IMPROVING THE SAFETY OF SMOKED FISH THROUGH KILN DESIGN: THE CASE OF FAO-THIAROYE TECHNIQUE IN GHANA

[AMÉLIORER LA SÉCURITÉ DU POISSON FUMÉ GRÂCE AU MODÈLE DE FOUR: LE CAS DE LA TECHNIQUE FAO-THIAROYE DE TRANSFORMATION AU GHANA]

by/par
Kennedy Bomfeh[1,21], Bruno DeMeulenaer[22], Liesbeth Jacxsens[23], Wisdom Kofi Amoa-Awua[34], Isabella Tandoh[25], Emmanuel Ohene Afoakwa[26], Yvette DieiOuadi[47], Esther GarridoGamarro[48]

Abstract

Smoked fish is a major source of animal protein for Ghanaians. However, traditional methods for processing the commodity potentially expose consumers to food safety risks. The methods typically rely on burning wood as fuel to cook and flavour fish. This practice is known to result in high amounts of carcinogens known as polycyclic aromatic hydrocarbons (PAHs) in the smoked fish, with the consequence that the products could endanger public health and have reduced market access. An innovative processing system, called the FAO-Thiaroye Processing Technique (FTT), was launched in 2014 in Ghana to address concerns linked to polycyclic aromatic hydrocarbons. It was envisaged that the design characteristics of FTT and its reliance on alternative fuel use would reduce polycyclic aromatic hydrocarbons levels in smoked fish. This study therefore investigated the efficacy of the innovation through comparative fish smoking tests between FTT and the traditional kilns. Data obtained show that products from traditional kilns had polycyclic aromatic hydrocarbons levels up to 33 times the globally referenced European Union maximum limits for polycyclic aromatic hydrocarbons regulation, whereas products from FTT had lower values than European Union maximum limits. The results demonstrate the efficacy of FTT to reduce polycyclic aromatic hydrocarbons in smoked fish and thus improve the safety and market access of the products.

Key words: Hot-smoking, smoked fish, polycyclic aromatic hydrocarbons, PAHs, the FAO-Thiaroye Processing Technique, food safety

Résumé

Le poisson fumé est une source majeure de protéines animales pour les Ghanéens. Cependant, les méthodes traditionnelles de transformation du produit exposent potentiellement les consommateurs à des risques liés à la sécurité sanitaire des aliments. Les méthodes reposent généralement sur la combustion du bois comme combustible pour cuire et aromatiser le poisson. Cette pratique est connue pour occasionner de grandes quantités de cancérogènes connus sous le nom d'hydrocarbures aromatiques polycycliques (HAP) dans le poisson fumé, avec pour conséquence que ces produits puissent mettre en danger la santé publique et avoir un accès au marché réduit. Un système de transformation innovant, appelé Technique FAO-Thiaroye de transformation (FTT), a été lancé en 2014 au Ghana pour répondre à la préoccupation par rapport aux hydrocarbures aromatiques polycycliques. Les caractéristiques de conception du FTT associées à l'utilisation de carburants alternatifs pouvaient potentiellement réduire les niveaux d'hydrocarbures aromatiques polycycliques dans le poisson fumé. Cette étude a donc étudié l'efficacité de l'innovation à travers des tests comparatifs de fumage du poisson entre le FTT et les fours traditionnels. Les données obtenues montrent que les produits des fours traditionnels avaient des niveaux d'hydrocarbures aromatiques polycycliques jusqu'à 33 fois supérieurs aux limites maximales de l'Union Européenne pour la

1 kbomfeh@gmail.com; Kennedy.Bomfeh@UGent.be (Corresponding Author)
2 Bruno.DeMeulenaer@UGent.be
3 Liesbeth.Jacxsens@UGent.be
4 wis.amoa@gmail.com
5 itandoh22@gmail.com
6 eafoakwa@ug.edu.gh
7 Yvette.DieiOuadi@fao.org
8 Esther.GarridoGamarro@fao.org
[1]University of Ghana, [2]Ghent University, [3]Food Research Institute of Ghana, [4]Food and Agriculture Organization, Rome

réglementation des hydrocarbures aromatiques polycycliques, alors que les produits du FTT avaient des valeurs inférieures à celles de l'Union Européenne. Les résultats démontrent l'efficacité du FTT pour réduire les hydrocarbures aromatiques polycycliques dans le poisson fumé et ainsi améliorer la sécurité sanitaire et l'accès au marché des produits.

Mots-clés: fumage à chaud, poisson fumé, hydrocarbures aromatiques polycycliques, HAP, la technique FTT-Thiaroye de transformation, sécurité sanitaire des aliments

1. INTRODUCTION

Fish is the major source of animal protein in Ghanaian diets. With an average per capita intake of 27 kg – close to three times the estimated Africa averageof 9.7 kg (FAO, 2014a) – the commodity makes up about 60% of animal protein in Ghanaian diets and accounts for 16% of household food expenditure (Ghana Living Standards Survey, 2008; Atta-Mills *et al.*, 2004). The bulk of fish consumed in the country is traditionally processed by hot-smoking, sun-drying, deep frying, and salting (Nketsia-Tabiri and Sefa-Dedeh, 2000; Adu-Gyamfi, 2006). Of these methods, traditional smoking is the most practiced (Adu-Gyamfi, 2006), thus making smoked fish the most consumed fish product.

Historically, traditional fish smoking in Ghana has relied on the use of two main types of kilns: metal drum kiln and the Chorkor Smoker (Fig.1) (Brownell, 1983; Nketsia-Tabiri and Sefa-Dedeh, 2000; Bomfeh, 2011). The latter was built in the late 1960s as an improvement on the former through the collaborative efforts of the Food Research Institute of Ghana, the Food and Agriculture Organization of the United Nations (FAO), and fish processors in Chorkor, a fishing community in Ghana's capital city. The drum kiln has low capacity, low fuel efficiency, requires excessive product handling during processing, and predisposes processors to burn injuries (Brownell, 1983). Its low capacity invariably translates into high post-harvest losses during bumper seasons. These shortfalls were adequately addressed by the introduction of the Chorkor Smoker, which currently enjoys widespread use across Africa.

Although Chorkor smoker improved product throughput and reduced the drudgery associated with traditional fish smoking, like the drum kiln, it runs on firewood as fuel. This practice is known to result in the production of carcinogens known as polycyclic aromatic hydrocarbons (PAH) (EFSA, 2008). Those compounds are produced when complex organic materials are exposed to high temperatures and/or pressures (Gehle, 2009). In hot-smoking with wood as fuel, smoke from the wood coupled with high processing temperature results in the deposition of several PAH on the fish (Stolyhwo and Sikorski, 2005). Studies have reported the occurrence of the compounds in traditionally smoked fish on informal markets in Nigeria (Olabemiwo *et al.*, 2011) and Ghana (Palm *et al.*, 2011).

The Codex Alimentarius Commission has established guidelines for reducing PAH levels through different instruments. Section 12 of the *Code of practice for fishery products on smoked fish, smoke-flavoured fish and smoke-dried fish* (CAC/RCP 52-2003) provides examples of technological guidance to be used for developing control measures and corrective actions. The *Code of practice for the reduction of contamination of food with PAH from smoking and direct drying processes* (CAC/RCP 68-2009) was an important initial text for national authorities and manufacturers, and was followed by other work in this area. The last and most relevant instrument is the *Standard for smoked fish, smoke-flavoured fish and smoke-dried fish* (CODEX STAN 311–2013) adopted in 2013 and amended in 2016. These Codex texts identify, *inter alia*, the use of wood fuels, distance between food being smoked and heat source, fat content of food, smoking duration, smoking temperature, and cleanliness and maintenance of equipment as important parameters affecting the occurrence of PAH on products during smoking. By their design, the traditional kilns enhance the possibility of these parameters to facilitate the occurrence of PAH in the smoked products.

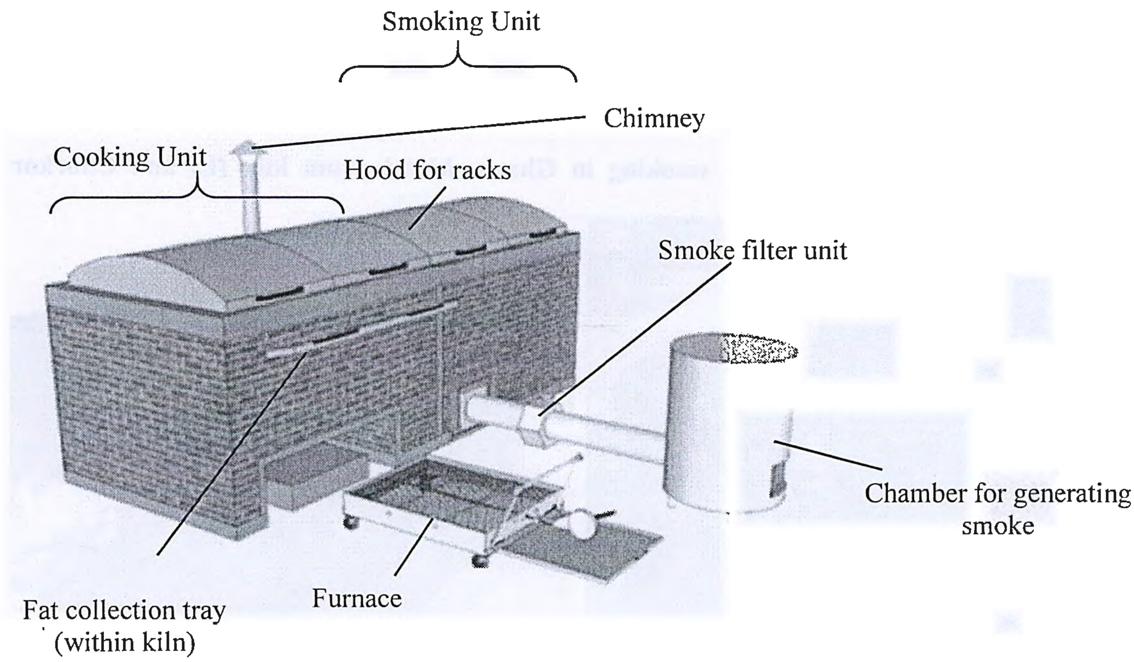
To address this concern, an innovative processing system, called FAO-Thiaroye Fish Processing Technique (FTT), was introduced in Ghana in 2014. The important differences between FTT and the traditional kilns are summarized in Table 1. By its design (Fig. 2), FTT allows a shift from the use of wood fuel to completely combusted charcoal or butane, prevents dripping of fish fat into heat source during processing, and allows indirect flavouring of fish with filtered smoke (Ndiaye *et al.*, 2015; FAO, 2014b). With these features, the FTT is expected to yield smoked products with lower PAH levels than those from the traditional kilns.

Figure 1. Traditional kilns for fish smoking in Ghana. Metal drum kiln (L) and Chorkor smoker (R)

Table 1. Key differences between traditional kilns and FTT

Traditional Kiln (Chorkor or Metal drum)	FTT
Uses firewood as cooking fuel	Uses completely lit charcoal and heat-retention stones as cooking fuel (amenable to alternative non-wood fuels such as butane gas)
Simultaneous cooking and smoking	Separate cooking and smoke flavouring unit operations
Direct smoking	Indirect smoking
Smoke not filtered	Smoke filtered with dried sponge cucumber (*Luffa aegyptiaca*) or similar food-grade plant material
Fish fat drips into fire	Fish fat drains out over fat collection tray into an external container

Figure 2. Schematic of FTT (Ndiaye *et al.*, 2015; FAO, 2014b)



This study was therefore undertaken to investigate the efficacy of FTT to yield products with lower levels of PAH. PAH of interest were the internationally recognized markers for the compounds: benzo(a)pyrene (BaP), chrysene, benzo(a)anthracene, and benzo(b)fluoranthene. The sum of these four are collectively referred to as PAH4.

The specific objectives were:

i. to compare the levels of BaP and PAH4 in *Sardinella sp* smoked-dry[9] with FTT, Chorkor Smoker and the metal drum kiln
ii. To test the effect of fuel type on BaP and PAH4 levels across the kilns.

2. MATERIALS AND METHODS

Overview
Fresh batches of *Sardinella* sp, were hot-smoked separately on FTT, Chorkor smoker, metal drum kiln and FTT in five replicates per kiln. Samples of fish from each batch of smoking were then tested for their levels of BaP and PAH4 using gas-chromatography mass spectrometry (GC-MS). Differences among mean PAH levels of products from the different kilns were tested through analysis of variance (ANOVA) runs with the SPSS® software (version 23).

Smoking experiments
Frozen *Sardinella* sp. were procured from cold stores at Tema New Town in Accra and smoked following the process flow in Fig. 3. The combination of fuel types and kilns for the smoking experiments are shown in Table 2. Conventionally, traditional kilns are fueled with several kinds of dry wood. One of the most patronized species is *Pterocarpus erinaceus* (locally called "*esa*"). In contrast, FTT is designed such that charcoal (or gas or other non-wood fuel) first fuels the cooking of fish in a cooking chamber, after which the cooked fish is transferred to an adjoining chamber and flavoured with filtered smoke produced from lit moistened sugarcane bagasse, corn cobs or coconut husk (Fig. 2 and 3). This practice was followed, using sugarcane bagasse as material for generating the smoke.

[9] Smoked-dry fish is fish that has been smoked to a final moisture content of 10-15% and can be stored for several months

To allow for comparison of PAH results among the kilns,

i. the dry wood fuel were used across all kilns (traditional and FTT)

Chorkor smoker was experimentally fueled with charcoal to compare with FTT (Table 2). For this, the fish was first cooked over fully lit charcoal in the stoke hole of the Chorkor smoker, and subsequently flavoured with smoke generated from moistened sugarcane bagasse lit in the same stoke hole.

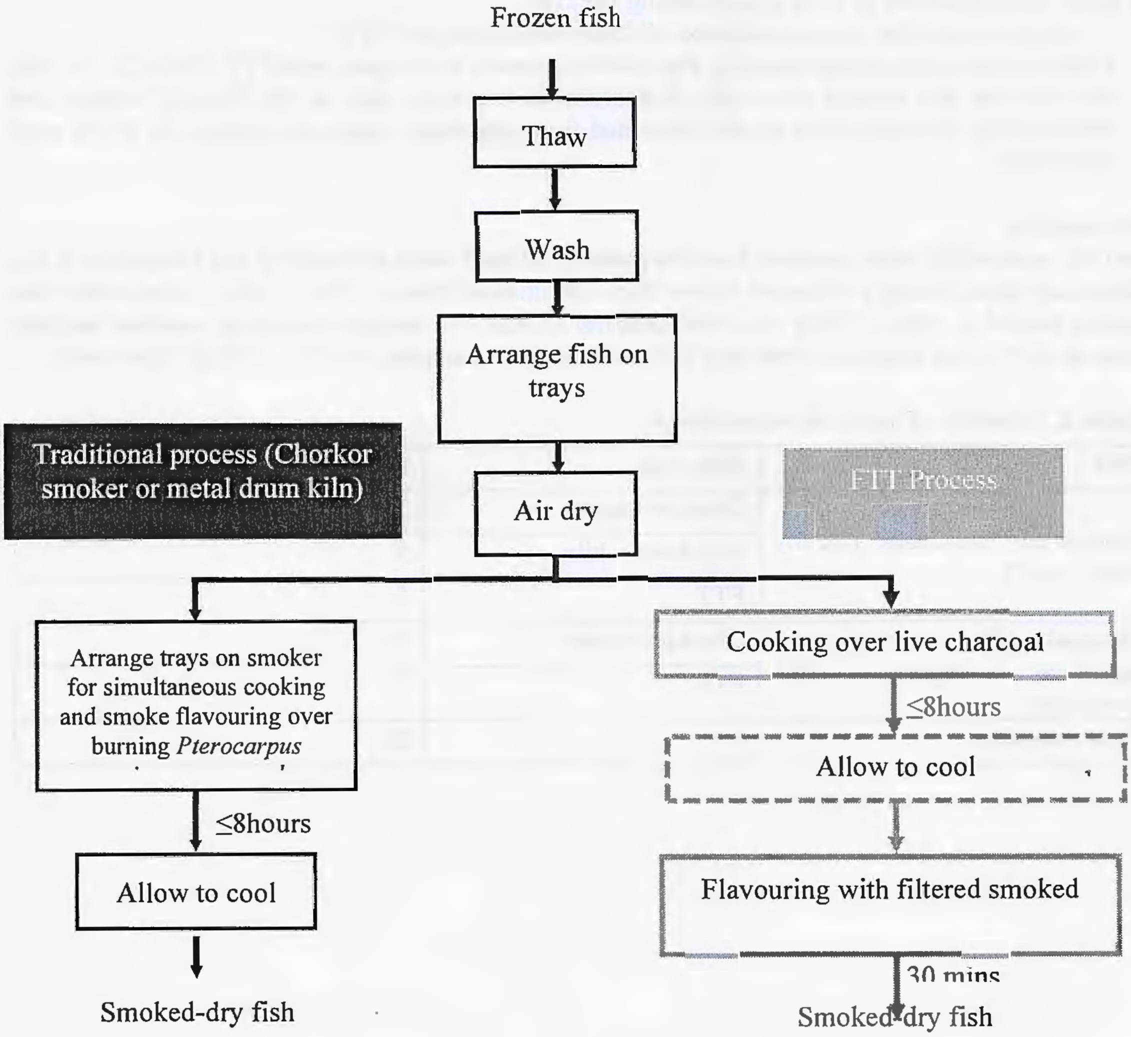
Fish sampling

Ten (10) smoked fish were sampled from the products of each batch of smoking and blended as is (i.e. without any liquid) using a Warren® Heavy Duty Commercial blender. The resulting blends were then vacuum packed in units of 250g with Henkelman® JUMBO 42 vacuum packaging machine and kept frozen at -22°C until analysed. Fresh raw fish were similarly sampled prior to smoking experiments.

Table 2. Schedule of smoking experiments

Fuel	**Kiln type**	**No. of smoking experiments**
Pterocarpus erinaceus (locally called "esa")	Chorkor smoker	5
	Metal drum kiln	5
	FTT	5
Charcoal (for cooking) and sugarcane bagasse (for flavouring)	Chorkor smoker	5
	FTT	5
Total samples		**25**

Figure 3. General process flow diagram for hot-smoked fish: traditional kilns vs. FTT



Determination of PAH

For each sample, 2g of homogenized fish was treated with 20ml hexane and 10µl IS (1µg/ml). After shaking, the mixture was held for 1h in an ultrasound bath and then placed in the freezer for 2 h at -20°C. Frozen fat and solid components were separated by centrifuging for 2 min at 5000 rpm. The supernatant clear solution was transferred to a 10ml vial and placed into a Gerstel MPS sample tray 1. For a further clean-up step, after solid phase extraction, 0.25g Silica was weighed in another MPS vial, which was put on another sample tray 2. Finally, the MPS sample tray 3 was filled up with BEKOlut SPE cartridges. After clean up, samples were immediately injected in the GC-MS. Below are the method and equipment characteristics:

- Calibration range: 0.2 ppb – 10ppb (R2=0.999)
- Recovery = 94%
- Relative Standard Deviations (RSD) = 2.6%
- Gas chromatograph: Agilent 7890B
- Mass spectrometer: Agilent 5977B
- MPS 2XL Sampler: Gerstel

- Centrifuge: Hettich Universal 320
- Column: Agilent J&W DB 35MS, 122-3822 (30m x 0.25 mm ID, 0.25 µm film)
- Temperature: PTV injector 50°C/ 1 min, 500°C/min to 320°C (Purge 1 min)
- Oven: 50°C, 3 min isotherm, 30°C/min to 200°C, 4°C/min to 300°C, 19 min isotherm
- Carrier Gas: Helium 1.0 ml constant flow
- Injection: 1 x 100 µl

Statistical analysis
Mean values of BaP and PAH4 were compared using SPSS® version 23. Statistical significance was set at 5%.

3. RESULTS AND DISCUSSION

Comparing FTT and traditional kilns as smoking systems
Among the products tested, those from FTT had the lowest PAH levels, all of which were also lower than EU maximum limits (ML) (Commission Regulation Numbers 1881/2006; 835/2011). PAH in products from the traditional kilns exceeded EU ML by up to 30 times for BaP and 33 times for PAH4 (Fig. 4 and 5).

Between the traditional kilns, metal drum kiln product recorded significantly lower ($p<0.05$) PAH levels than Chorkor smoker (Fig. 4 and 5). This could be attributed to the higher degree of smoke retention in the Chorkor smoker than the metal drum kiln. Longer/greater exposure to smoke has been cited as a contributor to high PAH in smoked products (CAC, 2009). Interestingly, the characteristic of better smoke retention in the Chorkor smoker was considered an advantage when that kiln was introduced in Ghana in 1969, since this feature allowed better flavouring of products (Brownell, 1983). It is seen, however, that this apparent gain in sensory appeal led to a loss in the safety of the products.

Figure 4. Benzo(a)pyrene levels in smoked-dry *Sardinella sp.*
(FTT vs. Traditional kilns vs. EU ML. Fuels: FTT - Charcoal for cooking; sugarcane bagasse for flavouring; Chorkor & Drum - *Pterocarpus erinaceous* firewood)

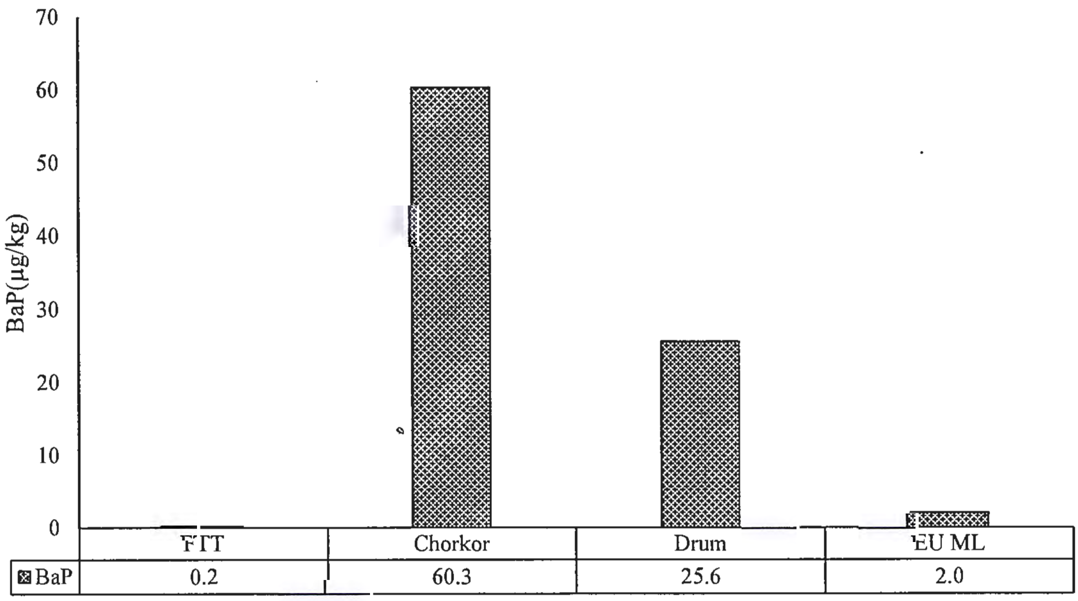
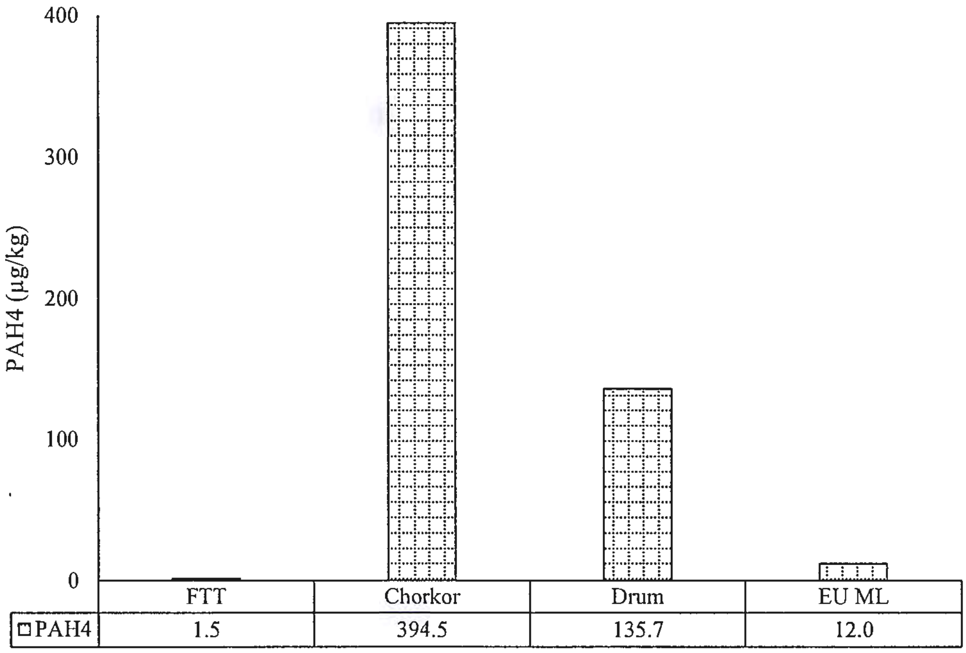


Figure 5. PAH4 levels in smoked-dry *Sardinella sp.*
(FTT vs. Traditional kilns vs. EU ML. Fuels: FTT - Charcoal for cooking; sugarcane bagasse for flavouring; Chorkor & Drum - *Pterocarpus erinaceous* firewood)

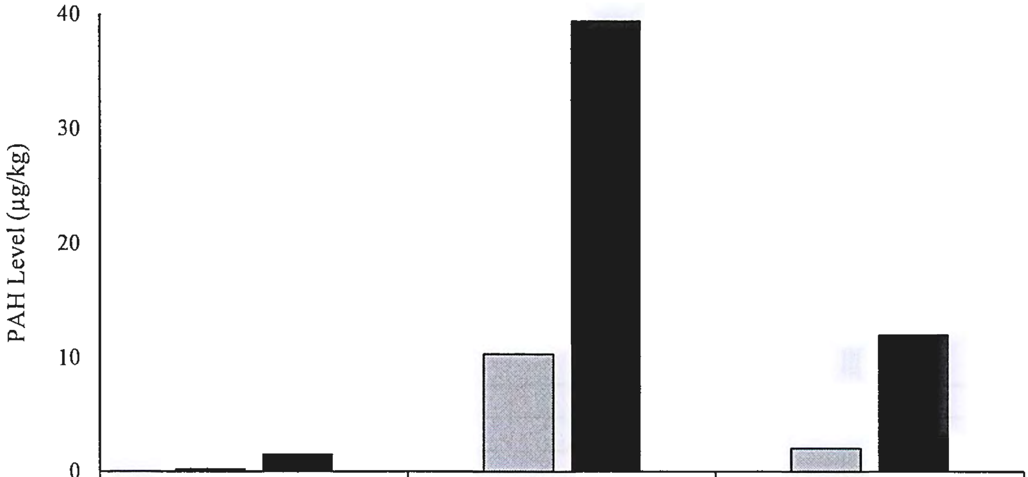


BaP and PAH4 levels in fresh *Sardinella* sp were <0.20µg/kg, well below the levels in their corresponding smoked forms. This highlights processing as the source of the contamination.

Effect of fuel type and kiln design on PAH

Using charcoal as cooking fuel in Chorkor smoker resulted in significantly lower ($p<0.05$) BaP and PAH4 levels than when *Pterocarpus erinaceous* wood was used (Fig. 5 and 6). This points to the strong impact of *fuels* on PAH levels in smoked products. The shift from dry wood to completely combusted charcoal drastically reduced the PAH levels in the products (cf. BaP of 10.28µg/kg for charcoal; 60.30 µg/kg for wood; Fig.5 vs. Fig.6). It is also noted that although lower, the levels still exceeded those for FTT products and EU ML (Fig.6). This, therefore, points to the impact of *kiln design* on PAH levels, since only a change in fuel type in Chorkor did not result in reduction of PAH levels to values presently considered acceptable.

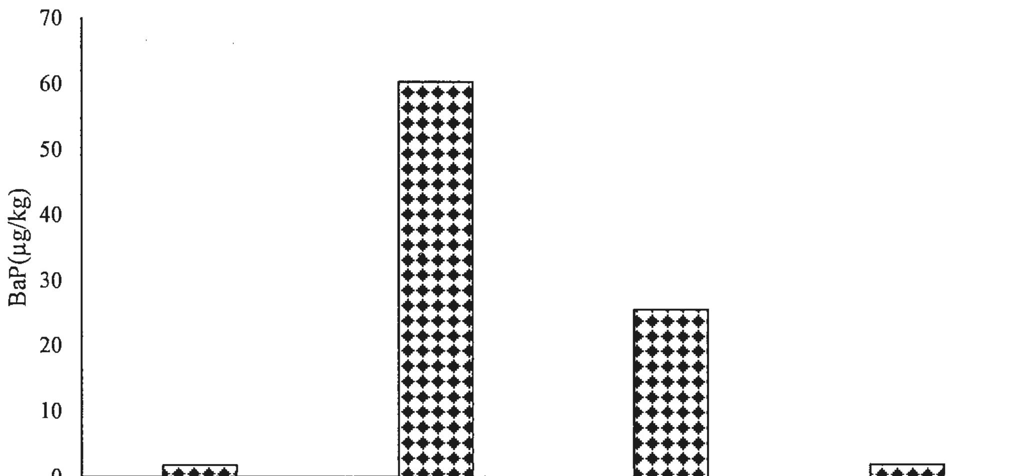
Figure 6. Benzo(a)pyrene levels in smoked-dry *Sardinella* sp
(FTT vs. Chorkor smoker vs. EU ML. Fuels: Charcoal for cooking; sugarcane bagasse for flavouring in both kilns)



	FTT	Chorkor	EU ML
□BaP	0.2	10.28	2
■PAH4	1.5	39.38	12

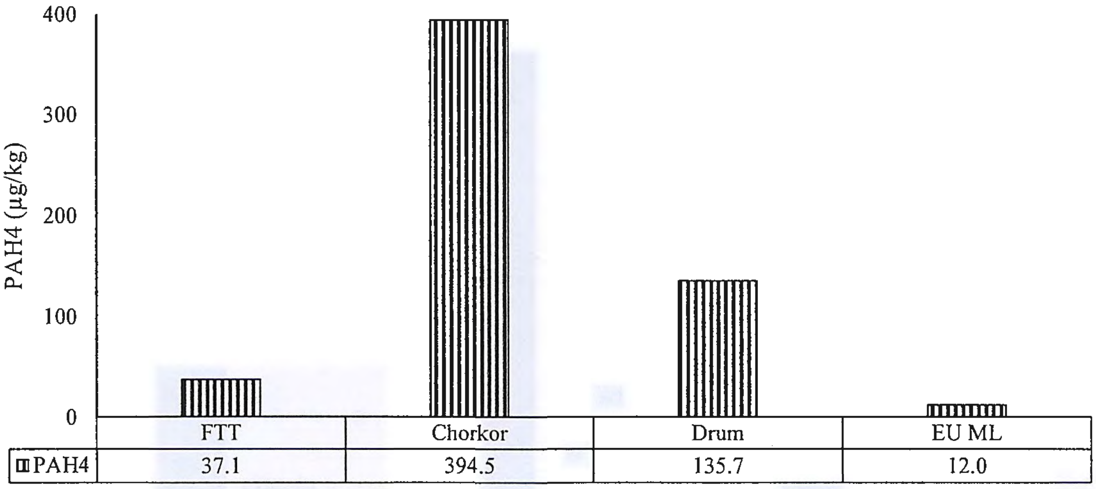
FTT products exceeded EU ML for PAH4 when charcoal was replaced with *Pterocarpus erinaceus* as fuel (Fig.7 and 8). This suggests that using wood as cooking fuel for FTT could defeat the objective of the innovation. It is noted, however, that FTT still performed better than the traditional kilns when wood was used as fuel across the kilns (Fig. 7 and 8). This further buttresses the earlier comment on the combined impact of *fuel type* and *kiln design* on PAH levels in smoked products. This is seen in the significantly higher PAH4 levels in smoked products from FTT when wood is used instead of charcoal, and the failure to have to PAH at acceptable limits when wood is replaced with charcoal in Chorkor smoker without structural modifications to the kiln.

Figure 7. Benzo(a)pyrene levels in smoked-dry *Sardinella sp*
(FTT vs. Traditional Kilns vs. EU ML. Fuel - *Pterocarpus erinaceous* firewood across kiln types for entire processing)



	FTT	Chorkor	Drum	EU ML
BaP	1.8	60.3	25.6	2.0

Figure 8. PAH4 pyrene levels in smoked-dry *Sardinella sp* (FTT vs. Traditional Kilns vs. EU ML). Fuel - *Pterocarpus erinaceous* firewood across kiln types for entire processing



4. CONCLUSION AND RECOMMENDATIONS

The results suggest that smoking fish with Chorkor smoker or metal drum kilns following the traditional practice of burning wood as fuel results in high PAH levels in products, significantly exceeding EU ML for BaP and PAH4. On the other hand, smoking fish with FTT results in products with PAH levels that are both significantly lower than values for traditional kiln products and also below EU maximum limits for BaP and PAH4. However, if dried wood is used instead of charcoal as fuel in FTT, products record high PAH4 levels that exceed EU maximum limits. The findings demonstrate the efficacy of FTT to yield hot-smoked fish with lower and safer PAH levels than in products from traditional kilns. It also highlights the key impact of both fuel type and kiln design on PAH levels in smoked fish.

Given the observed performance of FTT against the traditional kilns, the former is recommended as a viable kiln option in policy actions aimed at protecting public health vis-à-vis PAH levels in smoked products. In this regard, the present findings provided the basis for an ongoing work that is assessing the impact of the components of FTT on PAH levels within a broader risk assessment framework. This is to provide evidence for informed policy making, risk management and overall improvements in the value chain. Investigations into the acceptability and ease of adoption of FTT in particular contexts are recommended.

5. ACKNOWLEDGEMENT

This study was funded by the Food and Agriculture Organization (FAO) and the Ghent University Special Research Fund for Developing Countries.

6. REFERENCES

Bomfeh, K. 2011. Risk Assessment for Traditionally Processed Fish from Informal Markets in Accra and Tema. MPhil. Thesis. Department of Nutrition and Food Science, University of Ghana.

Brownell, B. 1983. A Practical Guide to Improved Fish Smoking in West Africa. UNICEF. http://www.greenlight2015.org/chorkor/Brownell/Intro.htm Retrieved on September 25, 2016

Codex Alimentarius Commission. 2003. Code of Practice for Fish and Fishery Products. CAC/RCP 52-2003.

Codex Alimentarius Commission. 2009. Code of Practice for the Reduction of Contamination of Food with Polycyclic Aromatic Hydrocarbons (PAH) from Smoking and Direct Drying Processes. CAC/RP 68-2009.

Codex Alimentarius Commission. 2013. Standard for smoked fish, smoke-flavoured fish and smoke-dried fish. CODEX STAN 311–2013.

Commission Regulation (EC) No. 1881/2006. Setting Maximum Levels of Certain Contaminants in Foodstuffs. http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:364:0005:0024:EN:PDF Retrieved January 5, 2015.

Commission Regulation (EU) No 835/2011. Amending Regulation (EC) No. 1881/2006 as Regards Maximum Levels for Certain Polycyclic Aromatic Hydrocarbons in Foodstuffs.http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:215:0004:0008:EN:PDF Retrieved January 5, 2015

European Food Safety Authority (EFSA). 2008. Polycyclic Aromatic Hydrocarbons in Food. Opinion of the Panel on Contaminants in the Food Chain. The EFSA Journal (2008) 724, 1-114

Food and Agriculture Organization. 2014a. Fishery and Aquaculture Statistics. FAO Year Book 2014. www.fao.org/3/a-i5716t.pdf Retrieved on September 12, 2016

Food and Agriculture Organization. 2014b. Overview, parts, use and maintenance of FTT Thiaroye. Three-part videos on FTT Thiaroye with the following links:
www.youtube.com/watch?v=zgqPlYNUL7A
www.youtube.com/watch?v=yxtG3VL1WNw
www.youtube.com/watch?v=xFW05he_TC8

Videos uploaded September 29, 2014. Retrieved December 14, 2014.

Gehle, K. 2009. Toxicity of polycyclic aromatic hydrocarbons. https://www.atsdr.cdc.gov/csem/pah/docs/pah.pdf. Retrieved on 2-Aug-17, 20:50.

Ghana Living Standards Survey. 2008. Report of the Fifth Round. http://www.statsghana.gov.gh/docfiles/glss5_report.pdf Retrieved January 5, 2015.

Ndiaye, O., Komivi, B.S. and Diei-Ouadi, Y. 2015. Guide for Developing and Using the FAO-Thiaroye Processing Technique. Food and Agriculture Organization of the United Nations. www.fao.org/3/a-i4174e.pdf

Olabemiwo, O.M., Alade, A.O., Tella, A.C. and Adediran, G.O. 2011. Assessment of Polycyclic Aromatic Hydrocarbons Content in Smoked C. Gariepinnus and T. guineensis Fish Species Available in Western Nigeria. International Journal of Basic & Applied Sciences IJBAS-IJENS Vol: 11 No: 02

Palm, L.M.N, Carboo, D., Yeboah, P.O, and Quasie, W.J. 2011. Characterization of Polycyclic Aromatic Hydrocarbons Present in Smoked Fish from Ghana. Advanced Journal of Food Science and Technology 3(5): 332-338, 2011.

Stołyhwo, A. and Sikorski, Z.E. 2005. Polycyclic aromatic hydrocarbons in smoked fish – a critical review. Food Chemistry 91 (2005) 303–311.