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Development of innovative technology reducing the levels of Polycyclic Aromatic Hydrocarbons in grilled meat and smoked fish

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ABSTRACT

Meat and fish are mainly processed in Benin by grilling, smoking and smoking-drying. Recent studies revealed that traditional equipments led to high contamination of end-products by polycyclic aromatic hydrocarbons (PAHs). This study aimed to assess the performances of new equipments and reduce the level of PAHs in end-products. Thirty-six controlled production trials were performed using three improved and new equipments in combination with charcoal and wood as fuel. The temperature at the core of grilled pork (77.5 ± 3.8 °C) and smoked fish (76.4 ± 2.8 °C) showed the highest thermal efficiency of QUALISANI equipment (FAQ) used with charcoal compared to other combinations fuel-equipment. The benzo[*a*]pyrene (BaP) (0.2 ± 0.1–1.9 ± 2.1 μg/Kg) and sum of PAH4 (2.4 ± 0.2 μg/Kg) in grilled pork obtained with FAQ-charcoal used with or without filter were the lowest levels of PAHs in compliance with Beninese and European standards. Smoked and smoked-dried fishes obtained from FAQ-charcoal with or without filter, FAQ-wood-filter, and the modified barrel kiln (FBM) used with charcoal-filter had ranges of BaP (0.1–0.2 μg/Kg) and PAH4 (0.4–2.9 μg/Kg) significantly lower than the maximal limited values of 2 μg/Kg (BaP) and 12 μg/Kg (PAH4) admitted by European Commission.

1. Introduction

Fresh fish and meat are perishable foodstuffs because of their high moisture content which causes the development of spoilage micro-organisms (Duan et al., 2004). In Benin like other countries in West African region, the post-capture losses of fresh fish are estimated at 20 % (Anihouvi et al., 2005) while the post-slaughtering losses of fresh meat are evaluated to 6 % (Codjia, 2016). To limit these losses of fish and meat, many traditional preservation practices such as salting, fermentation, crackling, grilling, smoking and drying were used separately or in association. According to Gnimadi et al. (2006), fish was preserved by smoking, crackling and drying-salting. Smoked and roasted or grilled products from traditional processing methods are of uncertain health quality due to the formation and accumulation of carcinogenic compounds such as Polycyclic Aromatic Hydrocarbons (PAHs) (Ratsimba et al., 2014). Morever, recent studies carried out in Benin and Tenzanie revealed that smoked and grilled products obtained from artisanal processing are strongly contaminated by PAHs which levels exceed the limits authorized by standard (Kpoclou et al., 2014; Mahugijaa and Njale, 2018). Iko Afé et al. (2020a) showed that grilled pork samples obtained from traditional grilling in Benin had concentrations in PAHs ranged between 0.4 and 17.9 μg/kg for benzo[*a*]pyrene (BaP), and 3.7 and 129.6 μg/kg for sum of PAH4 (benzo[*a*]pyrene, chrysene, benzo[*b*]fluorenthene and benzo[*a*]antracene) with 70.8 % of samples which were not in compliance with the limits of 2 μg/kg and 12 μg/kg recommended by European Commission for BaP and PAH4 respectively and the limit of 5 μg/kg for BaP authorized by beninese regulations (Arrêté 2007 N° 0362/MAEP/Bénin). The situation is even more

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alarming for smoked and smoked-dried fish of which 100 % of samples presented concentrations in BaP (2.1–1403.4 μg/kg) and PAH4 (15.9–10966.4 μg/kg), 700 times higher than the limit values (Iko Afé et al., 2021). Assogba et al. (2021b) also proved that smoked fish obtained from follow up of traditional processing method were highly contaminated with PAHs, and showed maximal levels of benzo[*a*]pyrene (52.7 μg/kg) and PAH4 (i.e. sum of benzo[*a*]pyrene, chrysene, benzo[*b*]fluoranthene and benzo[*a*]anthracene) (290.9 μg/kg) exceeding the European Union limits by about 25-fold. Many other studies demonstrated that traditional processing conditions such as direct exposure of products to smoke, high temperature in combustion chamber and type of fuel mainly the wood could allow to the contamination of end-products by PAHs (Babić et al., 2017; Assogba et al., 2019; Assogba et al., 2020; Iko Afé et al., 2020d; Assogba et al., 2021b). Even if the risk associated with the consumption of certain products such as baby foods, meat, poultry and seafood is tolerable in Iran (Samiee et al., 2020; Moazzen et al., 2022; Khalili et al., 2023), this is not the case in Africa and particularly in Benin where the high levels of products contamination by PAHs might result in carcinogenic risks and public health issues (Iko Afé et al., 2020a). Yousefi et al. (2019) demonstrated the reduction of PAHs in aqueous media using lactic acid bacterias and probiotics, but it could be interesting to prevent contamination by controlling processing methods. Previous studies were performed in different countries in order to reduce contamination level of smoked and grilled products by PAHs (Essumang et al., 2013; Parker et al., 2017; Babić et al., 2018; Bomfeh et al., 2019). The limitations of these studies are related to the low technological performance of the equipments, the exposition of processors to heat and smoke and the contact of product oil with the combustion place with risk of formation of many others harmful chemical compounds. In addition, in Benin, any study had not been done before to reduce PAHs contamination of smoked and grilled products. It appears necessary to solve this issue by improving equipments used for smoking and grilling processes in Benin in order, not only to take into account the mentioned limitations above, but to also ensure end-product safety and to satisfy the real needs of processors (good performances of equipments and their protection against exposure to smoke and heat) and consumer's expectations as reported by Assogba et al. (2019).

The present study aimed to improve the chemical quality of grilled meat and smoked fish products by the development of new and improved equipments using wood and charcoal of *Acacia auriculiformis* as fuels. Specifically, the thermal and technological performances of the manufactured equipments were investigated, and their effects on the physico-chemical characteristics and the level of contamination of processed products by PAHs were assessed.

2. Material and methods

2.1. Design and manufacturing of improved equipments

Three equipments were designed and manufactured according to Adapted Equipment Design Method in the Context of Southern Countries (Marouzé, 1999) using TopSolid 2010 software. This work was performed by a team regrouping manufacturers and researchers from different scientific disciplines (mechanic, food science and economy). The design approach was mainly based on the limitation of the contamination of processed products by PAHs avoiding sanitary risk to consumers. The design also took into account, the constraints and potentialities of the traditional grilling and smoking processes, and the expectations of processors as reported by Assogba et al. (2019). The four innovations introduced during the design and the manufacturing of these improved equipments are related to: thermal insulation of the walls of equipment using clay; installation of chimneys for smoke evacuation; installation of granite-based filter which nature is able to retain polycyclic aromatic hydrocarbons (PAHs), and installation of fat and exudates collection plate.

2.2. Description and operation of designed, manufactured and improved equipments

2.2.1. QUALISANI equipment

The equipment named QUALISANI (FAQ) in Fig. 1 is designed and manufactured for grilling of meat and smoking and smoking-drying of fish. Its estimated load capacity is 20–30 kg against 5–10 kg for traditional equipments such as barrel kiln and clay grill with two chambers currently in use by processors. FAQ has two essential parts: a combustion chamber (4) and a grilling/smoking chamber (1) supplied with five grids. The load capacity of each grid oscillated between 4 and 6 kg according to the type of product (pork or fish). The two chambers are equipped with smoke evacuation chimney (7 and 8). They are also separated by a handling windows which can be opened or closed with a lever in order to regulate heat transfer from combustion chamber to grilling/smoking chamber. Between the handling windows and grilling/smoking chamber, it was installed a broken granite filter (4–8 mm of size) which allows to retain eventually, PAHs from smoke and heat, avoiding product contamination by PAHs. Indeed, granite with its composition (presence of zeolite) is recognized as a potential sensor of PAHs (Babić et al., 2018). This reason motivates its use as filter. QUALISANI equipment is used as described in its invention patent (Assogba et al., 2023).

2.2.2. Modified barrel kiln

The modified barrel kiln (FBM) has the form of right prism (Fig. 2) which design was inspired from the functions of traditional barrel kiln used by smoked and smoked-dried fish processors (Assogba et al., 2021b). From bottom to top, FBM is equipped with combustion chamber (5), broken granite based-filter in horizontal position, a dropped fat collector device (3) and smoking or smoking-drying chamber (1) which can receive five superimposable grids (2). The granite based-filter plays the same role of PAHs retention as indicated previously. The dropped fat collector device is built with galvanized iron plate having five circular

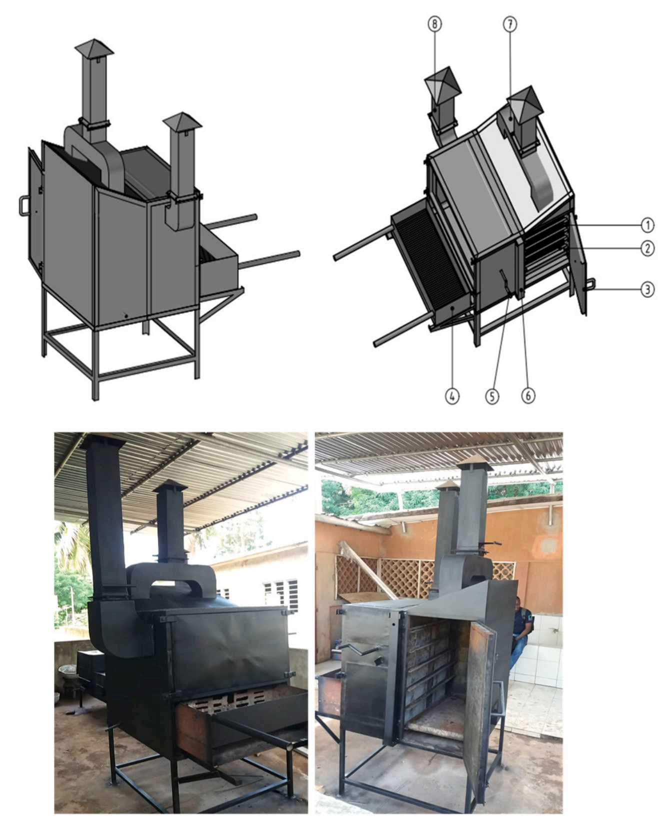

Fig. 1. QUALISANI equipment (FAQ).

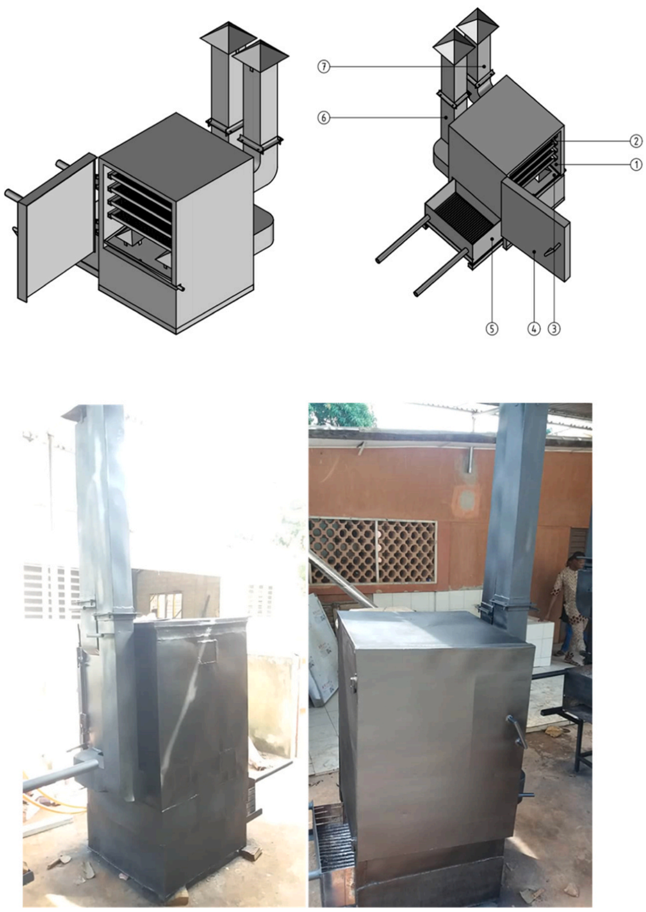

Fig. 2. Modified barrel kiln (FBM).

openings headed with small roofs which allow to remove fat from the system under the inclined position of the plate. From outside to inside, all the walls of the kiln are maded using successively galvanized iron plate, clay and galvanized iron plate which constitute thermal insulation avoiding heat dissipation, and protection of equipment's users against heat during the processing. FBM is also equipped with two chimneys (6 and 7) to ensure smoke evacuation.

2.2.3. Improved clay grill with two chambers (GA2C)

This prototype of grill shown in Fig. 3, is designed and manufactured by the improvement of traditional clay grill with two chambers currently in use in Benin for grilled pork production and previously described by Assogba et al. (2020). The wall of GA2C is like the same described for FAQ and FBM. GA2C is also equipped with two chambers: grilling chamber (1) and combustion chamber (3) which has circular opening supporting pot used for sauce cooking. The two chambers are equipped with chimneys (5) and (6) respectively. They are separated by broken granite based-filter to retain PAHs. Before starting grilling process, the chimney (6) of combustion chamber is opened. The pot over the combustion chamber is heated by a part of heat from incomplete combustion of wood or charcoal. Another part of heat diffused by convection towards to the grilling chamber through granite based-filter. Only three grids are used in grilling chamber for GA2C. It is also equipped with dropped fat collection plate (7) which allow to remove fat from the system.

2.3. Evaluation of designed and improved equipments

2.3.1. Study area, raw materials, experimental design and sampling

The experiments were performed at agro-food processing workshop of the Faculty of Agronomic Sciences of the University of Abomey-Calavi (Benin). The three equipments designed and manufactured were used for the production of grilled pork, smoked fish and smoked-dried fish. The processed products were obtained according to methods described by Assogba et al. (2019; 2020). Pigs of 50 kg, with 10 months age, fed and bred under the same conditions on the same farm were used as biological material for grilled pork production while marine flying fish species: *Avion* (*Cypselurus cyanopterus*) was used for the production of

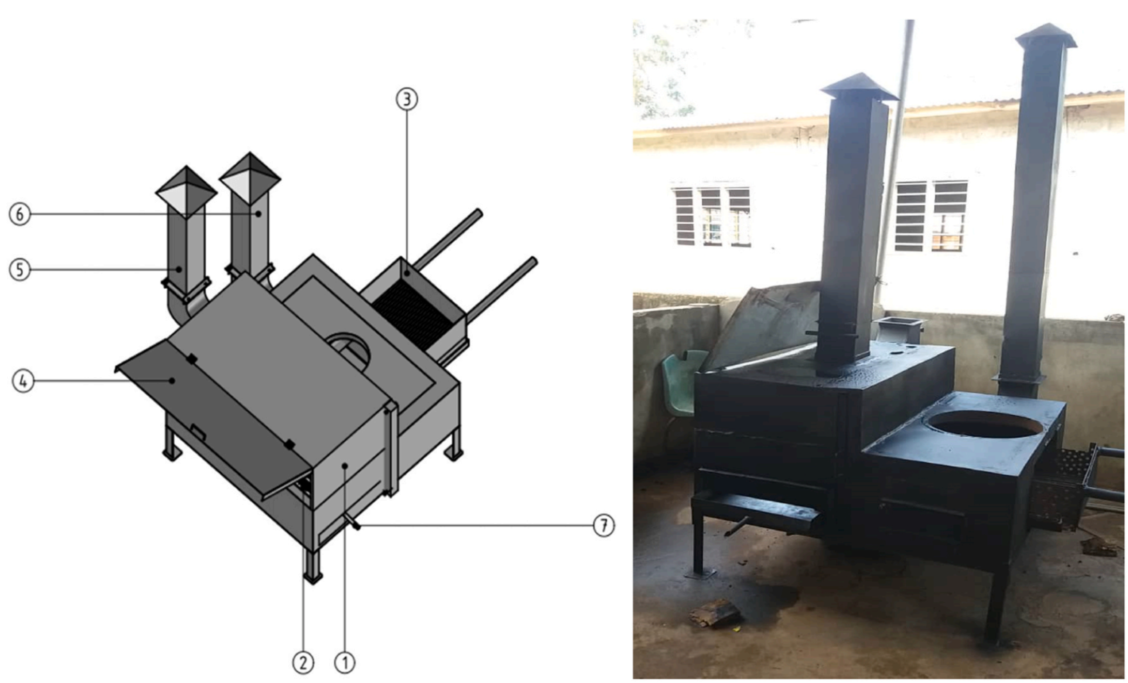

Fig. 3. Improved clay grill with two chambers (GA2C). (1): Grilling chamber; (2): Grid; (3): Combustion chamber; (4): Cover windows; (5): Chimney of grilling chamber; (6): Chimney of combustion chamber; (7): Dropped fat collection plate.

smoked and smoked-dried fishes. Two sets of experiments were performed. During the first set, a total of 24 controlled production trials (12 grilling and 12 smoking-drying) were performed using the three equipments with two types of fuels (charcoal and wood, all from the same tree species, *Acacia auriculiformis* with presence of granite filter between combustion chamber and grilling or smoking chamber (Table 1). QUALISANI equipment (FAQ) and the improved grill with two chambers (GA2C) were used for grilling, while FAQ and modified barrel kiln (FBM) were used for smoking-drying. Each association equipment-fuel was repeated three times (Table 1). For the second set of experiments, 12 controlled production trials (6 grilling and 6 smoking-drying) were performed using FAQ-charcoal with granite filter (3 replicates) and FAQ-charcoal without granite filter (3 replicates) for each type of product (pork and fish) (Table 1).

Forty-eight (48) samples including 6 slices of fresh pork, 12 grilled pork, 6 fresh fish, 12 smoked fish and 12 smoked-dried fish were collected at different stages of grilling and smoking-drying processes during the first set experiments. Other 18 samples (6 grilled pork, 6 smoked fish and 6 smoked-dried fish) were also collected from the second set of experiments for laboratory analysis.

2.3.2. Determination of technological performances and thermal efficiency of developed equipments

The technological performances (load capacity, duration and specific consumption of fuel) and the thermal parameters (temperature at different parts of equipment) of the three equipments were evaluated using the methods described by Assogba et al. (2020, 2021b). The load capacity was determined using a 50 kg range scale. The duration of each production trial was recorded using chronometer and this allowed to estimate the quantity of product processed per unit of time for each equipment. The specific consumption of fuel (SCF) of each equipment (kg of fuel / kg of fresh product) was obtained by the ratio of the quantity of wood or charcoal and the quantity of fresh product processed. The fuels were weighed before their introduction into the combustion chamber. The mass of the remaining fuel was weighed at the end of the process and the difference represented the quantity of fuel really used during the process. The temperatures in the combustion chamber, inside the grilling or smoking chamber and at the core of the product were recorded using probe thermocouples (Traceable digital thermocouple 620–2006, France). With regard to core temperature, it was determined simultaneously in five different samples of meat or fish located on five trays at different level of FAQ and FBM, but it was recorded in three samples located on the three trays at different level of GA2C.

Table 1
Experimental design and sampling.

Set of experiments	Processing methods	Equipments	Fuel	Use of filter	Replicate
First set	GP	FAQ	Charcoal	Filter	03
		FAQ	Wood	Filter	03
		GA2C	Charcoal	Filter	03
		GA2C	Wood	Filter	03
	SDP	FAQ	Charcoal	Filter	03
		FAQ	Wood	Filter	03
		FBM	Charcoal	Filter	03
		FBM	Wood	Filter	03
Second set	GP	FAQ	Charcoal	Filter	03
		FAQ	Charcoal	No filter	03
	SDP	FAQ	Charcoal	Filter	03
		FAQ	Charcoal	No filter	03

GP: Grilling process; SDP: Smoking-drying process; FAQ: QUALISANI equipment; FBM: Modified barrel kiln; GA2C: Improved grill with two chambers

2.4. Physico-chemical characterization and PAHs determination

The samples collected during the experiments were analysed in laboratory for the determination of moisture content, water activity, colour parameters and the level of PAHs. The moisture content was determined by oven drying of samples at 103 ± 2 °C up to constant weight (ISO 1442: 1997). Water activity (a_w) was measured using thermo-hygrometer (Rotronic HygroLab C1) while colour was assessed with a portable chromameter (MINOLTA-CR/DP 400/410) using L* , a* , b* and ΔE coordinates. The saturation (C *) which is an indicator of the colour intensity was calculated from a* and b* coordinates according to Castellar et al. (2006).

For PAH determination, the three replicate samples of grilled pork, smoked fish and smoked-dried fish obtained with each combination equipment-fuel were grouped into a pool of samples before analysis. A total of 12 pools including 04 of grilled pork, 04 of smoked fish and 04 of smoked-dried fish were analysed. The other 18 samples collected during the second set experiments were analysed individually. PAHs were determined using analytical method described by Kpoclou et al. (2014). Prior for extraction and purification, grilled pork, smoked fish and smoked-dried fish samples were ground with a grinder (Kenwood, Pro 1600, Model MG510, UK) and 75 g of samples were lyophilized for 48 h using a lyophilizer (Freezemobile Virtis, INC. Gardiner, New York). One gram of freeze-dried sample was used for PAH analysis. Samples were extracted with hexan/aceton (50:50, v/v) using an accelerated solvent extraction (ASE 200, Dionex Corporation) and purification was performed using Solid Phase Extraction (SPE) columns cartridges (Chromabond HR-X 6 ml/500 mg) according to the method described by Veyrand et al. (2007). High Performance Liquid Chromatography analysis coupled with Fluorescence Detector (HPLC/FLD) was carried out using a Model 600 E solvent delivery system, equipped with a Model 717 automatic injector, a Mistral TM oven and a 2475 Fluorescence detector (all from Waters, Milford, MA, USA) as described by Brasseur et al. (2007) and Danyi et al. (2009). For each series of injection, seven calibration solutions containing the 15 PAHs in increasing concentrations from 2.5 to 400 pg/μL, except for BjF and IcP (from 10 to 1600 pg/μL) were injected. The calibration curve was used to calculate PAH concentration from the response factor (ratio between both native and injection standard PAHs peak areas). Any concentration below the concentration of the first point of standard curve was not quantifiable. The concentration of the first point of calibration curve was set as limit of quantification (LOQ). The PAH LOQ expressed on fresh weight (based on average of 50 % of moisture) was 0.1 μg/kg, except for IcP and BjF which displayed a LOQ of 0.5 μg/kg fresh weight. The limit of detection (LOD) was the half of LOQ after checking that the signal to noise ratio was higher than 3 at that level. The recovery of PAH compounds in fish and meat samples ranged between 58,9–87,4 % and 60.1–86.0 % respectively. The levels of 15 PAHs out of the 16 defined by European Union (CE, 2002) were determined. The levels of benzo[*a*]pyrène and PAH4 (benzo[*a*]pyrène, chrysène, benzo[*a*]anthracène and benzo[*b*] fluoranthène) were used as main indicators to evaluate the safety of analysed products (EFSA, 2008).

2.5. Sensory analysis of grilled pork, smoked fish and smoked-dried fish from FAQ-charcoal compared to those from traditional processing

Sensory evaluations were performed under fluorescent lighting, in a spaced, well-ventilated room, free of odor and noise, at a temperature of 20 °C with separate boxes for each participant.

As shown in Table 2, six (6) grilled/smoked products of which three (3) from designed and manufactured equipment (FAQ-charcoal) and three (3) from traditional equipment were submitted to sensory evaluation. Each kind of product, produced the same day were evaluated two by two, with two different groups of consumers. The samples of grilled pork from designed and manufactured equipment (GP-DME) and traditional processing (GP-TPE) were presented randomly and

Table 2
Experimental design.

Raw material	Processing equipments	Products
Fresh pork	DME	GP- DME
	TPE	GP-TPE
Fresh *Scomber scombrus*	DME	SF- DME
	TPE	SF-TPE
Fresh *Cypselurus cyanopterus*	DME	SDF- DME
	TPE	SDF-TPE

DME: Designed and manufactured equipment (FAQ and charcoal); TPE: Traditional processing equipment; GP: Grilled pork; SF: Smoked fish (Scomber scombrus); SDF: Smoked-dried fish (Cypselurus cyanopterus)

successively to the first group composed of 75 consumers (58 males and 17 females, age 19–79). In the same way, the second group of consumers (n = 75, 32 males and 43 females, age 18–83) evaluated two samples of smoked *Scomber scombrus* (SF-DME and SF-TPE) and two samples of smoked-dried *Cypselurus cyanopterus* (SDF-DME and SDF-TPE) obtained by designed and manufactured, and traditional processing equipments.

Consumers were asked to evaluate the overall acceptability of each sample and Just-About-Right (JAR) level for the product attributes using the method described by Lawless and Heymann (2010) and Narayanan et al. (2014). The overall acceptability was assessed using a 9-point hedonic scale (1 =“Dislike Extremely” to 9 =“Like Extremely”). For JAR test, panelists rated the same sample on a 5-point JAR scale (1 = much too low, 2 = a little too low, 3 = just about right, 4 = a little too much, and 5 = much too much) for the four different attributes (colour, texture, odour and taste) used. Participants rinsed their mouth with room temperature water between each sample test to reduce potential carry-over effects. After evaluation of samples, consumers were asked to fill a demographic questionnaire.

2.6. Data analysis

Data from this work were analysed in Excel for the determination of descriptive statistics (mean and standard deviation). The one way ANOVA test was performed to compare the averages of technological and thermal performances of improved equipments using R Version 3.5.1 software (R Core Team, 2018). The physico-chemical parameters of samples from the three equipments were also compared using one way ANOVA test. Sensory evaluation data were analysed by penalty analysis combining JAR and overall acceptability tests to relate the decrease in consumer acceptance to attributes not at JAR levels (Lawless and Heymann, 2010; Narayanan et al., 2014). As described by ASTM International (2009), the 5-point JAR scale was firstly reduced to a 3-point scale consisting of 3 levels: “not enough” (by grouping “much too low” and “little too low” responses), JAR, and “too much” (by grouping “little too much”, and “much too much” responses). The levels “not enough” and “too much” belong to the “not-JAR” category. Those attributes that received at least 20 % responses (Pareto principle) in any of the 2 not-JAR categories became a candidate for penalty analysis. For each of the selected attributes, mean decrease in overall acceptability was calculated by subtracting the acceptability values obtained from the hedonic scale of the consumers in the not-JAR category from the JAR category (i.e., mean decrease = JAR linking − not-JAR liking). A 2-sample t-test was conducted between the consumers in the not-JAR and JAR categories to test for significant mean decrease in liking difference ($p < 0.1$). Penalty value was calculated for those attributes that received significant mean decreases in liking through the 2-sample t-test, using the following formula:

$$\text{Penalty} = \%\ \text{not-JAR} \times \text{mean decrease in overall acceptability},$$

where, % not-JAR = percentage of consumers that indicated either too much or not enough for the attribute on the JAR scale. For penalty analysis, results from both sensory analysis tests were analyzed for significant differences using a 2-sample t-test ($p < 0.10$) in XLSTAT 2010 software (Addinsoft, New York, NY).

3. Results and discussion

3.1. Technological performances of designed, manufactured and improved equipments

3.1.1. Case of pork grilling

QUALISANI equipment (FAQ) and improved clay grill with two chambers (GA2C) were experimented for grilling pork process. The technological performances of this two equipments are showed in Table 3. The load capacity of FAQ (14.9 ± 2 kg) is significantly ($p < 0.05$) higher than that of GA2C (9.7 ± 0.9 kg). These two values are 3–4 times higher than that obtained by Assogba et al. (2020) for traditional barrel grill (3.8 ± 0.9 kg) and traditional clay grill with two chambers (4.8 ± 0.7 kg). The highest quantities of fresh pork processed per time (QFPPPUT) are obtained when FAQ is used either with charcoal or wood as fuel (Table 3). The value of fresh pork processed per time for FAQ-charcoal (0.34 ± 0.06 kg/min) is three times higher than that of GA2C used with charcoal (0.11 ± 0.00 kg/min) and wood (0.08 ± 0.01 kg/min). On the other hand, the quantity of fresh pork processed per time for GA2C-wood and GA2C-charcoal were not significantly different ($p > 0.05$) to those reported by Assogba et al. (2020) for traditional barrel grill used with wood (0.09 ± 0.02 kg/min) and for traditional clay grill with two chambers used with wood (0.10 ± 0.02 kg/min). It was noticed that the quantity of fresh pork processed per time for GA2C used either with wood or charcoal was significantly similar ($p > 0.05$) to those obtained with traditional equipments used with wood. In addition, the grilling duration with FAQ-charcoal (40 ± 0 min) was significantly ($p < 0.05$) lower than those of other equipments-fuel which ranged between 73 and 117 min (Table 3). Thus, the use of FAQ-charcoal could be recommended to grilled pork processors who will be able to produce high quantity of product in few times with the possibility to serve more consumers and therefore increase their daily income.

The specific consumption of fuel (SCF) of FAQ (1.13 ± 0.17 kg of wood/kg fresh pork) was significantly ($p < 0.05$) lower than those reported by Assogba et al. (2020) for traditional barrel grill (1.74 ± 0.15 kg/kg) and traditional clay grill with two chambers (2.10 ± 0.35 kg/kg). The SCF of improved grill with two chambers (GA2C) (1.83 ± 0.21 kg/kg) was also lower than that of traditional clay grill with two chambers. These results showed that the quantity of wood used with FAQ was the lowest compared to those of GA2C and the traditional grills (barrel grill and clay grill with two chambers). The SCF of charcoal

Table 3
Technological performances of designed and manufactured (FAQ) and improved (GA2C) equipments.

Technological parameters	Combination equipment-fuel			
	FAQ Wood (n = 3)	FAQ Charcoal (n = 3)	GA2C Wood (n = 3)	GA2C Charcoal (n = 3)
LC (kg)	14.9 ± 2.0a[a]		9.7 ± 0.9b	
Duration (min)	73 ± 6c	40 ± 0d	117 ± 6a	90 ± 6b
QFPPUT (kg/min)	0.22 ± 0.02b	0.34 ± 0.06a	0.08 ± 0.01c	0.11 ± 0.00c
QF (kg)	18.3 ± 2.9a	10.0 ± 0.0b	17.7 ± 2.5a	11.7 ± 2.9b
SCF (kg/kg)	1.13 ± 0.17a	0.74 ± 0.12a	1.83 ± 0.21b	1.20 ± 0.35b

[a] Values with different letters in the same row are significantly different at the α threshold of 5 %. FAQ: QUALISANI equipment; GA2C: Improved grill with two chambers; LC: Load capacity (kg); QFPPPUT: Quantity of fresh pork processed per unit time (kg of fresh product/minute); QF: Quantity of fuel (kg); SCF: Specific consumption of fuel (kg of fuel/kg of fresh product); n: Number of trials.

by FAQ (0.74 ± 0.12 kg charcoal/kg of pork) was significantly lower than that of GA2C (1.20 ± 0.35 kg/kg). FAQ is then known as beneficial grill because it provided economy to processors in term of fuel purchased.

3.1.2. Case of smoking and smoking-drying of fish

Table 4 showed the technological performances of QUALISANI equipement (FAQ) and modified barrel kiln (FBM) used in combination with wood and charcoal for smoking and smoking-drying of fish. The load capacity (kg of fish) of FAQ was not significantly different ($p > 0.05$) to that of FBM. Likewise, the four combinations equipment-fuels did not show significant difference ($p > 0.05$) related to the duration of smoking-drying process. This could explain perfectly the fact that the quantity of fresh fish processed per unit of time (QFFPPUT) did not change significantly ($p > 0.05$) from one combination equipment-fuel to another. The QFFPPUT of improved equipments (0.09–0.10 kg/min) was the double of the QFFPPUT (0.04 kg/min) for traditional barrel kiln (Assogba et al., 2021b). Therefore, the improved equipments compared to traditional barrel kiln, allow to process high quantity of fresh fish in short time. During smoking-drying of fish with charcoal, no significant difference was observed between the specific consumption of fuel (SCF) of the two improved equipments. On the other hand, when wood is used as fuel, the SCF of FAQ (0.69 ± 0.06 kg/kg) was significantly lower than that of FBM (0.87 ± 0.03 kg/kg). Meanwhile, the SCF in wood of the two improved equipments were significantly lower than the value of 0.93 ± 0.29 kg/kg obtained for traditional barrel kiln (Assogba et al., 2021b). It can be assumed that the two improved equipments evaluated could provide enough economic to processors because of the low quantity of fuel needed for fish processing.

3.2. Thermal performances of improved equipments

3.2.1. Case of pork grilling

The change of temperature in combustion chamber (TCC), grilling chamber (TGC) and at the core of product (TCP) during the grilling process with FAQ and GA2C are showed in Fig. 4. When FAQ is used with charcoal, the temperature in combustion chamber increased significantly from 715.7 ± 27.5 °C to 894.5 ± 45.3 °C between 15 and 45 min of grilling before falling to 780.0 ± 24.1 °C at the end of grilling (55 min) (Fig. 4a). The increase of temperature in combustion chamber was also oberved when FAQ is used with wood. It increased from 398.2 ± 44.1 °C to 678.8 ± 31.0 °C between 15 and 55 min before decreasing to 467.5 ± 112.0 °C after 85 min of grilling (Fig. 4a). As shown in Fig. 4b, the temperature in combustion chamber (TCC) of GA2C also evoluated in two main phases during grilling when charcoal is used as

Table 4
Technological performances of improved equipments during trials of smoking-drying of fish.

Technological parameters	Combination equipment-fuel			
	FAQ Wood (n = 3)	FAQ Charcoal (n = 3)	FBM Wood (n = 3)	FBM Charcoal (n = 3)
LC (kg)	29.2 ± 2.0a[a]		30.6 ± 2.1a	
Duration (mn)	310 ± 17a	320 ± 17a	330 ± 0a	310 ± 17a
QFFPPUT (kg/mn)	0.09 ± 0.00a	0.09 ± 0.01a	0.09 ± 0.01a	0.10 ± 0.00a
QF (kg)	20.0 ± 0.0b	16.3 ± 1.2a	26.3 ± 1.2c	17.3 ± 2.5ab
SCF (kg/kg)	0.69 ± 0.06b	0.55 ± 0.02a	0.87 ± 0.03c	0.56 ± 0.05a

[a] Values with different letters in the same row are significantly different at the α threshold of 5 %. FAQ: QUALISANI equipment; FBM: Modified barrel kiln; LC: Load capacity (kg); QFFPPUT: Quantity of fresh product per unit time (kg of fresh product/minute); QF: Quantity of fuel (kg); SCF: Specific consumption of fuel (kg of fuel/kg of fresh product); n: Number of trials.

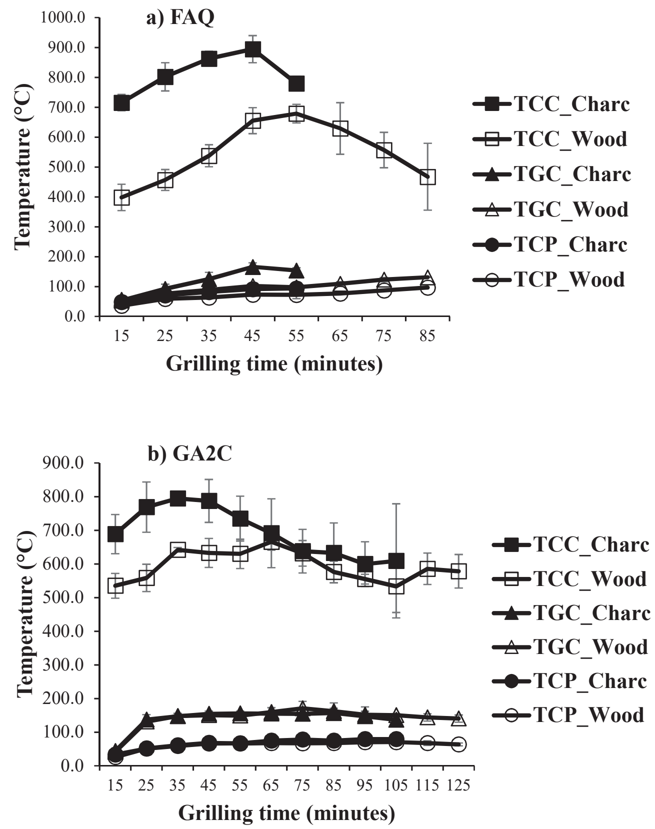

Fig. 4. Change of temperature in combustion chamber (TCC), in grilling chamber (TGC) and at the core of the product (TCP) during pork grilling using FAQ (a) and GA2C (b) as equipments, and charcoal and wood as fuels.

fuel. The TCC (GA2C-charcoal) varied between 688.5 ± 58.3 °C and 794.5 ± 20.7 °C from 15 to 35 min of grilling. Then, it decreased slowly and reached the value of 609.0 ± 169.7 °C after 90 min of grilling (t = 105 min). As regards the grilling with GA2C and wood, the temperature in combustion chamber changed discontinously between 533.2 ± 77.6 °C and 665.7 ± 25 °C during all the time of grilling. These changes of temperature observed in combustion chamber of each equipment induced heat transfer to the grilling chamber and at the core of the product. Indeed, the temperature recorded at the core of the product (TCP) varied between 49.1 ± 3.9 and 93.9 ± 13.4 °C for FAQ-charcoal; 36.1 ± 2.7 and 96.6 ± 9.0 °C for FAQ-wood; 33.6 ± 5.6 and 79.3 ± 7.1 °C for GA2C-charcoal and finaly 25.9 ± 1.5 and 70.3 ± 5.6 °C for GA2C-wood (Fig. 4a and b). During all the grilling time, the average value of temperature recorded in the combustion chamber of FAQ used with charcoal (811.1 ± 14.2 °C) is significantly ($p < 0.05$) higher than those obtained for the other combinations equipment-fuel. The same combination (FAQ-charcoal) presented the highest average value of temperature at the product core (77.5 ± 3.8 °C). These results showed that FAQ-charcoal is very power than other equipment-fuel in term of heat production and heat transfer to the product.

3.2.2. Case of smoking-drying of fish

Fig. 5 showed the change of temperature during smoking-drying of fish using FAQ and FBM as equipments. The temperature in combustion chamber of the two equipments used either with wood or charcoal oscillated discontinuously from the beginning to the end of the process. This discontinuous change of temperature could be explained by the fact that the fuel was added at different range time to increase heat intensity. When FAQ is used with charcoal, the temperature in combustion chamber oscillated between 382.4 ± 49.3 °C and 936.1 ± 34.8 °C while that recorded for FAQ-wood varied between 450.9 ± 18.5 °C and 629.5

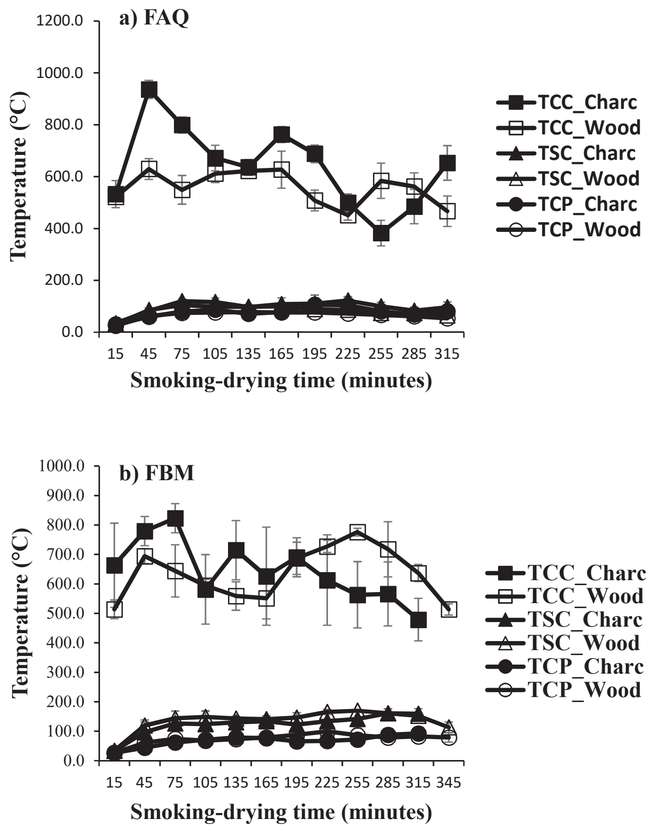

Fig. 5. Change of temperature in combustion chamber (TCC), in smoking chamber (TSC) and at the core of the product (TCP) during smoking-drying of fish using FAQ (a) and FBM (b) as equipments, and charcoal and wood as fuels.

± 39.8 °C (Fig. 5a). As concerned FBM, the temperature in combustion chamber changed between 478.8 ± 72 °C and 822.9 ± 49.4 °C when charcoal is used as fuel while that of FBM-wood oscillated between 513.5 ± 19.3 °C and 775.8 ± 12.9 °C (Fig. 5b). The temperatures in combustion chamber (TCC) of the two equipments used with charcoal are above the TCC obtained when these equipments are used with wood from 15 to 225 min for FAQ (Fig. 5a) and 15–195 min for FBM (Fig. 5b). The average value of TCC obtained for FAQ-charcoal (625.6 ± 10.3 °C) during all time of smoking-drying is significantly higher than that of FAQ-wood (550.9 ± 22.6 °C). No significant different was obtained between FAQ-charcoal and FBM-charcoal for the average value of TCC during all time of smoking-drying process. But, the average temperature in smoking chamber of FBM (136.5 ± 6.3 °C with wood and 123.9 ± 15.7 °C with charcoal) were significantly higher than those obtained for FAQ (81.8 ± 4.8 °C with wood and 96.5 ± 2.1 °C with charcoal). Therefore, heat transfer from the combustion chamber to the smoking chamber of FBM is better than that of FAQ. Nevertheless, the average value of the temperature at the core of the product (TCP) with FAQ-charcoal (76.4 ± 2.8 °C) was significantly higher than that of FBM-charcoal (68.2 ± 4.2 °C). This opposite difference of TCP in the two equipments showed that the heat transfer from smoking chamber to the core of the product could be affected by others factors such as the heat dissipation or it concentration depending on the design and the functioning mode of the equipment. On the over hand, the average TCP of FBM was significantly higher than that of FAQ when the two equipments are used with wood as fuel showing that the thermal performances of the two equipments changed according to the type of fuel used for smoking-drying process.

3.3. Effects of equipment and fuel on physical characteristics of end-products

3.3.1. Case of grilled pork

The moisture content of grilled pork samples from the four combinations equipment-fuel are varied between 43.2 ± 0.6 % and 49 ± 0.9 % (Table 5). These values are similar to the average moisture content obtained by Iko Afe et al. (2020b) in grilled pork collected from different processors (47.3 ± 5.7 %). There are also similar to the moisture content in grilled pork from traditional direct grilling process (46.8 ± 3.2 %) and grilled pork from traditional indirect grilling process (43.9 ± 7.1 %) (Assogba et al., 2020). It is suitable to notify that the moisture content of grilled pork from FAQ-charcoal is significantly ($p < 0.05$) lower than those of grilled pork samples obtained from the three other combination equipment-fuels.

The water activity (a_w) of grilled pork samples obtained from the four combinations equipment-fuels ranged between 0.94 ± 0.01 and 0.95 ± 0.01 without significant difference (Table 5). These high values of water activity approximately closed to 1 could be explained by the high water content of grilled pork. The logic consequence is that the grilled pork in this state could not be preserved in ambient temperature. It is the reason why the grilled pork is consumed within the day of it production.

As concerned colour parameters, only the red index (a*) changed significantly in the grilled pork samples according to the type of equipments and the high value was obtained when GA2C was used with charcoal. Nevertheless, the saturation index (C*) which indicated the colour intensity did not changed significantly nor from one equipment to another, nor from one fuel to another and this supposed that the type of equipment and fuel did not have effect on the colour saturation index of grilled pork.

3.3.2. Case of smoked and smoked-dried fish

The physical properties of smoked and smoked-dried fishes obtained from designed and manufactured equipments are shown in Table 6. The moisture contents in smoked-dried fish from the four combinations equipment-fuels ranging between 17.9 ± 2.2 and 24.2 ± 2.6 % are significantly lower than those of smoked fish which varied between 42.4 ± 1.4 and 44.1 ± 1.4 %. The lowest value of moisture content in smoked-dried fish was obtained with FAQ-charcoal (17.9 ± 2.2 %). Although this moisture content is lower, it remains very high than the limited value of 10 % authorized by FAO (2003) to prevent pathogenic bacteria development. Nevertheless, this moisture content is significantly lower than that of 20.2 ± 6.1 % reported by Iko Afe et al. (2020c) for smoked-dried fish obtained with traditional equipment. Even if FAQ-charcoal reduces significantly the moisture content in smoked-dried fish, it will be appropriate to increase the drying time in order to reach the limited value which can assure the preservation of smoked-dried fish with advantage for increasing its shelf life. As concerned moisture content of smoked fish, there is no significant difference between FAQ and FBM on the one hand, and between charcoal and wood on the other hand.

The water activity of smoked fish (*Cypselurus cyanopterus*) ranged between 0.89 ± 0.01 and 0.91 ± 0.01 without significant change between the four combinations equipment-fuels (Table 7.8). The values of water activity of smoked-dried fish from the four combinations equipment-fuels (0.71 ± 0.01–0.82 ± 0.01) are significantly ($p < 0.05$) lowers than those obtained for smoked fish certainly due to the significant water reduction in smoked-dried fish. It is important to point out that only FAQ used with charcoal allowed to obtain water activity lower than 0.75, value from which pathogenic bacteria development could be stopped (FAO, 2003).

The colour parameters (L*, a*, b* et C*) of smoked and smoked-dried fish changed significantly between equipments and fuels with exception for FAQ which colour parameter of smoked fish did not change between wood and charcoal. The saturation index of smoked fish is significantly

Table 5
Physical characteristics of grilled pork samples from improved equipments.

		Combination equipment-fuel			
		FAQ	FAQ	GA2C	GA2C
Physical characteristics		Charcoal (n = 3)	Wood (n = 3)	Charcoal (n = 3)	Wood (n = 3)
Moisture content (%)		43.2 ± 0.6a* *	47.9 ± 1.8b	48.5 ± 0.1b	49 ± 0.9b
Water activity		0.95 ± 0.01a	0.94 ± 0.01a	0.95 ± 0.01a	0.95 ± 0.01a
Colour	L*	54.7 ± 2.7a	51.3 ± 1.3a	50.1 ± 3.1a	52 ± 4.4a
	a*	1.8 ± 0.3a	1.4 ± 0.5a	4.8 ± 0.6c	3.2 ± 0.1b
	b*	12.0 ± 0.6a	10.5 ± 0.7a	12.1 ± 0.6a	10.6 ± 1.9a
	C*	12.2 ± 0.6a	10.6 ± 0.7a	13.0 ± 0.7a	11.1 ± 1.8a

**Values with different letters in the same row are significantly different at the α threshold of 5 %. FAQ: QUALISANI equipment; GA2C: Improved grill with two chambers; L* : Light index; a* : Red index; b* : Yellow index; c* : Saturation index; n: Number of trials.

Table 6
Physical characteristics of smoked and smoked-dried fish obtained with improved equipments.

Products		Smoked fish				Smoked-dried fish			
Equipments		FAQ	FAQ	FBM	FBM	FAQ	FAQ	FBM	FBM
Fuels		Charcoal (n = 3)	Wood (n = 3)	Charcoal (n = 3)	Wood (n = 3)	Charcoal (n = 3)	Wood (n = 3)	Charcoal (n = 3)	Wood (n = 3)
Water content (%)		42.4 ± 1.4a**	42.6 ± 0.8a	44.1 ± 1.4a	42.8 ± 0.6a	17.9 ± 2.2c	24.2 ± 2.6b	23.6 ± 1.3b	22.9 ± 0.1b
Water activity		0.91 ± 0.01a	0.90 ± 0.00a	0.89 ± 0.01a	0.91 ± 0.01a	0.71 ± 0.01b	0.74 ± 0.01bc	0.76 ± 0.05c	0.82 ± 0.01d
Colour	L*	54.7 ± 1.8abc	55.7 ± 1.1abc	57.7 ± 2.8a	51.5 ± 2.7b	56.8 ± 1.3ac	55.6 ± 0.6abc	57.4 ± 1.6a	52.4 ± 1.1bc
	a*	0.4 ± 0.2a	0.3 ± 0.2a	0.8 ± 0.8ab	0.2 ± 0.2a	1.6 ± 0.2bc	0.7 ± 0.3a	2.3 ± 0.7c	1.7 ± 0.1bc
	b*	9.1 ± 0.6ab	8.3 ± 1.1ab	10.5 ± 2.3b	7.0 ± 1.6a	11.3 ± 0.5b	9.4 ± 0.4ab	13.2 ± 1.6c	10.0 ± 0.4ab
	C*	9.1 ± 0.6ab	8.3 ± 1.1ab	10.5 ± 2.4b	7.0 ± 1.6a	11.4 ± 0.5bc	9.4 ± 0.4ab	13.4 ± 1.7c	10.2 ± 0.3b

**Values with different letters in the same row are significantly different at the α threshold of 5 %. FAQ: QUALISANI equipment; FBM: Modified barrel kiln; L* : Light index; a* : Red index; b* : Yellow index; c* : Saturation index; n: Number of trials.

marked when FBM is used with charcoal (10.5 ± 2.4). The saturation index is also very marked for smoked-dried fish obtained from FBM-charcoal (13.4 ± 1.7). Only sensory profiling of smoked and smoked-dried fish could help to determine the ideal value of colour parameters which encountered processors and consumers' expectations.

3.4. *Effects of different combinations equipment-fuel on the level of PAHs in grilled pork, smoked and smoked-dried fish*

The levels of PAHs (μg/kg wet weight) in different pools of samples obtained from the first set of experiments including different combinations equipment-fuel were summarized in Table 7. Even if 15 PAHs concentrations were determined for each category of product, only the levels of BaP and PAH4 are discussed as they are considered as PAHs markers by EFSA (2008). The results showed that the concentrations of BaP in the pools P4 (11.9 μg/kg) and P6 (116 μg/Kg) of grilled pork samples obtained with the combination FAQ-wood-filter and GA2C-wood-filter were not only higher than those of the pools P5 (2.5 μg/kg) and P7 (5.1 μg/kg) from FAQ-charcoal-filter and GA2C-charcoal-filter, but they also exceeded 06 and 58 times the maximal limit values of 2 μg/kg (BaP) fixed by European Commission (EU, 2023) respectively. In addition, the concentration of PAH4 (757 μg/Kg) of the pool P6 of grilled pork obtained from GA2C-wood-filter was not only higher than that of the pool P7

Table 7
Average contents of PAHs (μg/Kg fresh weight) in the pools of samples.

PAHs	Grilled pork				Smoked fish				Smoked-dried fish			
	FAQ	FAQ	GA2C	GA2C	FAQ	FAQ	FBM	FBM	FAQ	FAQ	FBM	FBM
	Wood P4	Charc P5	Wood P6	Charc P7	Wood P10	Charc P11	Wood P14	Charc P15	Wood P12	Charc P13	Wood P16	Charc P17
BbF	12.7	4.3	74.0	5.5	0.3	0.3	32.7	1.3	0.4	0.9	38.5	3.5
DlP	<LOQ	<LOQ	2.9	<LOQ	<LOQ	<LOQ	0.6	<LOQ	<LOQ	<LOQ	0.9	<LOQ
DhA	0.4	<LOQ	7.7	<LOQ	<LOQ	<LOQ	2.1	<LOQ	<LOQ	<LOQ	3.5	0.3
BgP	8.1	1.9	64.1	2.5	0.2	0.2	34.5	1.1	0.2	0.4	48.4	3.3
DeP	0.6	0.9	5.9	1.6	<LOQ	<LOQ	1.7	0.2	<LOQ	<LOQ	2.3	2.2
BjF	10.2	2.7	55.4	3.7	0.2	0.3	25.1	1.0	0.2	0.4	28.6	2.0
BcL	19.5	21.1	173	32.0	1.2	2.3	17.6	3.9	3.6	1.9	14.3	4.0
BaA	<LOQ	10.9	259	22.8	0.6	1.2	56.7	2.5	1.3	1.3	46.8	4.5
CHR	<LOQ	23.1	308	30.6	0.9	2.1	68.4	3.9	1.9	2.0	57.1	6.7
5MC	<LOQ	<LOQ	1.9	<LOQ	<LOQ	<LOQ	0.2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
BkF	5.9	1.3	40.4	1.7	<LOQ	<LOQ	18.1	0.5	<LOQ	0.2	20.2	1.1
BaP	**11.9**	**2.5**	**116**	**5.1**	**0.2**	**0.3**	**36.3**	**1.1**	**0.3**	**0.5**	**52.4**	**2.8**
IcP	4.3	0.5	34.8	1.1	0.2	0.2	18.8	0.8	0.3	0.5	28.3	1.9
DiP	<LOQ	<LOQ	4.5	1.0	<LOQ	<LOQ	2.1	0.7	<LOQ	<LOQ	2.9	1.1
DhP	<LOQ	<LOQ	0.6	0.4	<LOQ	<LOQ	0.2	0.3	<LOQ	<LOQ	0.6	0.4
PAH4	**24.6**	**41.3**	**757**	**63.9**	**2.0**	**4.0**	**194**	**8.8**	**3.9**	**4.8**	**195**	**17.5**

PAH: Polycyclic Aromatic Hydrocarbons; Charc: Charcoal; FAQ: QUALISANI equipment; GA2C: Improved grill with two chambers; FBM: Modified barrel kiln; P4, P5, P6, P7, P10, P11, P12, P13, P14, P15, P16 and P17 are each one a pool of three samples from the same combination equipment-fuel. The limit of quantification (LOQ) of PAH expressed on fresh weight (based on average of 50 % of moisture) was 0.1 μg/kg, except for IcP and BjF which displayed a LOQ of 0.5 μg/kg fresh weight.

(63.9 μg/Kg) of grilled pork obtained with GA2C-charcoal-filter, but it also exceeded 63 times the limit values of 12 μg/kg (PAH4) fixed by European Commission (EU, 2023). PAH contamination from wood is so worse than that from charcoal because of the excessive smoke produced by wood combustion, which smoke contains toxic compounds including PAHs. Thus, the use of wood as fuel for grilling with the two equipements (FAQ and GA2C) in the presence of granite filter did not allow to obtain grilled pork in compliance with standards, compared to the grilled pork samples from FAQ-charcoal-filter and GA2C-charcoal-filter which concentrations in BaP (2.5 μg/kg and 5.1 μg/kg) were in compliance with the maximal limit of 5 μg/Kg authorized by beninese regulation (Arrêté 2007 N° 0362/MAEP/Bénin). FAQ used with charcoal reduced significantly the levels of PAHs in grilled pork than GA2C. The levels of BaP and PAH4 decreased respectively from 29 ± 18 μg/Kg and 162 ± 87 μg/Kg in grilled pork obtained with traditional barrel grill (Iko Afé et al., 2020a) to 2.5 μg/Kg and 41.3 μg/Kg in grilled pork obtained from FAQ-charcoal-filter, corresponding to the reducing percentages of 95.5 % and 74.5 % for BaP and PAH4 respectively. In the same way, the levels of BaP and PAH4 decreased from 17 ± 11 μg/Kg and 107 ± 46 μg/Kg respectively in grilled pork obtained with traditional clay grill (Iko Afé et al., 2020a) to 2.5 μg/Kg and 41.3 μg/Kg in grilled pork obtained from FAQ-charcoal-filter, corresponding to reducing percentages of 92.8 % and 61.3 % for BaP and PAH4 respectively.

The results also showed that the concentrations of BaP and PAH4 in smoked fish (36.3 μg/Kg and 194 μg/Kg) and smoked-dried fish (52.4 μg/Kg and 195 μg/Kg) obtained with the combination FBM-wood-filter (P14 and P16) were higher than those obtained with the other combinations equipement-fuel, and exceeded 18–26 times and 16 times the maximal limit values of 2 μg/Kg (BaP) and 12 μg/Kg (PAH4) fixed by European Commission (EU, 2023) respectively. Thus, the use of wood as fuel for smoking and smoking-drying of fish with FBM did not allow to obtain smoked and smoked-dried fishes in compliance with standards. Smoked fish obtained from FAQ-wood (P10), FAQ-charcoal (P11) and FBM-charcoal (P15) had concentration in BaP (0.2; 0.3 and 1.1 μg/Kg) and PAH4 (2; 4 and 8.8 μg/Kg) significantly lower than the maximal limited values of 2 μg/Kg (BaP) and 12 μg/Kg (PAH4) admitted by European Commission (Table 7). The similar results were obtained for smoked-dried fish from FAQ-wood (P12) and FAQ-charcoal (P13) which concentrations in BaP (0.3 and 0.5 μg/Kg) and PAH4 (3.9 and 4.8 μg/Kg) are in compliance with European Commission (EU, 2023) and the regulation of Benin (Arrêté 2007 N° 0362/MAEP, Benin). It is also observed that smoked-dried fish from FBM-charcoal (P17) had concentration in BaP (2.8 μg/Kg) lower than the limit of 5 μg/Kg fixed by Benin regulation even if its concentration in PAH4 was not in compliance. The reducing percentage of BaP level in smoked fish when FAQ is used either with wood or charcoal is estimated to 98.7–99.1 % because BaP level decreased from 23 ± 19 μg/kg in smoked fish from traditional barrel kiln (Assogba, 2020) to 0.2 and 0.3 μg/kg in smoked fish from FAQ used with wood and charcoal. The reducing percentage of PAH4 in smoked fish from traditional barrel kiln to FAQ used with wood and charcoal is also evaluated to 95.5–97.8 % because the level of PAH4 decreased from 90.1 ± 3.6 μg/kg in smoked fish from traditional barrel kiln (Assogba et al., 2021b) to 2 and 4 μg/kg in smoked fish from FAQ used with wood and charcoal. FAQ used with wood and charcoal also lead to significant reduction of PAHs levels in smoked-dried fish with the levels of BaP and PAH4 which decreased from 31 ± 16 μg/kg in smoked-dried fish from traditional barrel kiln (Assogba et al., 2021b) to 0.3 μg/kg and 0.5 μg/kg for BaP, and 154 ± 86 μg/kg to 3.9 μg/kg and 4.8 μg/kg for PAH4. The reducing percentages in this case are evaluated to 98.3–99.0 % (BaP) and 96.9–97.5 % (PAH4). These results showed that FAQ out from the three evaluated equipments contributed to better reduction of product contamination by PAHs with the values of BaP and PAH4 which are in compliance with European Commission (EU, 2023) and the regulation of Benin (Arrêté 2007 N° 0362/MAEP, Benin).

3.5. *Effect of granite filter on concentration of PAHs in grilled pork, smoked fish and smoked-dried fish produced using FAQ and charcoal*

After identification of the best combination equipment-fuel which showed the best performance and also reduced significantly the levels of PAHs in grilled pork and smoked and smoked-dried fishes, the second set of experiments was performed to know if the use of granite filter influenced the levels of PAHs in end-products. The mean levels of PAHs (μg/Kg wet weight) in different samples (grilled pork, smoked fish and smoked-dried fish) obtained from this second set of experiments including two combinations (FAQ-charcoal-filter and FAQ-charcoal-No filter) were showed in Table 8. When the combination FAQ-charcoal was used without granite filter, the levels of PAHs in the grilled pork sample obtained were not significantly different ($p > 0.05$) to those of grilled pork obtained with FAQ-charcoal in presence of granite filter even if the lowest values of BaP (0.2 ± 0.1 μg/Kg) and PAH4 (2.4 ± 1.5 μg/Kg) were obtained for grilled pork from FAQ-charcoal without filter. These levels of BaP and PAH4 in grilled pork from FAQ-charcoal without filter are lower than the maximal values of 29 ± 18 μg/Kg (BaP) and 162 ± 87 μg/Kg (PAH4) for grilled pork from traditional barrel grill, and 17 ± 11 μg/Kg (BaP) and 107 ± 46 μg/Kg for the grilled pork from traditional clay grill with two chambers as reported by Iko Afé et al. (2020a). Indeed, the substitution of the traditional barrel grill by FAQ-charcoal without filter induced the reducing percentages of the levels of BaP and PAH4 in grilled pork estimated to 99.3 % and 98.5 % respectively. In the same way, the use of FAQ-charcoal without filter

Table 8
Effect of granite filter on concentration of PAHs in grilled pork smoked fish and smoked-dried fish samples.

PAHs	Grilled pork (μg/kg)		Smoked fish (μg/kg)		Smoked-dried fish (μg/kg)	
	FAQ (n = 3) Charc Filter	FAQ (n = 3) Charc No filter	FAQ (n = 3) Charc Filter	FAQ (n = 3) Charc No filter	FAQ (n = 3) Charc Filter	FAQ (n = 3) Charc No filter
BbF	2.9 ± 2.0	0.3 ± 0.2	<LOQ	<LOQ	0.5 ± 0.4	0.3 ± 0.2
DlP	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DhA	0.2 ± 0.1	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
BgP	1.1 ± 1.0	0.3 ± 0.2	<LOQ	<LOQ	0.3 ± 0.2	0.3 ± 0.1
DeP	0.3 ± 0.2	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
BjF	2.1 ± 1.4	0.3 ± 0.2	<LOQ	<LOQ	0.4 ± 0.3	<LOQ
BcL	12.8 ± 6.0	2.2 ± 2.4	0.4 ± 0.2	0.2 ± 0.1	1.2 ± 0.7	0.3 ± 0.1
BaA	5.8 ± 3.8	0.6 ± 0.4	<LOQ	<LOQ	0.8 ± 0.7	0.2 ± 0.1
CHR	10.1 ± 7.0	1.3 ± 0.8	0.4 ± 0.1	<LOQ	1.3 ± 0.8	0.3 ± 0.2
5MC	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
BkF	1.0 ± 0.9	<LOQ	<LOQ	<LOQ	0.2 ± 0.1	<LOQ
BaP	**1.9 ± 2.1a**	**0.2 ± 0.1a**	**<LOQa**	**<LOQa**	**0.3 ± 0.2a**	**0.1 ± 0.1a**
IcP	0.9 ± 0.8	<LOQ	<LOQ	<LOQ	0.2 ± 0.2	<LOQ
DiP	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DhP	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
PAH4	**21 ± 13a**	**2.4 ± 1.5a**	**0.7 ± 0.2a**	**0.4 ± 0.0a**	**2.9 ± 2.0a**	**0.8 ± 0.3a**

Values with different letters in the same row (BaP and PAH4) for each category of product are significantly different ($p < 0.05$); PAH: Polycyclic Aromatic Hydrocarbons; Charc: Charcoal; n: number of replicates; FAQ: QUALISANI equipment; GA2C: Improved grill with two chambers; FBM: Modified barrel kiln; The limit of quantification (LOQ) of PAH expressed on fresh weight (based on average of 50 % of moisture) was 0.1 μg/kg, except for IcP and BjF which displayed a LOQ of 0.5 μg/kg fresh weight instead the traditional clay grill with two chambers also induced the reducing percentages of the levels of BaP and PAH4 in grilled pork evaluated to 98.8 % and 97.7 % respectively. Furthermore, the concentrations of PAHs in grilled pork from FAQ-charcoal without filter (0.2 ± 0.1 μg/kg for BaP and 2.4 ± 1.5 μg/kg for PAH4) were 145 times and 68 times lower than the maximal concentrations (29 ± 18 μg/Kg for BaP and 162 ± 87 μg/Kg for PAH4) in grilled pork from traditional equipments (Iko Afé et al., 2020a). The same concentrations of BaP and PAH4 in grilled pork from FAQ-charcoal without filter are 10 times and 05 times lower than the maximal limit values of BaP (2 μg/Kg) and PAH4 (12 μg/Kg) fixed by European Commission respectively.

All the samples of smoked fish and smoked-dried fish obtained with FAQ-charcoal-Filter and FAQ-charcoal-No filter had ranges of concentrations in BaP (0.1 ± 0.0–0.3 ± 0.2 μg/Kg) and PAH4 (0.4 ± 0.0–2.9 ± 2.0 μg/Kg) significantly lower than the maximal limited values of 2 μg/Kg (BaP) and 12 μg/Kg (PAH4) admitted by European Commission, and 5 μg/Kg (BaP) fixed by regulation of Benin (Arrêté 2007 N° 0362/MAEP, Benin). Similarly to grilled pork, when the combination FAQ-charcoal is used without granite filter, the levels of BaP (0.1 ± 0.0 μg/Kg) and PAH4 (0.4 ± 0.0 μg/Kg) in the smoked fish sample obtained were not significantly different ($p > 0.05$) to the levels of BaP (0.1 ± 0.0 μg/Kg) and PAH4 (0.7 ± 0.2 μg/Kg) in smoked fish obtained with FAQ-charcoal in presence of granite filter. In the same way, no significant difference was found in the levels of BaP and PAH4 of the smoked-dried fish samples obtained with FAQ-charcoal filter and FAQ-charcoal-No filter. The combination equipment-fuel inducing the lowest levels of PAHs in smoked fish and smoked-dried fish is FAQ-charcoal used either with filter or without filter. Indeed, the mean values of BaP and PAH4 in smoked fish obtained with the traditional barrel kiln were 23 ± 19 μg/Kg and 90 ± 93 μg/Kg respectively, while the mean values of BaP and PAH4 in smoked-dried fish from the same device were evaluated to 31 ± 16 μg/Kg and 154 ± 86 μg/Kg respectively (Assogba et al. 2021b). The reducing percentage of the levels of BaP and PAH4 in smoked fish when FAQ-charcoal is used either with filter or without filter instead the traditional barrel kiln are estimated to 99.6 % and 99.6 % for BaP and PAH4 which decreased significantly from 23 ± 19 μg/kg to 0.1 ± 0.0 μg/kg and 90 ± 93 μg/kg to 0.4 ± 0.0 μg/kg respectively. Furthermore, the levels of BaP and PAH4 in smoked fish when FAQ-charcoal is used either with filter or without filter are 230 and 225 times lower than those of smoked fish obtained from the traditional barrel kiln respectively. In the case of smoked-dried fish, the reducing percentages induced by the use of FAQ-charcoal with filter or without filter compared to the traditional barrel kiln are estimated to 99.6 % for BaP and 99.5 % for PAH4 which decreased significantly from 31 ± 16 μg/kg to 0.1 ± 0.1 μg/kg, and 154 ± 86 μg/kg to 0.8 ± 0.3 μg/kg respectively. Thus, the levels of BaP and PAH4 in smoked-dried fish when FAQ-charcoal is used either with filter or without filter are 309 and 192 times lower than those of smoked-dried fish obtained from the traditional barrel kiln respectively.

The levels of BaP (0.1 ± 0.0 μg/kg) and PAH4 (0.4 ± 0.0–0.7 ± 0.2 μg/kg) in smoked fish obtained from FAQ-charcoal used with or without filter are lower than those obtained in smoked-soft *Sardinella sp.* (0.2 ± 0.0 μg/kg for BaP and 1.5 ± 0.2 μg/kg for PAH4) and smoked-soft *Sphyraena sp.* (0.6 ± 0.2 μg/kg for BaP and 3.6 ± 0.9 μg/kg for PAH4) when smoking process was done using FAO-Thiaroye Technique (FTT) kiln with charcoal as fuel (Bomfeh et al., 2019). The mean concentrations of BaP (0.1 ± 0.1–0.3 ± 0.2 μg/kg) and PAH4 (0.8 ± 0.3–2.9 ± 2.0 μg/kg) in smoked-dried fish obtained with FAQ-charcoal used with or without filter were also significantly lower than those of 1.8 ± 1.0 μg/kg (BaP) and 7.6 ± 3.0 μg/kg (PAH4) obtained in smoked-dry *Sphyraena sp.* processed using FAO-Thiaroye Technique (FTT) kiln with charcoal (Bomfeh et al., 2019).

These results showed that FAQ out from the three evaluated equipments contributed to better reduction of product contamination by PAHs with the values of BaP and PAH4 which are in compliance with European Commission (EU, 2023) and the regulation of Benin (Arrêté 2007 N° 0362/MAEP, Benin).

3.6. Effect of designed and manufactured equipment on sensory properties of grilled pork, smoked and smoked-dried fishes

The overall acceptability scores of grilled pork (7.7 ± 1.1), smoked fish (7.4 ± 1.5) and smoked-dried fish (7.8 ± 0.8) produced with designed and manufactured equipment are significantly higher ($p < 0.05$) than those of the same products obtained using traditional processing equipment (Table 9). Besides, before the use of designed and manufactured equipment the traditional products were highly preferred by consumers with acceptability scores ranged between 6.9 and 7.4 for grilled pork, 7.2–7.5 for smoked fish and 7.3–7.6 for smoked-dried fish (Assogba et al., 2021a). It could be assumed that the designed and manufactured equipment (FAQ and charcoal) conferred the best sensory properties to the end-product as there are preferred by consumers. Nevertheless, it was important to know the optimal level of different sensory attributes which decrease the acceptability of product and for which it will be need to adjust to obtain the best sensory properties. Therefore, the penalty analysis was performed and the mean decrease in acceptability for each product and the percentage of consumers that defined the product attributes levels as not-JAR are indicated in Table 9. Results showed that althought grilled pork from designed and manufactured equipment (GP-DME) had high acceptability score than grilled pork from traditional processing method (GP-TPE), more than 20 % respondents in not-JAR attribute, “colour not enough” and “texture not enough” caused a significant negative impact on this product acceptability. In other hand, consumers thought that the golden colour of GP-DME could be increase and its moisture content could be reduced to have an ideal end-product. For grilled pork from traditional processing equipment (GP-TPE), “taste too much” decreased significantly the mean acceptability of the product. Taste level could be reduced by controlling the time of product exposition to heat and smoke during the grilling process. As shown in Table 9, this negative impact was adjusted by the designed and manufactured equipment. In case of smoked fish from designed and manufactured equipment (SF-DME), any not JAR attribute did not impact negatively the mean acceptability of the product, contrary to SF-TPE for which “colour too much”, “texture not enough”, “odor too much” and “taste too much” reduced significantly the mean acceptability of the product. Even if smoked-dried fish from designed and manufactured equipment (SDF-DME) was higher acceptability than those from traditional processing equipment (SDF-TPE), any not JAR attributes did not impact negatively the mean acceptability of the two products. Therefore, any improvement is not need for SDF-DME shown in this study.

4. Conclusion

The designed and manufactured equipment named FAQ used with charcoal allowed to process in few times a high amount of meat and fish with specific consumption of fuel lower than those of the improved equipments (GA2C and FBM) and the traditional equipments such as barrel grill, barrel kiln and clay grill with two chambers. When the three equipments (FAQ, GA2C and FBM) are used with charcoal, they allowed to obtain the best sanitary quality of end-products because the concentrations of BaP and PAH4 in end-products are in compliance not only with limit fixed by Benin regulation but also in compliance with maximum limit authorized by European Commission. Therefore, the new and improved equipments could be useful for processors which would not be exposed to smoke and heat during their processing activities. These equipments also contributed to a high reduction of product contamination by PAH and that is a good news for consumers who will preserve their health by eating safe quality of grilled pork, smoked fish and smoked-dried fish. Furthermore, the improved processing method using QUALISANI equipement (FAQ) with charcoal allowed to confer the best sensory properties to the end-products. However, other studies

Table 9
Penalty analysis results of mean decrease in overall acceptability, percentage of not JAR and overall acceptability of grilled pork, smoked fish and smoked-dried fish by consumers.

		Penalty category							
		Colour		Texture		Odor		Taste	
Samples	Overall acceptability[a]	Mean decrease	Not JAR (%)	Mean decrease	Not JAR (%)	Mean decrease	Not JAR (%)	Mean decrease	Not JAR (%)
GP-DME	7.7 ± 1.1^a	**ne: 0.7***	**ne: 22.7**	**ne: 0.8***	**ne: 30.6**	ne: 0.2; tm: 0.8	ne: 61.3; tm: 1.3	ne: 0.2	ne: 28
GP-TPE	5.6 ± 1.5^b	ne: −3; tm: 0.4	ne: 1.3; tm: 92	ne: −0.3; tm: −0.2	ne: 45.3; tm: 38.7	ne: −1.5; tm: −0.5	ne: 22.7; tm: 45.3	ne: 2; **tm: 0.7***	ne: 8; **tm: 41.3**
SF-DME	7.4 ± 1.5^a	ne: 0.4	ne: 53.3	ne: 0.5; tm: −0.3	ne: 14.6; tm: 5.3	ne: 0.5	ne: 65.3	ne: 0.6; tm: −0.5	ne: 24; tm: 1.3
SF-TPE	5.3 ± 1.7^b	ne: 0.6; **tm: 1.4***	ne: 13.3; **tm: 68**	**ne: 0.8***	**ne: 68.7**	ne: 0.5; **tm: 1.4***	ne: 25.3; **tm: 60**	ne: 0.4; **tm: 1.6***	ne: 16; **tm: 37.3**
SDF-DME	7.8 ± 0.8^a	ne: 0.0	ne: 77.3	tm: −0.2	tm: 26.7	ne: −0.2	ne: 1.3	NF	NF
SDF-TPE	5.8 ± 0.1^b	tm: 0.5	tm: 77.3	ne: 0.2	ne: 32	tm: 0.0	tm: 70.7	tm: 0.1	tm: 61.3

[a] Values with different letters in column are significantly different at **a** = 0.05;* P < 0.10 (significant mean decrease in overall liking based on 2-samples-test); NF: Not found; ne = not enough; tm = too much; GP-DME: Grilled pork from designed and manufactured equipment (FAQ-charcoal);GP-TPE: Grilled pork from traditional method; SF-DME: Smoked fish from designed and manufactured equipment; SF-TPE: Smoked fish from traditional processing equipment; SDF-DME: Smoked-dried fish from designed and manufactured equipment; SDF-TPE: Smoked-dried fish from traditional processing equipment.

will need to be carried for the incorporation of solar energy, the mathematical modeling of heat transfer and mass transfer phenomena, and the development of a small model of QualiSani equipment for domestic use in order to solve the problem of PAH contamination in grilled and smoked products at household level.

CRediT authorship contribution statement

Mahunan François Assogba: Data curation, Conceptualization, Methodology, Formal analysis, Writing – original draft. **Roger Houêchéné Ahouansou**: Conceptualization, Methodology. **N. Olive Ruth Djohi**: Data curation, Formal analysis. **Yénoukounmè Euloge Kpoclou**: Conceptualization, Data curation. **Gildas Dona Anihouvi**: Conceptualization, Data curation. **Herbert Ogouyôm Iko Afé**: Conceptualization, Data curation. **Biowa Franck Tchibozo**: Conceptualization, Methodology. **Caroline Douny**: Formal analysis. **Jacques Mahillon**: Writing – review & editing. **Marie-Louise Scippo**: Project administration, Writing – review & editing. **Djidjoho Joseph Hounhouigan**: Project administration, Writing – review & editing. **Victor Bienvenu Anihouvi**: Supervision, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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