumption namely washing and cooking. These samples were then designated as *Fresh* or *Cooked. Fresh* samples were only washed under running water for about 3 min. *Cooked* samples were boiled for 20 min in water (500 ml water to 500 g *wele*) in an enamel-coated saucepan, the cooking water was drained off and the *wele* allowed to cool. All treatments were done in duplicates and samples were immediately frozen at -20 ºC before analysis.

Reagents and chemicals

All reagents were of pesticide analytical grade and included acetonitrile (CH_3CN), primary-secondary amine (PSA), anhydrous magnesium sulphate ($MgSO_4$), ethyl acetate ($C_4H_8O_2$). Extraction and purification were attained with the Agilent Bond Elut QuEChERS dSPE kit (Agilent Technologies).

A modification of the renowned and well-recognised QuEChERS and dSPE approach coupled with the Agilent J&W DB-5 ms UI GC-column was chosen for this study because of the excellent recoveries of pesticides from 80 to 139% with RSD below 6.0 for some fish samples [16]. Martínez-Domínguez et al. [17] also obtained pesticide recoveries ranging from 70 to 117% for black, green, red, and white teas. The above method and reagents were used to determine the concentration of the 8PAHs on the EFSA priority list (chrysene (CHR), benzo[g,h,i]perylene (BgP), benzo[a]anthracene (BaA), benzo[a]pyrene (BaP), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), indeno[1,2,3-c,d]pyrene (InP), and dibenzo[a,h]anthracene (DaA).

Extraction of PAHs

Frozen *wele* samples were milled in a food processor until powdered and then homogenized using a homogenizer (Ultra Turrax TX 25). All these were done under sub-ambient conditions. Three (3) grams of the pulverized homogenous samples were weighed into 50 ml centrifuge tubes, and 15 ml of acetonitrile was added to each tube as the extraction solvent. The mixtures were macerated for 2 min after which they were centrifuged (Hermle Z300, Hermle LaborTechnik GmbH, Wehigen, Germany) for 3 min at 3000 pm.

The acetonitrile extract (supernatant) was transferred into fresh tubes, and 6 ml pipetted into 15 ml centrifuge tubes containing 150 mg PSA (primary-secondary amine) and 900 mg magnesium sulphate anhydrous. The mixtures were shaken vigorously for 1 min and then centrifuged for 3 min at 3000 rpm.

An aliquot of 4 ml was pipetted from the supernatant into a sterile 50 ml pear-shaped flask and the filtrate was concentrated using a rotary evaporator (Buchi R-210, Buchi Labortechnik AG, Switzerland) to dryness below 40°C. The sample obtained was dissolved in 1 ml ethyl acetate. The final extract was transferred into a 2 ml standard opening vial for quantification by GC/MS (Agilent 7890B (GC) and Agilent 7000C (GC-MS), Agilent Technology, Hachioji, Japan).

Quality control measures were taken to validate data integrity. Confirmatory tests were run after every batch and between samples to ascertain elution time and response factors using reagent blanks. Reagent blanks were prepared by running acetonitrile aliquot through the same process, and this was done to correct sample readings. The GC-MS was used to analyse all extracts in triplicates.

The GC instrument specifications followed those published by Smith and Lynam [16]:
Instrument: Agilent
Column: Agilent J&W DB-5ms Ultra Inert (UI) 20 m × 0.18 mm, 0.18 μm
Carrier Gas: Helium (He)
Column Flow: 1.7 ml/min
Injection temp: 320°C
Injection Mode: Splitless
MS CONDITIONS
Acquisition mode: Multiple reaction monitoring (MRM)
Ion source temp: 250°C
Interface temp: 280°C
Solvent cut time: 4 min

Carcinogenic exposure and risk assessments

The carcinogenic exposure limits and cancer risk assessments were determined by calculating the Benzo[a]pyrene **(**BaP) equivalent concentration in food (BEC), the daily dietary intake (DDI) and the incremental lifetime cancer risk (ILCR).

BaP equivalent concentration in food (BEC)

The toxic equivalency factors (TEFs) used for the PAHs were 0.01 for chrysene (CHR), and benzo[g,h,i]perylene (BgP); 0.1 for benzo[a]anthracene (BaA), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), and indeno[1,2,3-c,d]pyrene (InP); and 1 for benzo[a]pyrene and dibenzo[a,h]anthracene (DaA) (Agency for Toxic Substances and Disease Registry [[18]R], 2022; [19])

The TEF values were used to convert estimated PAHs as benzo[a]pyrene equivalents for adults. The summation of individual TEF multiplied by the individual PAH level in the food sample calculates approximately the toxic potency of BaP and PAH in food as BaP equivalent concentration, BEC, as shown in Eq. (1) [18,20]

$$BEC = \sum_{i=1}^{n} C_i \ x \ TEF_i \tag{1}$$

BEC = BaP equivalent concentration of PAHs in food (ng g^{-1})
C_i = concentration of PAH congener (i) in food (ng g^{-1})
TEF = toxicity equivalency factors (BaP relative potency value)

Dietary exposure dose assessment (E_D)

The daily dietary intake of PAHs from *wele* was determined by multiplying the BEC levels in *wele* by the ingestion rate of *wele* (27 g day^{-1}). The ingestion rate is the weight of food consumed daily by a regular weight adult (70 kg) . Thus, the dietary exposure dose concentration (E_D) was determined with Eq. (2) below [21]:

$$E_D = BEC_i xIR \tag{2}$$

E_D = daily dietary intake (ng day^{-1})
BEC = B[a]P equivalent concentration of PAHs in food (ng g^{-1})
IR = ingestion amount of food per day (g day^{-1}) (27 g day^{-1})

Cancer risk

Incremental lifetime cancer risk (ILCR) for PAHs was calculated based on a method proposed by Xia et al. [21]. The ILCR associated with the daily consumption of BEC in *wele* samples prepared using LPG, firewood and scrap tires was calculated using Eq. (3)

$$ILCR = \frac{E_D \ x \ EFx \ ED \ x \ CSF \ x \ CF}{BW \ x \ AT} \tag{3}$$

ILCR= Incremental lifetime cancer risk (dimensionless)
E_D (daily dietary intake): PAH exposure dose in *wele* sample (ng day^{-1})
EF (Exposure frequency): 156 days $year^{-1}$

ED (Exposure duration (years): 63 years

CSF (oral cancer slope factor of benzo[a]pyrene): 7.3 mg/kg-day (Agency for Toxic Substances and Disease Registry [[18]R], 2022)

CF (conversion factor): 10−6 mg ng^{-1} [22]

AT (Average lifespan): This is the exposure duration (70 years x 365 days = 25550 days)

BW (Body weight of an average adult): 70 kg

Statistical analysis

Concentrations of PAHs were expressed as means. ANOVA was used to evaluate the effect of multiple levels of fuel and treatment using a 95% confidence interval. Microsoft Excel 2016 and Statgraphics Centurion XVI.I statistical software were used to compute and analyse mean concentrations.

Results and discussion

The concentration of 8PAHs in wele

Table 1 shows the mean concentrations of the 8 different PAHs in fresh and cooked *wele* samples processed with scrap tires, firewood, and LPG. BaA and Chr were dominant in all *wele* singed with the three types of fuels. In general, the levels of the specific PAH were consistently and significantly higher in the scrap tire-singe samples (both fresh and cooked) followed by firewood singed samples with the LPG singed *wele* recording the least in all cases. Thus the PAH levels in *wele* singed with different fuels were ranked as scrap tires > firewood > LPG. This implies that the use of LPG yielded a better product than the two other fuels based on their total PAH content. The high PAH content in *wele* singed with scrap tires compared to those singed with firewood and LPG might be due to the differences in the length between the cowhide and smoke source, smoke generation conditions, the temperature of pyrolysis, or singeing duration [9,23]. The formation of PAHs can occur during cooking, however, the amounts produced and/or present in the cooked food are influenced by the type of food, fuel used and cooking method.

All eight (8) PAHs analysed were detected in the scrap tire-singed *wele* samples while a total of five (5) and three (3) PAHs respectively were detected in the firewood and LPG singed *wele* samples. Only Benzo[a]anthracene and Chrysene were detected in all six (6) samples whiles Benzo[b]fluoranthene was detected in all samples except fresh firewood singed *wele*. Benzo[k]fluoranthene was detected in all scrap tire-singed and firewood-singed samples but was not detected in any samples singed with LPG. Benzo[a]pyrene was detected in three out of the six samples, namely fresh and cooked scrap tire-singed and cooked firewood-singed samples. Finally, Indeno[1,2,3-cd]pyrene, dibenzo[a,h]anthracene and Benzo[g,h,i]perylene were only detected in scrap tire-singed samples.

Chrysene was the highest contributor to the total PAH content of all samples irrespective of the type of fuel and treatment. Dibenzo[a,h]anthracene was the lowest contributor to PAH content in the scrap tire-singed wele. Conversely, a similar study by Tay et al. [24] found indeno[1,2,3-cd]pyrene to be the highest PAH (561 ug/kg) while benzo[a]anthracene was the lowest (85 ug/kg). These concentrations were far higher than those obtained in the current study.

Cooking reduced the level of the specific PAHs in scrap tire-singed samples, however, the reverse occurred in firewood and LPG singed *wele* where a significant increase ($p = 0.01$) was observed. Mahugija and Njale [25] demonstrated that washing smoked fish in hot water (60°C) for 2-3 min generally resulted in a significant (average 31.5 – 86%) reduction in total and individual PAH content of 2 out of 3 fish species (38 total samples). Subsequently, PAHs were detected in the wash water. They suggested this reduction could be because the PAHs were adsorbed on the surface of the fish and then desorbed during the washing processes. Other studies have also indicated a reduction in PAH content by marinating pork belly in water for 10 h [26] or steaming meat prior to grilling [27]. It is known that the combustion temperature of the fuel is a critical factor in the formation of PAHs which is initiated at temperatures above 450°C. Essumang [28] indicated that

Table 1
Concentrations (mean ± standard deviations) of PAHs (ng g^{-1}) in fresh and cooked *wele* signed with various fuels.

Fuel	Treatment	BaA	Chr	BbF	BkF	BaP	InP	DaA	BgP
Spent Tires	Fresh	28.5 ±10.04^a	63.2 ± 28.8^a	29.55 ± 13.5^a	38.4 ± 24.8^a	49.4 ± 24.8^a	14.7 ± 8.5^a	12.2 ± 7.1^a	13.35 ± 7.7^a
	Cooked	18.3 ± 19.8^a	32.65 ± 32.4^a	13.5 ± 16.9^a	17.7 ± 27.8^a	22.85 ± 27.8^a	5.75 ± 6.0^a	0.85 ± 0.6^a	5.3 ± 5.5^a
Firewood	Fresh	3.1 ± 2.7^b	3.9 ± 2.8^b	ND	0.35 ± 0.5^b	ND	ND	ND	ND
	Cooked	5.6 ± 4.1^b	6.45 ± 4.9^b	1.55 ± 1.9^b	2.3 ± 2.2^b	2.75 ± 3.2^b	ND	ND	ND
LPG	Fresh	0.15 ± 0.21^c	0.15 ± 0.21^c	0.1 ± 0.14^c	ND	ND	ND	ND	ND
	Cooked	0.9 ± 1.3^c	1.05 ± 1.5^c	0.75 ± 1.1^c	ND	ND	ND	ND	ND

BaA=benzo[a]anthracene; Chr=chrysene; BbF=benzo[b]fluoranthene; BkF=benzo[k]fluoranthene; BaP = benzo[a]pyrene; InP = indeno[1,2,3-cd]pyrene; DaA=dibenzo[a,h]anthracene; BgP = benzo[g,h,i]perylene.
ND – not detected (LOD = 0.1 ng g^{-1}).
Values in the same column followed by different superscript letter are significantly different ($p < 0.05$).

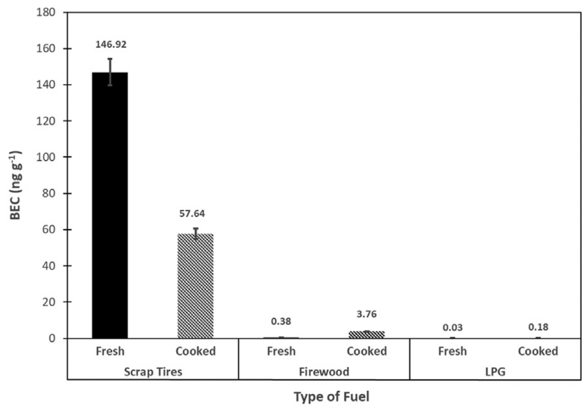

Fig. 1. The Benzo[a]pyrene equivalents (BEC) in 8PAHs in *wele* singed with scrap tires, firewood, and LPG. Error bars represent a 95% confidence interval.

the PAH content of cooked foods depends on cooking duration, proximity to and temperature of the heating source, and the presence of lipids in cooking.

The prevalence of the PAHs in smoked samples was not always in agreement with previously published data with either higher or lower variations recorded. The reasons for these variation in PAH content are not fully available but generally, reported quantitative data related to PAH content in smoked foods have shown high variability [29]. For the firewood singed *wele* samples, the results obtained in this study were higher than those reported by [30] in a study on cowhides singed with wood in Northern Nigeria. Specifically, for the three (3) PAHs detected in this study, BaA (3.1 ng g^{-1}), Chr (3.9 ng g^{-1}) and BkF (0.35 ng g^{-1}), Oko and Okoye [30] reported respective values of 0.112 ng g^{-1}, 0.059 ng g^{-1} and 0.012 ng g^{-1}. An immediate basis for the noted difference could be attributed to the wood type used since the composition of smoke generated will vary depending on the wood.

Conversely, for the scrap tire-singed samples, Essumang et al. [31] reported significantly higher PAH content in cattle hide singed with scrap tires in the Cape-Coast metropolis of Ghana. Notably, they reported values ranging from 30.6 ng g^{-1} to 3306.8 ng g^{-1} as compared to between 12.2 and 63.2 ng g^{-1} recorded in this study for the 8 PAH studied. Varying smoking conditions (temperature of combustion and the intensity of smoking), poor smoking practices (direct contact with smoke and unfavourable surface to volume ratios) and also fat content of products have been found to contribute to high levels of PAHs in smoked products [32,33].

The PAH content of the LPG singed *wele* samples was lower than for the other two (2) fuels, ranging from 0.1 ng g^{-1} (BbF) to 0.15 ng g^{-1} (BaA, Chr). There was no available published data on the PAH content of LPG singed *wele* to allow for comparison with the data obtained in this study. However, the near low levels of PAHs recorded in *wele* singed with LPG may be attributed to the clean fuel used, the proximity of the flame to the *wele* and the improved supply of oxygen which promotes complete combustion and finally blowing away smoke to prevent interaction with the wele [34].

With the exception of LPG singed *wele*, the levels of the PAHs recorded in this study were significantly higher than the maximum levels for BaP (2 ng g^{-1}) permitted by the European Commission Regulation [35] number 835/2011 for similar processed food categories. Results from this study are also in line with the findings of EFSA [15] which concluded that BaP is not a credible sole indicator for exposure to PAHs as it was not detected in three (3) out of the six (6) samples which contained other carcinogenic PAHs (BaA, Chr, BbF and BkF).

Daily dietary exposure assessment to Σ*8PAHs*

Benzo[a]pyrene equivalent concentrations (BEC) in wele processed with different fuels

Fig. 1 shows the mean concentration of benzo[a]pyrene equivalent (BEC) in *wele* samples processed with scrap tires, firewood, and LPG. BEC is a frequently used indicator of PAH contamination. In *wele* samples processed with scrap tires, the fresh *wele* had a concentration of 146.92 ng g^{-1} while the concentration in the cooked *wele* was 57.64 ng g^{-1}. In *wele* processed using firewood, the mean values of BEC were 0.38 ng g^{-1} and 3.76 ng g^{-1} for fresh and cooked *wele* samples, respectively, and 0.03 ng g^{-1} (fresh) and 0.18 ng g^{-1} (cooked) in *wele* processed using LPG. The findings suggest that the consumption of *wele* samples singed with scrap tires has a higher potential of exposing consumers to carcinogenic risks than the *wele* samples processed using firewood or LPG. This is a result of the type of fuel used.

Dietary exposure dose assessment from the consumption of wele processed using different fuels

Dietary intake of food contaminants is determined by both the dietary habits (food type and quantities of food consumed daily) of the test population groups and the concentrations of the contaminants in the foods [36]. The dietary intakes of the sum of 8 PAHs (8PAHs) in cooked *wele* were estimated to be 777.06 ng day^{-1} (scrap tires), 101.52 ng day^{-1} (firewood), and 9.45 ng day^{-1} (LPG) as shown in Fig. 2. The results suggest that consumption of cooked *wele* samples singed with

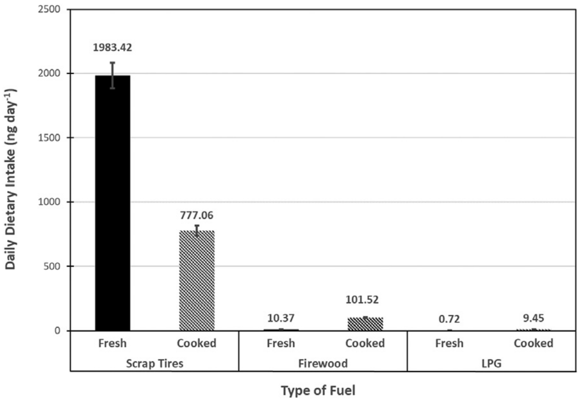

Fig. 2. The daily dietary intake of 8PAHs in *wele* singed with scrap tires, firewood, and LPG. Error bars represent a 95% confidence interval.

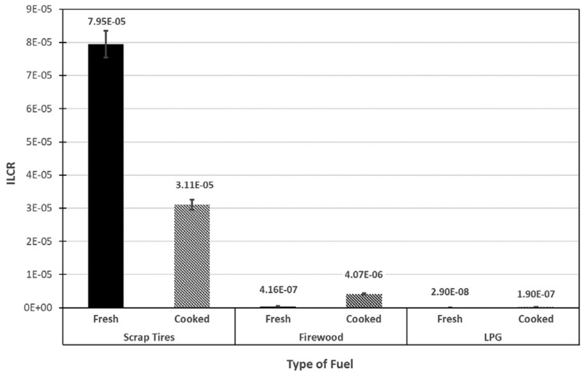

Fig. 3. Incremental lifetime cancer risks (ILCR) estimates of cooked and fresh *wele* samples processed with different types of fuel. Error bars represent a 95% confidence interval.

scrap tires will be the highest contributor to the daily dietary intake of PAHs in foods followed by firewood and LPG-singed. Thus, the current study's findings indicate a probable risk for consumers of *wele* singed with scrap tires. The high levels of 8PAHs observed in scrap tires singed *wele* accounted for the high BECs and daily dietary intake of PAHs. Darwish et al. [37] estimated that the dietary intake of 8PAHs by Egyptian consumers of meat (boiled, pan-fried, or grilled) ranged between 65.20 and 711.18 ng day^{-1}.

Cancer risk estimation

The ILCR estimates for cooked *wele* singed using scrap tires, firewood and LPG were 3.11×10^{-5}, 4.07×10^{-6} and 1.90×10^{-7}, respectively for exposed adults of 70 kg average body weight as shown in Fig. 3. The lifetime cancer risk associated with the consumption of *wele* singed with scrap tires was higher than the tolerable risk level (1×10^{-6}), thus implying a 17probable risk in the population [21,38]. LPG-singed *wele* had the least ILCR value (1.90×10^{-7}) of the three types of fuel used in processing the *wele* and was less than the tolerable risk level of 1×10^{-6}, suggesting no significant health effect posed to the population [39].

The ILCR estimate associated with consuming *wele* singed with LPG suggests 1 out of 10,000,000 in an adult population over a 70-year life expectancy is below the acceptable level of 1×10^{-6} and thus there was no significant health risk [21]. This suggests that LPG-singed wele may be safe for consumption compared to cowhide singed with scrap tires or firewood. The outcome of the study suggests that at least about four adults out of a million, and three out of a hundred thousand adults are likely to be diagnosed with cancer-related diseases in their lifetime due to consumption of cooked *wele* produced using firewood or scrap tires. The ILCR from the current study indicates that consuming *wele* singed with scrap tires or firewood is unsafe and detrimental to consumers' health.

Conclusion

The type and quantity of polycyclic aromatic hydrocarbons detected in the *wele* samples varied depending on the type of fuel used for singeing. All 8PAHs were detected in scrap tires singed *wele*, 5 out of the 8 PAHs were detected in firewood singed *wele* and 3 out of 8PAHs in LPG- singed *wele*. The levels of the PAHs in fresh and cooked *wele* were highest in *wele* samples singed with scrap tires due to the high PAH constituent of smoke from burnt tires. Only Benzo[a]anthracene and

Chrysene were detected in all six (6) samples of *wele*. The levels of BaP recorded for cooked *wele* samples processed using firewood and scrap tires were 2.75 ng g^{-1} and 22.85 ng g^{-1} respectively and these exceeded the 2.0 ng g^{-1} MRL proposed by the EU for smoked meat and meat products.

The use of scrap tires as a source of fuel contributed to the high contamination levels of PAHs in *wele*. This, in turn, contributed to the high benzo[a]pyrene equivalent, dietary exposure limit and the lifetime cancer risk of 8PAHs in cooked *wele*. The outcome of the study suggests that about three out of a hundred thousand adults may be diagnosed with cancer-related diseases in their lifetime as a result of consuming *wele* processed with scrap tires. Regulatory agencies will need to elaborate national policies to regulate the type of fuel used in the singeing of *wele* and consequently reduce the formation of PAHs in the products. An in-depth risk assessment model, other contributing sources of PAHs in *wele*, as well as the impact of temperature and distance between *wele* and heat source during processing, should be further studied.

Declaration of Competing Interest

None.

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References

[1] J.A.M. Mahugija, E. Njale, O. Idowu, K.T. Semple, K. Ramadass, W. O'Connor, P. Hansbro, P. Thavamani, A. Mueller, N. Ulrich, J. Hollmann, C.E. Zapata Sanchez, U.E. Rolle-Kampczyk, M. von Bergen, P. Gao, E. da Silva, L. Hou, N.D. Denslow, P. Xiang, A. Sojinrin, Polycyclic Aromatic hydrocarbons, Food Control 5 (1) (2016) 1–11, doi:10.1007/s002449900535.

[2] D. Samaila, H. Abubakar, A. Lushaikyaa, B. Joshua, P. Benjamen, S. Kojo, Financial Lvoats in Bauchi Central Abattoir of Bauchi State, Nigeria, Int. J. Livestock Res. 5 (2015) 28–28.

[3] Sunu, N. E. (2013). Comparative Assessment of Heavy Metal Levels in animal hide singed with motor vehicle scrap tyres and liquefied petroleum gas (LPG) as source of fuel (Kwame Nkrumah University of Science and Technology). Retrieved from http://dspace.knust.edu.gh/bitstream/123456789/6699/1/NAOMIELIKEMSUNU.pdf.

[4] D.K. Essumang, D.K. Dodoo, J.K. Adjei, Effect of smoke generation sources and smoke curing duration on the levels of polycyclic aromatic hydrocarbon (PAH) in different suites of fish, Food Chem. Toxicol. 58 (2013) 86–94, doi:10.1016/j.fct.2013.04.014.

[5] I.W. Abdul, O.M. Amoamah, A. Abdallah, Determinants of polycyclic aromatic hydrocarbons in smoked bushmeat, Int. J. Nutri. Food Sci. 3 (2014).

[6] L.L.A. Veiga, H. Amorim, J. Moraes, M.C. Silva, R.S.L. Raices, S.L. Quiterio, Quantification of polycyclic aromatic hydrocarbons in toasted guaraná (*Paullinia cupana*) by high-performance liquid chromatography with a fluorescence detector, Food Chem. 152 (2014) 612–618.

[7] L. Singh, J.G. Varshney, T. Agarwal, Polycyclic aromatic hydrocarbons' formation and occurrence in processed food, Food Chem. 199 (2016) 768–781.

[8] Z. Zelinkova, T. Wenzl, The occurrence of 16 EPA PAHs in food – a review, Polycyclic Aromat. Compd. 35 (2015) 248–284, doi:10.1080/10406638.2014.918550.

[9] L. Duedahl-Olesen, Polycyclic aromatic hydrocarbons (PAHs) in foods, Persistent Org. Pollut. Toxic Met. Foods (2013) 308–333, doi:10.1533/9780857098917.2.308.

[10] C. Anyakora, H. Coker, Determination of polynuclear aromatic hydrocarbons (PAHs) in selected water bodies in the Niger Delta, Afr. J. Biotechnol. 5 (2006) 2024–2031.

[11] T. Rengarajan, P. Rajendran, N. Nandakumar, B. Lokeshkumar, P. Rajendran, I. Nishigaki, Exposure to polycyclic aromatic hydrocarbons with special focus on cancer, Asian Pac. J. Trop. Biomed. 5 (2015) 182–189.

[12] A. Mrozik, Z. Piotrowska-Seget, S. Labuzek, Bacterial degradation and bioremediation of polycyclic aromatic hydrocarbons, Polish J. Environ. Stud. 12 (2002) 15–25.

[13] G. Purcaro, S. Moret, L.S. Conte, Overview on polycyclic aromatic hydrocarbons: occurrence, legislation, and innovative determination in foods, Talanta 105 (2013) 292–305.

[14] German Federal Environment Agency (GFEA). (2012). Polycyclic aromatic hydrocarbons –harmful to the environment! toxic! inevitable? *German Environment Agency*. Retrieved from www.umweltbundesamt.de/en/publikationen/polycyclicaromatic-hydrocarbons.

[15] European Food Safety Authority (EFSA), Polycyclic aromatic hydrocarbons in food –scientific opinion of the panel on contaminants in the food chain, EFSA J. 6 (8) (2008) 724, doi:10.2903/j.efsa.2008.724.

[16] Smith, D., & Lynam, K. (2012). Polycyclic aromatic hydrocarbon (PAH) analysis in fish by GC /MS using Agilent Bond Elut QuEChERS dSPE sample preparation and a high efficiency DB-5ms ultra inert GC application note. Agilent - Food Testing and Hydrocarbon Processing, 0–7.

[17] G. Martínez-Domínguez, A.J. Nieto-García, R. Romero-González, A.G. Frenich, Application of QuEChERS based method for the determination of pesticides in nutraceutical products (*Camellia sinensis*) by liquid chromatography coupled to triple quadrupole tandem mass spectrometry, Food Chem. 177 (2015) 182–190.

[18] Agency for Toxic Substances and Disease Registry (ATSDR)Guidance for Calculating Benzo(a)pyrene Equivalents for Cancer Evaluations of Polycyclic Aromatic Hydrocarbons, U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA, 2022.

[19] I.C. Nisbet, P.K. LaGoy, Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs), Regul. Toxicol. Pharm. 16 (1992) 290–300.

[20] M. Mohammadi, F. Valizadeh-Kakhki, Polycyclic aromatic hydrocarbons determination in grilled beef and chicken, Polycyclic Aromat. Compd. 38 (2018) 434–444.

[21] Z. Xia, X. Duan, W. Qiu, D. Liu, B. Wang, S. Tao, X. Hu, Health risk assessment on dietary exposure to polycyclic aromatic hydrocarbons (PAHs) in Taiyuan, China, Sci. Total Environ. 408 (2010) 5331–5337.

[22] C.M.A. Iwegbue, F.I. Bassey, I. Agbozu, E. Aganbi, G. Obi, Concentrations and risks of polycyclic aromatic hydrocarbons in smoke-cured fish products in Nigeria, Int. J. Environ. Stud. 73 (2016) 827–843.

[23] M. Hokkanen, U. Luhtasela, P. Kostamo, T. Ritvanen, K. Peltonen, M. Jestoi, Critical Effects of smoking parameters on the levels of polycyclic aromatic hydrocarbons in traditionally smoked fish and meat products in Finland, J. Chem. (2018) 2018, doi:10.1155/2018/2160958.

[24] C.K. Tay, L.K. Doamekpor, S. Mohammed, G. Dartey, R. Kuddy, E. Fianyaglo, M. Mawuena, Health risk assessment and source identification of Polycyclic Aromatic Hydrocarbons (PAHs) in commercially available singed cowhide within the Greater Accra Region, Ghana, West Afr. J. Appl. Ecol. 30 (1) (2022) 13–34, doi:10.4314/wajae.v30i1.

[25] A.M. Mahugija, E. Njale, Effects of washing on the polycyclic aromatic hydrocarbons (PAHs) contents in smoked fish, J. Food Control 93 (2018) 139–143, doi:10.1016/j.foodcont.2018.05.050.

[26] K.-C. Park, H.S. Pyo, W.S. Kim, K.S. Yoon, Effects of cooking methods and tea marinades on the formation of benzo[a]pyrene in grilled pork belly (Samgyeopsal), Meat. Sci. 129 (2017) 1–8.

[27] A. Farhadian, S. Jinap, H.N. Hanifah, I.S. Zaidul, Effects of meat preheating and wrapping on the levels of polycyclic aromatic hydrocarbons in charcoal-grilled meat, Food Chem. 124 (2011) 141–146.

[28] D.K. Essumang, Polycyclic aromatic hydrocarbon (PAH) in cooked (charred) rice: levels, risk assessment, and source characterization, Food Control 35 (1) (2014) 85–93, doi:10.1016/j.foodcont.2013.06.045.

[29] U.S. EPA. (1993). *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* (EPA/600/R-93/089; (NTIS PB94116571)).

[30] O.J. Oko, C.O.B. Okoye, Quantification of smoke contributed PAHs in roasted cowhide (Ponmo) from northern nigeria, FUW Trends Sci. Technol. J. 2 (2017) 55–59.

[31] D.K. Essumang, D.K. Dodoo, G. Hadzi, Distribution, levels, and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in singed cattle hide, Hum. Ecol. Risk Assess. An Int. J. 17 (2011) 1018–1038, doi:10.1080/10807039.2011.605332.

[32] A. Hitzel, M. Pöhlmann, F. Schwägele, K. Speer, W. Jira, Polycyclic aromatic hydrocarbons (PAH) and phenolic substances in meat products smoked with different types of wood and smoking spices, Food Chem. 139 (2013) 955–962, doi:10.1016/j.foodchem.2013.02.011.

[33] A. Zachara, D. Gałkowska, L. Juszczak, Contamination of smoked meat and fish products from Polish market with polycyclic aromatic hydrocarbons, Food Control 80 (2017) 45–51.

[34] L. Zastrow, M. Judas, K. Speer, K.-H. Schwind, W. Jira, Barbecue conditions affect contents of oxygenated and non-oxygenated polycyclic aromatic hydrocarbons in meat and non-meat patties, Food Chem. X 14 (2022) 100351, doi:10.1016/j.fochx.2022.100351.

[35] European Commission, Commission regulation (EU) No 835/2011 of 19 august 2011 amending regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs, Off. J. Eur. Union (2011) 4–8.

[36] D. Voutsa, C. Samara, Dietary intake of trace elements and polycyclic aromatic hydrocarbons via vegetables grown in an industrial Greek area, Sci. Total Environ. 218 (2-3) (1998) 203–216.

[37] W.S. Darwish, H. Chiba, W.R. El-Ghareeb, A.E. Elhelaly, S.-P. Hui, Determination of polycyclic aromatic hydrocarbon content in heat-treated meat retailed in Egypt: health risk assessment, benzo[a]pyrene induced mutagenicity and oxidative stress in human colon (CaCo-2) cells and protection using rosmarinic and ascorbic acids, Food Chem. 290 (2019) 114–124.

[38] S. Chawda, A. Tarafdar, A. Sinha, B.K. Mishra, Profiling and health risk assessment of PAHs content in tandoori and tawa bread from India, Polycyclic Aromat. Compd. 40 (2017) 21–32.

[39] S. Igbiri, N.A. Udowelle, O.C. Ekhator, N. Asomugha, Z.N. Igweze, O.E Orisakwe, Polycyclic aromatic hydrocarbons in edible mushrooms from Niger Delta, Nigeria: carcinogenic and non-carcinogenic health risk assessment, *Asian Pac. J.f Cancer Prevent.* (APJCP) 18 (2017) 437–447.