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Thermal and technological performances of traditional grills used in cottage industry and effects on physicochemical characteristics of grilled pork

Mahunan François Assogba[1] | Yénoukounmè Euloge Kpoclou[1] | Roger Houêchéné Ahouansou[2] | Aymard Dalode[1] | Emile Sanya[2] | Jacques Mahillon[3] | Marie-Louise Scippo[4] | Djidjoho Joseph Hounhouigan[1] | Victor Bienvenu Anihouvi[1]

[1]Laboratory of Food Science, School of Nutrition, Food Science and Technology, Faculty of Agronomic Sciences, University of Abomey-Calavi, Cotonou, Benin

[2]Department of Mechanic and Energetic Engineering, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Cotonou, Benin

[3]Laboratory of Food and Environmental Microbiology, Earth and Life Institute-Applied Microbiology, Louvain-la-Neuve, Belgium

[4]Department of Food Science, Laboratory of Food Analysis, Faculty of Veterinary Medicine, Fundamental and Applied Research for Animals & Health (FARAH), Veterinary Public Health (VPH), University of Liege, Liège, Belgium

Correspondence
Mahunan François Assogba, Laboratory of Food Science, School of Nutrition, Food Science and Technology, Faculty of Agronomic Sciences, University of Abomey-Calavi, 03 BP 2918 Jéricho, Cotonou, Benin.
Email: fassogba@gmail.com

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Abstract

Processing methods of grilled pork and performances of the two most used grills were assessed. Twelve experiments were performed with three processors. Results showed that the temperatures recorded in the combustion place of barrel grill (VBG1C) and clay grill (CG2C) reached 466.8 ± 41.7°C and 458.3 ± 90.8°C, respectively. These temperatures exceeded 450°C, value at which uncompleted wood combustion generates polycyclic aromatic hydrocarbons (PAHs). No significant difference was found between VBG1C and CG2C about load capacity (3.8 ± 0.9 and 4.8 ± 0.7 kg), grilling duration (42.2 ± 13.0 and 49.0 ± 6.3 min), and quantity of fresh pork processed by the time unit (0.09 ± 0.02 and 0.10 ± 0.02 kg/min), except fuel consumption which was significantly higher for CG2C than VBG1C. No significant difference was found for protein and fat contents (dry weight) of grilled pork according to the grill used. The levels of BaP and PAH4 in grilled pork did not change according to the grill but exceeded the maximal values fixed by standard regulations.

Practical applications

Knowledge development through the characterization of fresh pork grilling process, and the assessment of the thermal and technological performances of traditional grills could help to optimize the grilling process by developing improved equipment with facility to manage and check the heat and smoke transfer during the grilling process and preserve processors health. Through this study, the improved equipment could be designed to increase its load capacity and to reduce its specific fuel consumption. In addition, the best sanitary quality of grilled pork obtained with the improved equipment will avoid sanitary risk to consumers.

1 | INTRODUCTION

Pork plays an important role in human nutrition because it is the most consumed meat in the world with 115 million tons in 2013 corresponding to a part of 37% of all types of meat (FAO, 2018). The Beninese national livestock was estimated to 431,000 animals in 2014, with a total production of 5,172 tons of pork and 6,540 tons by 2020 (DE/MAEP, 2014). However, in tropical region like Benin, the preservation of fresh products from animal origin including pork is still difficult due to their extreme perishability. Consequently, many traditional processing techniques such as sun drying, salting, frying, and grilling are used to extend the shelf-life of such products (Anihouvi, Kpoclou, Assogba, et al., 2019; Anihouvi, Kpoclou, Massih, et al., 2019; Anihouvi, Ayernor, Hounhouigan, & Sakyi-Dawson, 2006). Various meat products such as ham, sausages, bacon, and braised or grilled meat are obtained from fresh pork (Mopate & Kabore-Zoungrana, 2013). *Hanlan mimin*, a grilled pork, is the most consumed form of pork in Benin (Assogba et al., 2017). This traditional ready-to-eat food, which is obtained by seasoning and grilling of fresh pork, because of processing method, differs from other processed porks such as the sliced smoked pork belly and bacon (Pearson & Gillett, 1999; Poma, 1998), *boucane*, and *unam inung*, two salted, dried, and smoked pork belly from Réunion (Poligné, Collignan, Trystram, & Pieribattesti, 2000) and Nigeria (Egbunike & Okubanjo, 1999), respectively. The processing of pork into *hanlan mimin* is still artisanal with the use of various grills, of which the most used were vertical barrel grill with one chamber (VBG1C) and clay grill with two chambers (CG2C) (Assogba et al., 2017). Based on the design and the functioning of these grills, two methods of grilling (direct and indirect) were distinguished (Assogba et al., 2017). The direct grilling (DG) was performed with VBG1C for which both wood combustion and grilling take place. The meat to be grilled was exposed above the combustion chamber and received directly heat and smoke produced by the fuel. The indirect grilling (IG) was accomplished with CG2C for which the combustion chamber was separated from the grilling chamber. Therefore, the heat produced in the combustion place moved by convection transfer to the grilling chamber and allow to grill the exposed pork on the grid. In addition, it was known that in the case where vertical barrel grill with one chamber was used, melted fat from pork fell directly into the combustion place and activated more the combustion, while this was not the case for clay grills with two chambers. These processing conditions could lead to various effects on the end-products in various ways. Many authors have demonstrated that grilling process involved the contamination of meat products (pork, beef) and fish by polycyclic aromatic hydrocarbons (PAHs) (Iko Afé et al., 2020; Oz & Yuzer, 2016; Ratsimba et al., 2014; Viegas, Novo, Pinto, Pinho, & Ferreira, 2012). As reported in the Practice Code for Reduction of Food Contamination (CAC/RCP-68, 2009), the direct grilling process led to high contamination of end-products by PAHs than indirect grilling process. According to Codex alimentarius (2005) grilled meat obtained by direct grilling was 10 to 30 times more contaminated than those obtained by indirect grilling. Furthermore, according to Branger, Richer, and Roustel (2007) and Pana (2012), high temperatures (70°C–140°C) in the core of product led to a progressive combination of denaturation, oxidation and aggregation of proteins. Therefore, the lack of information on the technological and thermal performances of the two grills investigated in this study could negatively affect the quality of the end-products. Therefore, it was useful to evaluate the performances of these grills and the quality of end-products for further improvements.

The aim of the present study was to characterize the grilling process of pork; to evaluate and compare the thermal and technological performances of the two types of grills and finally to determine and compare the effects of these grills on the physicochemical characteristics of processed pork.

2 | MATERIALS AND METHODS

2.1 | Raw materials

Six local pigs bred in an enclosing system, under the same conditions (coming from the same sow, previously subjected to the same diet, same age: 8 months with an average weight: 29.8 ± 5.1 kg) were purchased from a private farm at Cotonou. The pigs were subjected to authorized veterinary control before slaughter and the pork as well after slaughter.

2.2 | METHODS

2.2.1 | Experimental design of follow-up trials and sampling

Twelve (12) follow-up trials on the processing of pork into grilled pork were conducted with three experienced processors located at three different processing sites (Agbokannou, Akonaboe and Djegan-Kpevi) in Porto-Novo municipality, known as a main area of pig farming, commercialization, processing, and consumption (Ayissiwede, 2004; Houndonougbo, Adjolohoun, Aboh, Singbo, & Chrysostome, 2012; PAFILAV, 2014). Each of the three processors produced grilled pork under investigation using the same species of wood (*Acacia auriculiformis*) as fuel for all trials and two traditional grills: a vertical barrel grill with one chamber (VBG1C) and a clay grill with two chambers (CG2C). In order to document the processing methods, processors were asked to produce the grilled pork as they were used to. Two follow-up trials were performed per processor per type of grill, that is, a total of 12 follow-up trials of which six with VBG1C and six with CG2C. Fresh and grilled pork samples were taken at various steps of grilling. A total of 24 samples including six fresh meat, six fresh meat slices, six grilled meat obtained with VBG1C, and six with CG2C were collected for laboratory analysis.

2.2.2 | Determination of thermal and technological performances of grills

The thermal parameters including ambient temperature (AT), combustion temperature in combustion place (CTCP), temperature in combustion chamber (TCC), temperature at the contact point of grid with the product (TCPP), and temperature at the core of product (TCP) were recorded at 10 min frequency with a thermocouple (Traceable digital thermocouple no. 620-2006, France) according to Kpoclou et al. (2014). Air relative humidity (RH %) was recorded with a thermo-hygrometer (PRO Digital) equipped with a probe (Sebastian, Bruneau, Collignan, & Rivier, 2004). Technological parameters such as load capacity, grilling duration, quantity of fresh pork processed per time unit, specific fuel consumption, and yield were investigated. Three slices of fresh pork were randomly selected at three different parts on the grid and tagged. They were removed from the grid and put back for measurement purposes at each 10 min interval during the grilling. Their masses were monitored and recorded using an electronic balance (Terraillon, 5 kg) and the yields were calculated (Choi et al., 2015; Poligné, 2001). This allowed to assess the kinetics of matter loss during the grilling of pork. Mass transfer associated with losses of water and fat during the grilling was evaluated using Equations (1) and (2) as stipulated by Collignan and Raoult-Wack (1992).

$$\mathrm{WL} = X_t - X_{t+1}\left(\frac{m_{t+1}}{m_t}\right) \tag{1}$$

$$\mathrm{FL} = F_t - F_{t+1}\left(\frac{m_{t+1}}{m_t}\right) \tag{2}$$

With WL, water loss between t and $t + 1$ (kg/100 kg of product); FL, fat loss between t and $t + 1$ (kg/100 kg of product); X_t, water content at t (kg/100 kg of product) (wb); $X_t + 1$, water content at $t + 1$ (kg/100 kg of product) (wb); F_t, fat content at t (kg/100 kg of product) (wb); $F_t + 1$, fat content at $t + 1$ (kg/100 kg of product) (wb); m_t, mass of product at t (kg); $m_t + 1$, mass of product at $t + 1$ (kg); wb, wet basis. The calculations were made between steps t and $t + 1$.

The duration of grilling of pork was determined using a chronometer (Degnon et al., 2013). The quantity of wood used during each trial was obtained by weighing with a commercial balance of 20 kg range, according to the method described by Rivier, Kebe, and Goli (2009), Degnon et al. (2013), and Kpoclou et al. (2014).

2.2.3 | Determination of physicochemical characteristics of fresh and grilled pork

The physical characteristics such as size (length, width, and thickness) of fresh and grilled pork were determined using a caliper, while their real volume and density were obtained from Archimedes principle (Ahouansou, Agbobatinkpo, Sanya, Gnonlonfin, & Fandohan, 2016). The pH of pork samples was determined according to AFNOR NF V 04-408 using a digital pH meter (inoLab pH 730 WTW 82362 Wellheim, Germany). The color was measured with a portable chromameter (MINOLTA-CR/DP 400/410) using L^*, a^*, b^*, and ΔE coordinates. The dry matter content was determined by oven drying of samples at 103 ± 2°C up to constant weight (ISO 1442:1997). The protein content was determined according to the Kjeldahl method as described in Association of Official Analytical Chemists [AOAC] (1995), method No. 981.10. The fat content was assessed according to the method described by Folch, Lees, and Stanley (1957).

2.3 | Statistical analysis

The data collected were processed using the Excel software (2013) for descriptive statistics (mean and *SD*). STATISTICA software (StatSoft France 2006, version 7.1) was used to perform means comparison of two groups (Student's *t*-test or Mann and Whitney U test) and more than two groups (one-way ANOVA or ANOVA of Kruskal-Wallis). A significant difference was accepted when $p < .05$.

3 | RESULTS AND DISCUSSION

3.1 | Characteristics of the two grills used during the follow-up trials with processors

3.1.1 | Vertical barrel grill with one chamber

The vertical barrel grill with one chamber (VBG1C) used in this study had similar characteristics to that reported by Idah and Nwankwo (2013) and Assogba et al. (2019). This grill of the cylindrical form (Figure 1) was manufactured from recovered iron barrels. It had an opening (a) at the base whereby firewood was introduced, and a circular opening (b) at its apex on which the grid was laid. It had a single chamber where the combustion place was directly below the grid.

3.1.2 | Clay grill with two chambers

The clay grill with two chambers (CG2C) used by grilled pork processors was constituted of two compartments (Figure 2). The combustion chamber (A) above which was fixed a large pot used either for the pre-cooking of meat or for the cooking of a sauce made with pig blood (*kpètè* in *Goun*, a local language). The chamber (A) opens horizontally through a small hole into the grilling chamber (B), on which was placed the grid for meat grilling. The heat produced by wood combustion in chamber (A) diffused into the chamber (B). An iron rigid tray was used to regulate heat transfer from the chamber (A) to grilling chamber (B).

3.2 | Grilling of pork

3.2.1 | Preliminary steps

Prior to processing, the pig was slaughtered, depilated by skin grilling, washed, and gutted to obtain the carcass. Depilating by skin grilling as performed by stakeholders could be a factor of the contamination of the pig carcass with PAHs due to the exposition of the slaughtered pig to flames and smoke from wood combustion. The washing of slaughtered pig is performed by water and small knives; sometimes stone having a rough surface is used to remove all the waste accumulated on the animal skin since its lifetime, but also those coming from the flames and smoke during the skin grilling. Starting from a pig weighing 100 kg, the average carcass yield was about 75.3 kg (75.3 ± 8.1%).

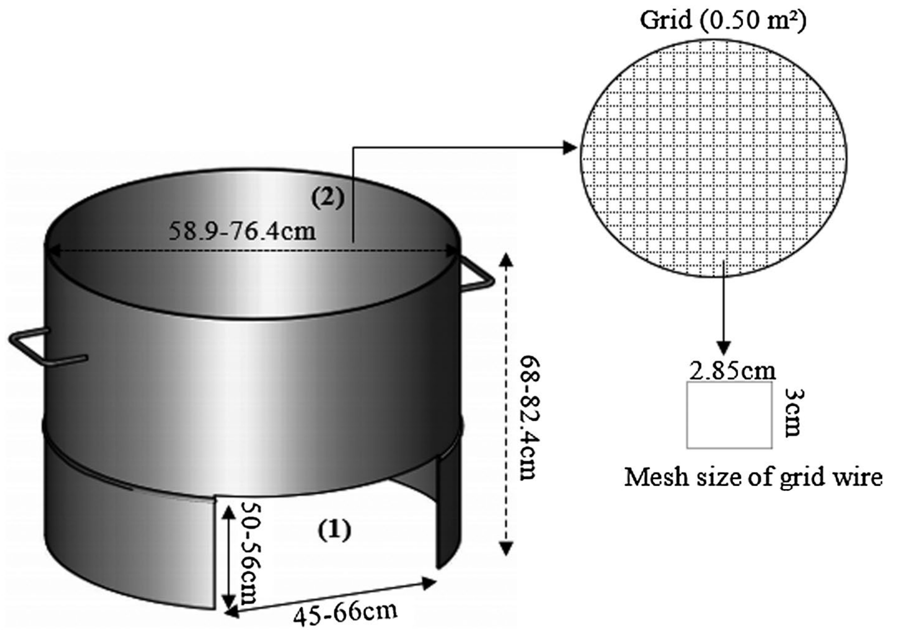

FIGURE 1 Vertical barrel grill with one chamber (VBG1C). (a) Combustion place, (b) Grid

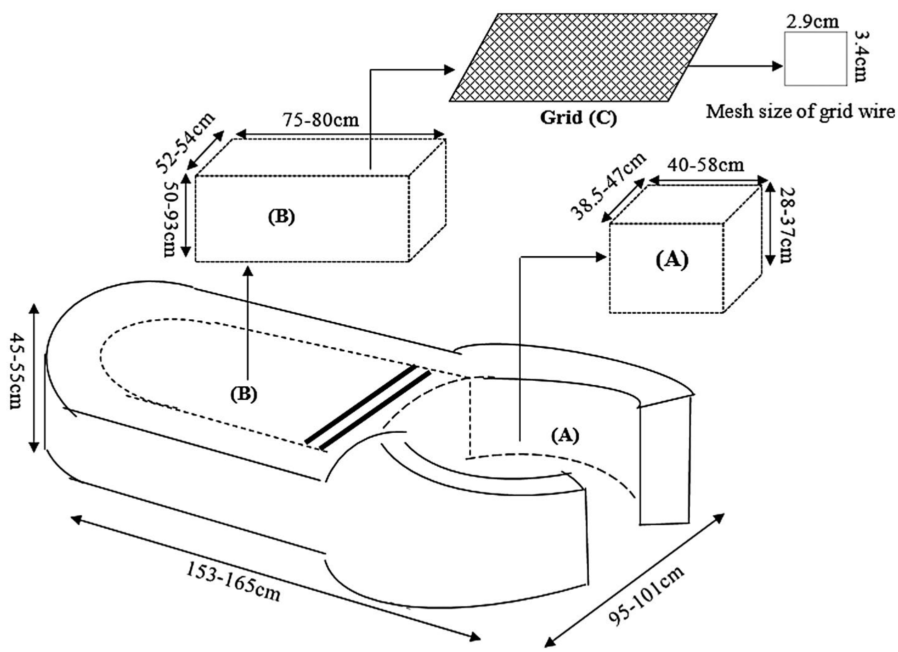

FIGURE 2 Clay grill with two chambers (CG2C). (a) Combustion chamber, (b) Grilling chamber, (c) Grid

3.2.2 | Dressing

As showed by the flow diagram (Figure 3), the carcass was cut into quarter, dressed (boning and fat removing), and then cut into meat slices. These unit operations were almost conducted simultaneously.

3.2.3 | Seasoning

Fresh pork slices were put in a basin and then seasoned with a mixture of various ingredients including salt, garlic, pepper, onion, ginger, laurel leaves, and magic cubes. According to processors, the seasoning plays a dual role. It makes the meat tender and gives an appetizing flavor to the end-product.

3.2.4 | Grilling

For grilling, the seasoned fresh pork slices were placed on the grid above the grill. As indicated below, two methods of grilling were distinguished: direct grilling (DG) and indirect grilling (IG). During the DG, the meat was directly placed on the grid just above the combustion chamber while for IG, the heat produced in the combustion place moved by convection to the grilling chamber above which pork slices were disposed on the grid.

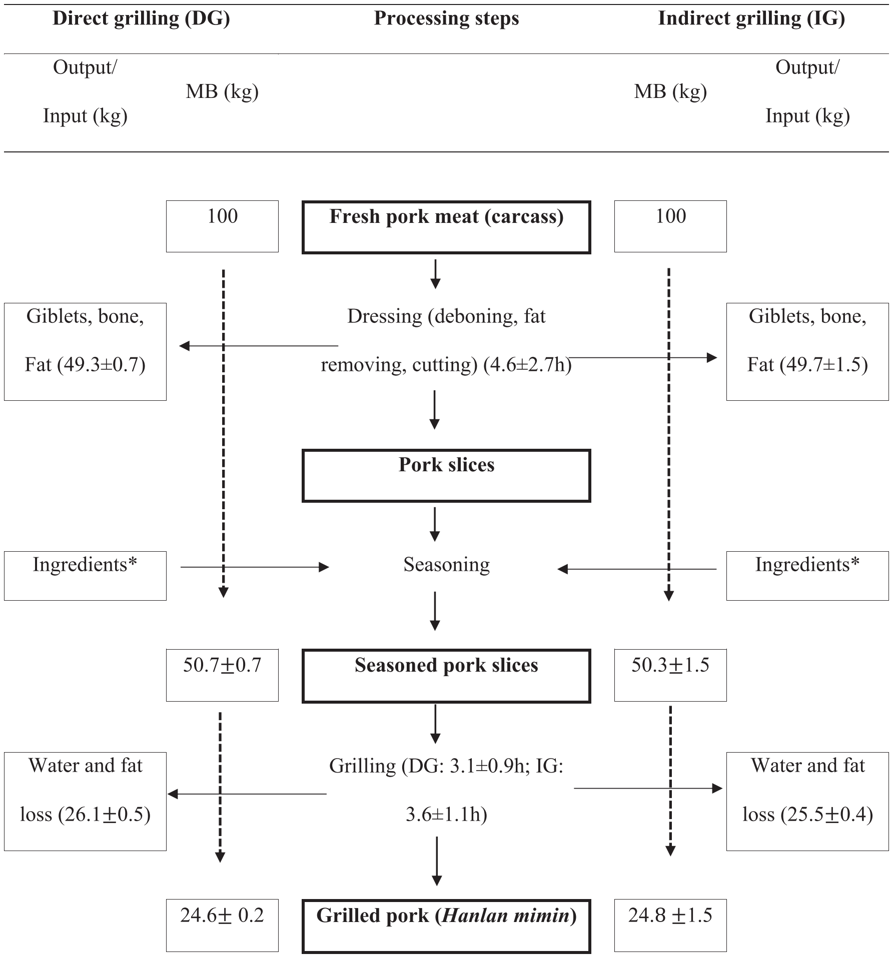

FIGURE 3 Flow diagram of processing of fresh pork into grilled pork and mass balance during the processing. DG, direct grilling; IG, indirect grilling; MB, mass balance; *Ingredients: Salt, garlic, pepper, onion, ginger, laurel leaves and and magic cubes

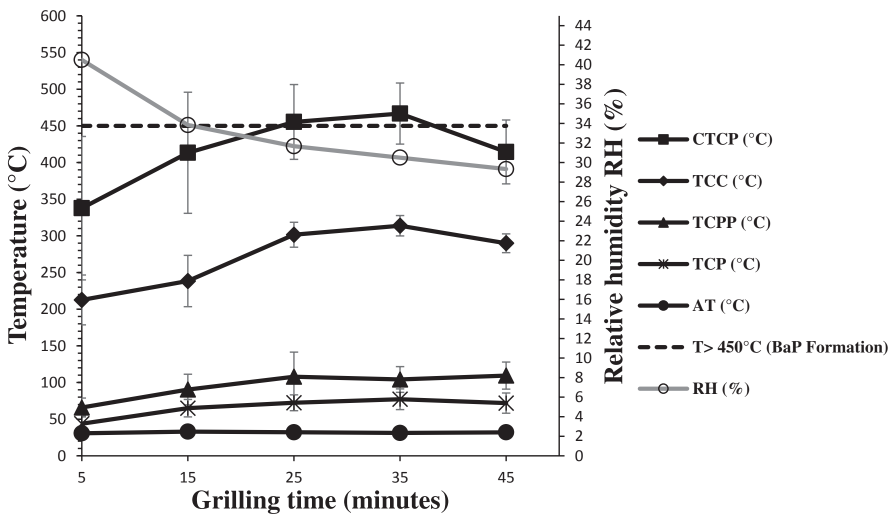

FIGURE 4 Changes in temperature outside of grill (AT), at combustion place (CTCP), in combustion chamber (TCC), at the contact point with product (TCPP), at the core of product (TCP), and air relative humidity (RH) during direct grilling. AT, ambient temperature; CTCP, combustion temperature in combustion place; RH, air relative humidity; TCC, temperature in combustion chamber; TCP, temperature at the core of the product; TCPP, temperature at the contact point with product

3.3 | Heat and mass transfer, and technological performances of the two grills investigated

3.3.1 | Changes in ambient air conditions during the grilling

Figures 4 and 5 show the variation in air conditions during the two grilling processes. Ambient temperature (AT) recorded on the processing site, out and within a radius of 0.5 m of the vertical barrel grill, oscillated between 30.7 ± 1.7°C and 33.0 ± 2.9°C from 0 to 40 min of direct grilling (DG) (Figure 4). Meanwhile, AT recorded during indirect grilling (IG) with the clay grill (Figure 5) ranged between 31.6 ± 0.9°C and 32.2 ± 1.4°C without a significant variation ($p > .05$). In the same time, the air relative humidity (RH) decreased gradually and significantly from 41 ± 7% to 29 ± 10% between 0 and 40 min during DG (Figure 4), while that

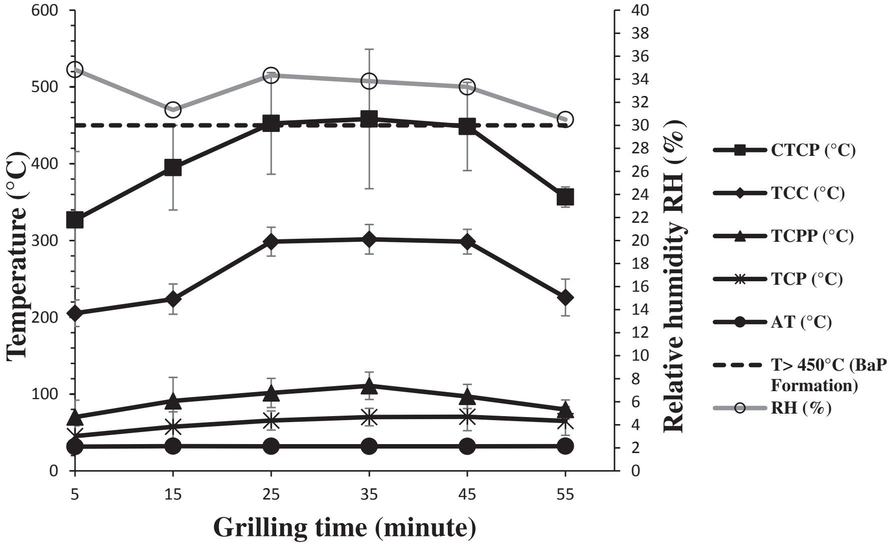

FIGURE 5 Changes in temperature outside of grill (AT), at combustion place (CTCP), in combustion chamber (TCC), at the contact point with product (TCPP), at the core of product (TCP), and air relative humidity (RH) during indirect grilling. AT, ambient temperature; CTCP, combustion temperature in combustion place; RH, air relative humidity; TCC, temperature in combustion chamber; TCP, temperature at the core of the product; TCPP, temperature at the contact point with product

of IG did not vary significantly, and ranged between 31 ± 5% and 35 ± 11% during all the grilling time (Figure 5). This could be due to the nature of material used for grill manufacturing. Indeed, the heat conductivity coefficient of iron alloy (160 w/mK) is higher compared to that of clay (1.5 w/mK) (Marti, 2002). The heat diffusion through VBG1C to air explains the decrease of air relative humidity during the direct grilling.

3.3.2 | Changes in temperature of grills and products during grilling processes

The trends of combustion temperature in combustion place (CTCP) during DG and IG can be subdivided into two phases. Between 5 and 35 min, the CTCP increased significantly from 337.7 ± 97.8°C to 466.8 ± 41.7°C for DG (Figure 4) and from 326.8 ± 89.2°C to 458.3 ± 90.8°C for IG (Figure 5), due to the increase of combustion intensity. During a second phase (from 35 to 45 min), the CTCP during DG decreased significantly ($p < .05$) from 466.8 ± 41.7°C to 414.5 ± 43.6°C, while CTCP for IG oscillated between 458.3 ± 90.8°C and 448.5 ± 57.4°C without significant variation ($p > .05$). However, the indirect grilling took more than 45 min (49.0 ± 6.3 min) with the significant decrease of CTCP from 448.5 ± 57.4°C to 356.6 ± 13.2°C. The highest average value of CTCP was obtained after 35 min of grilling. It was 466.8 ± 41.7°C with extreme values ranging between 432.5°C and 547.7°C for DG, while the highest average value of CTCP during IG was 458.3 ± 90.8°C with extreme values oscillating between 361.4 and 611.1°C. The comparison of mean values of CTCP of the two methods of grilling (DG and IG) indicated that there was no significant difference ($p > .05$). This could be due to the use of the same wood (*Acacia auriculiformis*) having the same moisture content during the two grilling trials.

During the grilling process (5–35 min), the temperature in the combustion chamber (TCC) increased significantly from 212.6 ± 34°C to 313.8 ± 13.9°C for DG (Figure 4) and from 205.3 ± 17.3°C to 301.6 ± 19.2°C for IG (Figure 5). In the same time, the temperature at the contact point of grid with the product (TCPP) increased significantly ($p < .05$) from 65.9 ± 12.9°C to 107.9 ± 33.5°C within 30 min for DG (Figure 4), while that of IG increased significantly from 70.1 ± 22.0°C to 110.8 ± 17.8°C within 30 min of grilling time (Figure 5). This quick increase of TCPP could be due to the increase of TCC induced by the increase of CTCP which assured heat transfer successively from the combustion place to the combustion chamber, and from the combustion chamber to the grid. Between 35 and 45 min, the TCPP during DG fluctuated between 104.1 ± 17.5°C and 109.4 ± 18.5°C without significant variation, while the TCPP during IG decreased significantly ($p < .05$) from 110.8 ± 17.8°C to 79.8 ± 12.5°C. Statistical analysis of TCPP values showed no significant difference between the two methods of grilling ($p > .05$).

The temperature at the core of product (TCP) remains the main parameter that should be controlled to guarantee product safety in terms of potential microbiological risks associated with the consumption of end-products. TCP during DG of meat increased significantly from 43.8 ± 10.2°C (t = 5 min) to 77.2 ± 14.1°C (t = 35 min) before falling to 71.9 ± 13.8°C at 45 min (Figure 4), while TCP during IG of meat increased gradually from 45.3 ± 13.3°C to 70.1 ± 11.4°C between 5 and 35 min (Figure 5). This was followed by a stationary phase from 35 to 55 min during which TCP did not change significantly (Figure 5). The increase of TCP during the first 30 min attested heat transfer from the combustion place to the grid and then to the product. There was no significant difference ($p > .05$) between TCP values of pork meat processed by DG and IG at different times of grilling. Although the two grills may have different capacities to preserve heat because of the difference related to their manufacturing materials, size, and functioning mode, it appeared that the temperature in the core of the product did not differ significantly when comparing the two grilling processes. Some practices of processors to maintain the combustion intensity at the normal level during processing may justify the compensatory and similar effects observed with respect to the TCP of product during the two grilling methods. In the case of DG, it was observed a continuous melting of fat which increased the combustion intensity. At this moment, as processors known that the increasing of the combustion temperature in combustion place could affect the quality of the end-product, they attenuated the fire intensity by adding water to the combustion chamber, or by reducing the firewood. The combustion intensity in the IG was not controlled like that of the DG because the heat produced in the combustion place was used simultaneously to cook a sauce based on pig blood, called *kpètè* in the cooking pot placed above the combustion chamber, or to grill meat exposed on grid above grilling chamber. This double role of CG2C may explain the fact that TCP values of both direct grilling using VBG1C and indirect grilling with CG2C were not significantly different ($p > .05$) during the two grilling methods.

Mean values of TCP obtained after 35 min of direct and indirect grilling were 77.2 ± 14.1°C and 70.5 ± 18.1°C, respectively, with extreme values of 64.6°C–100.7°C for DG and 39°C–90°C for IG. These two TCP mean values were similar to values ranging between 65°C and 75°C, which is a temperature range in which some authors observed denaturation of myofibrillar protein, collagen shrinkage, increasing of product hardness, and loss of water (Branger et al., 2007; Davey & Gilbert, 1974; Martens et al., 1982; Pana, 2012). TCP values recorded during the grilling were higher than 68°C after 20 to 40 min (DG) and 30 to 40 min (IG), and suggested that the end-product obtained in both cases could be considered as a safe product from a microbiological point of view (Anonymous, 2013). However, TCP during indirect grilling (IG) reached the safety temperature of 70°C, 10 min later when compared to TCP in the case of direct grilling (DG). This can probably be due to the larger volume (275.5–457.3 L) of CG2C compared to VBG1C (185.3–378.1 L). Apart CTCP, other parameters such as air velocity would be considered to determine the heat transfer phenomenon which takes place in the grills as reported by Poligné (2001) and Sebastian et al. (2004).

3.3.3 | Effect of temperature on polycyclic aromatic hydrocarbons levels in grilled pork

The combustion temperature in the combustion place values recorded during direct and indirect grilling processes using barrel and clay grills is higher than 450°C, sufficient value of temperature where the formation and detection of PAHs such as naphthalene, fluorene, phenanthrene, anthracene, pyrene, chrysene, and benzo[a]pyrene can occur (Horne & Williams, 1996; Ravindra, Sokhi, & Vangrieken, 2008; Stołyhwo & Sikorski, 2005; Williams & Horne, 1995). Hajaligol, Waymack, and Kellogg (1999), Hajaligol, Waymack, and Kellogg (2001) had also reported the formation of various aliphatic and aromatic hydrocarbons from pyrolysis between 350°C and 600°C temperature range, when cellulosic materials such as solid char residues derived from cellulose, glucose, pectin, and xylan were used. A linear increase of PAHs in smoke has been observed according to an increase in combustion temperature from 400 to 1,000°C (Toth & Blaas, 1972). Among PAHs, benzo(a)pyrene is considered by EU Scientific Committee on Food (SCF) as a marker for the occurrence of carcinogenic PAHs in food (SCF, 2002). The level of PAH4 (benzo[a]pyrene, chrysene, benz[a] anthracene, and benzo[b]fluoranthene) was used as an indicator to evaluate the sanitary quality of products (EFSA, 2008). The grilled pork samples collected during the present study were analyzed by Iko Afé et al. (2020) to evaluate the levels of their contamination by PAHs. Indeed, the concentration of benzo(a)pyrene (BaP) of grilled pork samples from VBG1C (28.9 ± 18.0 µg/kg, n = 6) and CG2C (16.7 ± 10.6 µg/kg, n = 6) exceeded the maximal limit of 2 µg/kg (BaP) fixed by the European Commission (CE: No 1881/2006, 2006) (Iko Afé et al., 2020). These values of BaP are not also in compliance with the value of 5 µg/kg (BaP) admitted by the Beninese regulation (Arrêté 2007 N° 0362/MAEP/République du Bénin). Moreover, the levels of PAH4 recorded by Iko Afé et al. (2020) were 161.8 ± 87.2 µg/kg and 106.8 ± 46.0 µg/kg in grilled pork samples from barrel and clay grills, respectively. These levels of PAH4 were at least 8 to 10 times higher than the maximal value of 12 µg/kg fixed by the European Commission (CE No 1881/2006, 2006). No significant difference was found between grilled pork samples from VBG1C and CG2C concerning their levels in BaP and PAH4. On the one hand, these results showed that the indirect functioning mode of clay grill (CG2C) compared to barrel grill (VBG1) did not limit the contamination of grilled pork by PAHs. The combustion chamber and grilling chamber of clay grill were not separated by physical material leading to the direct contact of smoke with the product during the grilling process (Iko Afé et al., 2020). On the other hand, chemical molecules formed at high temperature (>450°C) in the combustion place of the two grills were transferred to the product explaining the high levels of BaP and PAH4. Therefore, clay grill (CG2C) and barrel grill (VBG1C) need to be improved to reduce the contamination of the end-product by PAHs.

3.3.4 | Kinetics of product mass during grilling

Matter loss during each method of grilling was evaluated from the proximate composition of fresh and processed pork. Average values of moisture content (X_t) and fat content (F_t) of fresh pork were 64.73 ± 4.40 kg/100 kg and 11.14 ± 0.49 kg/100 kg, respectively. After the grilling, the moisture content ($X_t + 1$) and fat content ($F_t + 1$) in grilled pork were 45.22 ± 2.13 kg/100 kg and 16.70 ± 0.47 kg/100 kg, respectively, for DG, and 46.83 ± 3.53 kg/100 kg and 16.14 ± 0.71 kg/100 kg for IG. These data showed that moisture and fat losses were 43.11 ± 5.91 kg/100 kg and 3.22 ± 1.38 kg/100 kg, respectively, for DG, and 41.30 ± 4.07 kg/100 kg and 3.01 ± 1.07 kg/100 kg for IG. Figure 6 showed fresh pork mass loss kinetic during DG and IG. Fresh pork mass decreased from 100 kg to 48.6 ± 10.2 kg in the case of DG and from 100 kg to 49.3 ± 5.3 kg for IG. These decreases lead to a total weight loss of 51.4% and 50.7% of the product mass during DG and IG, respectively. There was significant variation ($p < .05$) in the product mass after each 10 min of grilling, and this for the two grilling methods. As showed by regression lines (Figure 6), the rate of the product mass loss during DG (13.19 kg/min) is higher than that of IG (9.77 kg/min). Mass loss during the grilling could be due to water and fat losses from the product which are caused by thermal treatment (Choi et al., 2015; Poligné, 2001; Sebastian et al., 2004).

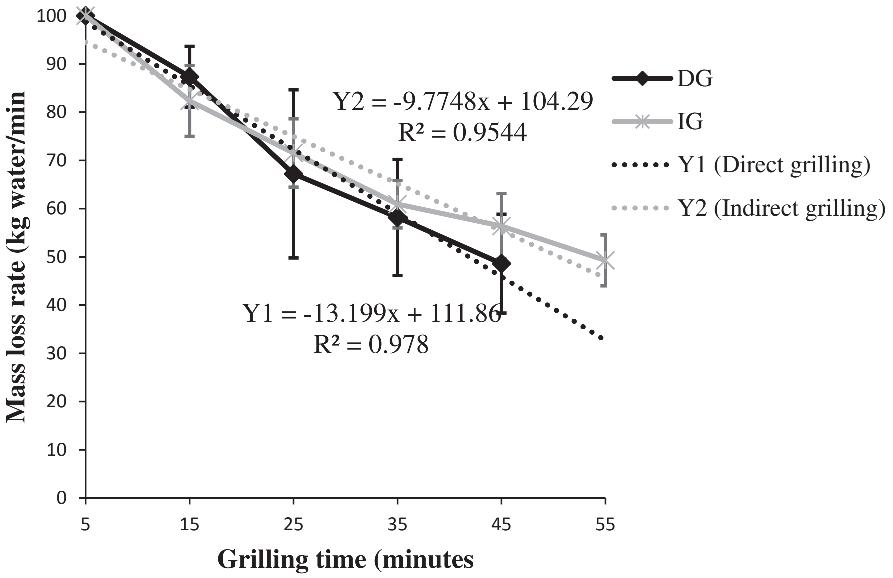

FIGURE 6 Mass loss kinetic in pork meat during the grilling. DG, direct grilling; IG, indirect grilling

Furthermore, the rate of mass loss could be attributed to heat transfer to the product during grilling. Indeed, the temperature at the core of the product exceeded 70°C after 20 and 30 min of direct and indirect grilling, respectively. This value of temperature around pasteurization temperature could reduce microbial load in the end-products as reported by Anihouvi, Kpoclou, Assogba, et al. (2019). Water and fat losses during the two methods of grilling were not significantly ($p > .05$) different, but water loss obtained for DG and IG in this study is higher than that (31.0 kg/100 kg) reported by Poligné (2001) during the processing of *Boucane*, a salted, dried, and smoked pork. Conversely, fat loss (6.2 kg/100 kg) reported by these authors is higher than the fat loss recorded in the present study: 3.22 ± 1.38 kg/100 kg and 3.01 ± 1.07 kg/100 kg for DG and IG, respectively. This difference in fat loss can be explained by the breed of pork used and the processing method.

3.3.5 | Comparison of the technological performances of grills experienced

Table 1 presents the technological performances of vertical barrel grill with one chamber (VBG1C) and clay grill with two chambers (CG2C). The direct grilling with VBG1C with a load capacity of 3.8 ± 0.9 kg of meat lasted an average time of 42.2 ± 13.0 min compared to 49.0 ± 6.3 min obtained for indirect grilling using CG2C with a load capacity of 4.8 ± 0.7 kg meat. There was no significant difference ($p > .05$) in load capacity and grilling time between both types of grills. This confirms the reason why the quantity of fresh pork processed per time unit with VBG1C (0.09 ± 0.02 kg/min) was not significantly different from that obtained for CG2C (0.10 ± 0.02 kg/min). Starting from 100 kg of fresh slices of pork, there was no significant difference ($p > .05$) between the average yield of grilled slices obtained by DG (48.6 ± 0.55%) and that of IG (49.3 ± 1.7%). However, the average yields of the two grilling methods were lower than the value of 67.4% obtained by Poligné (2001) during *Boucane* processing. The total time to grill 100 kg of fresh pork slices ranged between 17 and 18.4 hr (data not shown). This time was so high and showed that grilled pork processors would not be able to produce high quantity of grilled pork in a few time for a large number of consumers due to the lower performance of the grills they used.

The specific fuel consumption of CG2C (2.10 ± 0.35 kg/kg of fresh pork) was significantly higher ($p < .05$) than that of VBG1C (1.73 ± 0.15 kg/kg of fresh pork). The high fuel consumption recorded with CG2C could be due to the additional energy input needed to transfer heat from the first chamber to the second chamber of the grill. Indeed, the internal volume of CG2C (366.84 ± 90.88 liters) was larger than that of VBG1C (282.66 ± 96.43 liters) and therefore it is necessary to provide additional energy to assure heat transfer from the combustion chamber to the grilling chamber of CG2C. Moreover, unlike the VBG1C, CG2C had two functions, the grilling of slices of fresh pork placed on the top of the grilling chamber, and the cooking of pieces of meat and offal in an aluminum pan placed on the top of the combustion chamber. This dual function could require more energy and therefore high fuel consumption.

3.4 | Effects of grills on the physicochemical characteristics of grilled pork

3.4.1 | Changes in size and density

The length and width of grilled pork obtained by direct grilling and indirect grilling were significantly lower ($p < .05$) than those of fresh slices of pork (Table 2). The comparison of grilled pork obtained from DG and IG showed no significant difference ($p > .05$) in mean values of their size (lengths and widths). Conversely, grilling increased significantly ($p < .05$) the thickness of fresh pork slices from 0.59 ± 0.20 cm to 1.01 ± 0.23 cm and 0.94 ± 0.34 cm for DG and IG, respectively. These changes in the size of the end-product may be related to the contraction of myofibrils by the superposition of actin

TABLE 1 Technological performances of the grills used

	Types of grills	
Technological performances	VBG1C (n = 6)	CG2C (n = 6)
Load capacity (kg of fresh meat)	3.8 ± 0.9[a]	4.8 ± 0.7[a]
Duration (min)	42.2 ± 13.0[a]	49.0 ± 6.3[a]
Quantity of fresh pork processed per time unit (kg/min)	0.09 ± 0.02[a]	0.10 ± 0.02[a]
Specific fuel consumption (kg/kg of fresh meat)	1.73 ± 0.15[a]	2.10 ± 0.35[b]
Yield of grilling (%)	48.6 ± 0.55[a]	49.3 ± 1.7[a]

Note: Values with different letters in the same row are significantly different at α threshold of 5%.
Abbreviations: CG2C, clay grill with two chambers, VBG1C, vertical barrel grill with one chamber.

TABLE 2 Size, density, pH, and color of fresh and grilled pork

		Types of meat		
Parameters		FP (n = 6)	GP-DG (n = 6)	GP-IG (n = 6)
Length (cm, n = 20)		23.46 ± 9.84[a]	15.66 ± 5.69[b]	16.40 ± 6.84[b]
Width (cm, n = 20)		10.47 ± 4.05[a]	7.59 ± 2.56[b]	7.46 ± 2.86[b]
Thickness (cm, n = 20)		0.59 ± 0.20[a]	1.01 ± 0.23[b]	0.94 ± 0.34[b]
Density (g/ml, n = 20)		1.01 ± 0.04[a]	1.03 ± 0.03[a]	1.06 ± 0.08[a]
pH (n = 6)		5.48 ± 0.37[a]	6.58 ± 0.34[b]	6.44 ± 0.23[b]
Color (n = 6)	L^*	74.99 ± 3.12[a]	72.59 ± 0.53[b]	72.75 ± 1.17[b]
	a^*	7.41 ± 0.51[a]	7.30 ± 0.69[a]	6.75 ± 0.82[a]
	b^*	5.17 ± 1.16[a]	6.17 ± 0.60[a]	5.67 ± 0.84[a]
	ΔE	10.02 ± 1.45[a]	10.20 ± 0.28[a]	10.06 ± 0.88[a]

Note: Values with different letters in the same row are significantly different at α threshold of 5%.
Abbreviations: ΔE, difference of color; a^*, redness; b^*, yellowness; FP, fresh pork; GP-DG, grilled pork from direct grilling; GP-IG, grilled pork from indirect grilling; L^*, lightness.

and myosin, and the decreasing of the juiciness of the end-product (Branger et al., 2007). Furthermore, the average density of fresh pork (1.01 ± 0.04 g/ml) was not significantly different (p > .05) from the density of grilled pork obtained by direct grilling (1.03 ± 0.03 g/ml) and indirect grilling (1.06 ± 0.08 g/ml). Indeed, while the length and width of the fresh pork decreased after grilling, there was also loss of water and fat. Thus, the gradual decrease in product size, therefore its volume, was accompanied by a proportional diminution of product mass through the matter loss.

3.4.2 | Changes in pH and color

The pH of grilled pork obtained by DG (6.58 ± 0.34) and IG (6.44 ± 0.23) was not significantly different (p > .05) (Table 2). These pH values are similar to the pH value (6.29 ± 0.47) obtained by Ratsimba et al. (2019) on smoked pork *kitoza* produced in Madagascar. Furthermore, the pH values of grilled pork samples (from DG and IG) were significantly higher than that of fresh pork (5.48 ± 0.37). The pH values recorded are not so far away from those reported by Choi et al. (2009) and (2015) on fresh pork (5.79–5.82) and smoked pork (5.90 and 5.94).

The color parameter (lightness) was affected by the grilling. The lightness (L^*) of fresh pork decreased significantly (p < .05) from 74.99 ± 3.12 to 72.59 ± 0.53 and 72.75 ± 1.17 for grilled pork obtained by DG and IG, respectively (Table 2). The grilled pork was, therefore, darker than the fresh meat. This could be due to the melting and pyrolysis of lipids, the carbonization of proteins, and the caramelization of sugars (Branger et al., 2007). Martens (1982) have also observed that the use of high temperature to treat meat, led to the denaturation of myoglobin and hemoglobin which darkens the meat. The color change could also be explained by the occurrence of brown reaction products generated by the rearrangement and polymerization reactions of carbonyl compounds present in the smoke gas phase, and amines groups of meat proteins (Clifford, Tang, & Eyo, 1980; Poligné, 2001; Ruiter, 1979). In addition, the water losses (43.11 ± 5.91 kg/100 kg for DG and 41.30 ± 4.07 kg/100 kg for IG) observed in this study could explain the decrease in L^* index after grilling as reported by Chizzolini et al. (1996). The darkening of meat could also be due to the Maillard reaction. Except for lightness, any other color parameters such as the redness (a^*), the yellowness (b^*), and ΔE did not change significantly (p > .05) from fresh to grilled pork obtained by DG and IG methods. In addition, the two grilled pork from DG and IG did not

TABLE 3 Nutritional characteristics of fresh and grilled pork samples

Parameters (%)	Pork samples FP (n = 6)	GP-DG (n = 6)	GP-IG (n = 6)
Moisture	64.73 ± 4.40^{a}	45.22 ± 2.13^{b}	46.83 ± 3.53^{b}
Protein	18.87 ± 0.48^{a}	29.52 ± 1.68^{b}	28.50 ± 1.10^{b}
	(54.12 ± 6.39^{a})	(53.99 ± 4.23^{a})	(53.80 ± 4.17^{a})
Fat	11.14 ± 0.49^{a}	16.70 ± 0.47^{b}	16.14 ± 0.71^{b}
	(31.90 ± 3.17^{a})	(30.52 ± 1.09^{a})	(30.53 ± 3.19^{a})

Note: FP; GP-DG and GP-IG are the same as defined in Table 2. Values with different letters in the same row are significantly different at α threshold of 5%. Values in brackets are in dry matter basis and other values are in wet basis (wb). Values with different letters in the same row are significantly different at α threshold of 5%.

show any significant difference as far as all the color parameters are concerned.

3.4.3 | Changes in moisture, proteins, and fat of pork meat samples

Table 3 showed the nutritional characteristics of different pork samples. The moisture of grilled pork (DG) (45.22 ± 2.13%) was not significantly different from that of IG (46.83 ± 3.53%) but these two values were lower than that of fresh pork (64.73 ± 4.40%). These moisture values of grilled pork samples were close to 48.6% reported by FAO (2012) for grilled pork, but were higher than the moisture value of 28.5% obtained for *Boucane*, a smoked meat product (Poligné, 2001). Proteins (18.87 ± 0.48% wb) and fat (11.14 ± 0.49% wb) contents of fresh pork used in this study were similar to the values of 17%–21% wb and 4%–20% wb reported by Vautier (2006). These values are also similar to 20% proteins, and between 10% and 20% fat reported by Craplet and Josette (1980) for fresh pork. The fat contents of grilled pork obtained from the two methods of grilling, 16.70 ± 0.47% (DG) and 16.14 ± 0.71% (IG) were lower than the value of 25.3% wb reported by FAO (2012), but also lower than those obtained for similar products such as *kitoza* (20%), *Boucane* (24.2%–49.1%), and *unam inung* (24.0%–44.5%) (Andriamampianina, 2012; Poligné, 2001; Solomon, Ekanem, & Okubanjo, 1994). Also, the protein contents of pork meat after DG (29.52 ± 1.68% wb) and IG (28.50 ± 1.10% wb) were higher than the value of 24% wb reported by FAO (2012). On the dry matter basis (Table 3), the results showed that the protein and fat contents of fresh meat did not change significantly (p > .05) after grilling. In the same way, no significant difference (p > .05) was found between the protein and fat contents of grilled pork obtained by DG and IG.

4 | CONCLUSION

The study described the technological conditions of artisanal production of grilled pork with VBG1C and CG2C as practiced by stakeholders. The two types of grills had similar heat and mass transfer rates. They also had a similar grilling duration and yield. However, the CG2C had the highest specific fuel consumption when compared to the barrel grill. The physicochemical characteristics of grilled pork produced did not change significantly with the type of grill. As the processing conditions are similar to the two grills, the concentration of PAHs especially those of BaP and PAH4 did not vary significantly between grilled pork samples from the two processing methods. But these concentrations exceeded the limit values fixed by the standard regulations for BaP and PAH4. Data collected through this study could be used to improve the processing of fresh pork, and to design an improved grill in order to control and limit factor inducing high chemical contamination of grilled pork.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest in this article.

ORCID

Mahunan François Assogba https://orcid.org/0000-0002-6943-2827

REFERENCES

Ahouansou, R. H., Agbobatinkpo, P. B., Sanya, E. A., Gnonlonfin, B., & Fandohan, P. (2016). Comparative study of some physical properties of the shea kernels in the shea parks in Benin. *Intertional Journal of Biology and Chemical Sciences*, *10*(5), 2151–2162. https://doi.org/10.4314/ijbcs.v10i5.17

Andriamampianina, H. L. (2012). *Production, vente et consommation du Kitoza dans la province d'Antananarivo: qualité du Kitoza de porc*. Mémoire pour l'obtention du diplôme d'études approfondies en sciences de la vie. 115 p. agrictrop.cirad.fr/566108/ ; consulté le 10/08/2018.

Anihouvi, D. G. H., Kpoclou, Y. E., Assogba, M. F., Afé, O. H. I., Lègba, G., Scippo, M.-L., … Mahillon, J. (2019). Microbiol contamination associated with the processing of grilled pork, a ready-to-eat street food in Benin. *Journal of Food Safety*, *40*(1), 1–8. https://doi.org/10.1111/jfs.12731

Anihouvi, D. G. H., Kpoclou, Y. E., Massih, M. A., Iko Afé, O. H., Assogba, M. F., Covo, M., … Mahillon, J. (2019). Microbiological characteristics of smoked and smoked–dried fish processed in Benin. *Food Science and Nutrition*, *7*, 1821–1827. https://doi.org/10.1002/fsn3.1030

Anihouvi, V. B., Ayernor, S. G., Hounhouigan, D. J., & Sakyi-Dawson, E. (2006). Quality characteristics of Lanhouin: A traditional processed fermented fish product in the Republic of Benin. *African Journal of Food Agriculture, Nutrition and Development*, *6*, 1–15. https://doi.org/10.4314/ajfand.v6i1.19173

Anonymous. (2013). *Guide des bonnes pratiques d'hygiène et de salubrité alimentaires*. Bibliothèque et Archives Canada. 48 p.

Association of Official Analytical Chemists. (1995). *Official methods of analysis of AOAC International* (16th ed.). Washington, DC: AOAC.

Assogba, M. F., Anihouvi, D. G. H., Iko Afé, O. H., Kpoclou, Y. E., Mahillon, J., Scippo, M.-L., … Anihouvi, V. B. (2019). Processing methods, preservation practices and quality attributes of smoked and smoked-dried fishes consumed in Benin. *Cogent Food & Agriculture*, *5*(1), 1–13. https://doi.org/10.1080/23311932.23312019.21641255

Assogba, M. F., Kpoclou, Y. E., Ahouansou, R., Dalode, A., Sanya, E., Mahillon, J., … Anihouvi, B. V. (2017). *Performances technologiques comparées des grilloirs traditionnels utilisés dans la production de la viande de porc grillée au Sud-Bénin*. Communication orale présentée au VIème colloque de l'Université d'Abomey-Calavi: Arts, Sciences et Technologies pour le Développement Socio-économique des Nations, Septembre 2017, Bénin.

Ayissiwede, S. (2004). *La filière porcine au Bénin: Production, commercialisation, propositions d'amélioration et perspectives de développement* (Thèse de Doctorat). Université Cheikh Anta Diop De Dakar, 124 p.

Branger, A., Richer, M., & Roustel, S. (2007). *Alimentation et processus technologiques*, (153–156). Educagri éditions.

CAC/RCP-68. (2009). Code d'usages pour la réduction de la contamination des aliments par les hydrocarbures aromatiques polycycliques (HAP) issus des processus de fumage et de séchage direct. 18 p.

Chizzolini, R., Novelli, E., Campanini, G., Dazzi, G., Madarena, G., Zanardi, E., … Rossi, A. (1996). Lean colour of green and matured Parma hams: Comparative evaluation and technological relevance of sensory and objective data. *Meat Science*, *44*, 159–172. https://doi.org/10.1016/S0309-1740(96)00034-4

Choi, Y.-S., Choi, J.-H., Han, D.-J., Kim, H.-Y., Lee, M.-A., Kim, H.-W., … Kim, C.-J. (2009). Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. *Meat Science*, *82*, 266–271. https://doi.org/10.1016/j.meatsci.2009.01.019

Choi, Y. S., Kim, H. W., Hwang, K. E., Song, D. H., Kim, Y. J., Jung, T. J., … Kim, C. J. (2015). Optimizing the combination of smoking and boiling on quality of korean traditional boiled loin (*M. longissimus dorsi*). *Korean Journal of Food Science and Animal*, *35*, 149–155. https://doi.org/10.5851/kosfa.2015.35.2.149

Clifford, M. N., Tang, S. L., & Eyo, A. A. (1980). Smoking of foods. *Process Biochemistry*, *15*, 10–26.

Codex alimentarius. (2005). *Document de travail sur la contamination des denrées alimentaires par les hydrocarbures aromatiques polycycliques (HAP)*. 11 p.

Collignan, A., & Raoult-Wack, A. L. (1992). Dewatering through immersion in sugar/salt concentrated solutions at low temperature. An interesting alternative for animal foodstuffs stabilisation. In A. S. Mujumdar (Ed.), *Drying '92* (pp. 1887–1897). Amsterdam, The Netherlands: Elsevier Science Ltd.

Commission Européenne. (2006). *Règlement de la Commission (EU) No 1881/2006 du 19 décembre 2006 portant fixation de teneurs maximales pour certains contaminants dans les denrées alimentaires*. 40 p.

Craplet, C., & Josette, C. (1980). *Dictionnaire des aliments et de la nutrition* (p. 494). Paris, France: Le hameau éditeur.

Davey, C. L., & Gilbert, K. V. (1974). Temperature-dependent cooking toughness in beef. *Journal of the Science of Food and Agricultural*, *25*, 931–938. https://doi.org/10.1002/jsfa.2740250808

DE/MAEP. (2014). *Annulaire statistique sur l'élevage*. Rapport.

Degnon, R., Agossou, V., Adjou, E., Dahouenon-ahoussi, E., Soumanou, M., & Sohounhloue, C. (2013). Évaluation de la qualité microbiologique du chinchard (*Trachurus trachurus*) au cours du processus de fumage traditionnel. *Journal of Applied Biosciences*, *67*, 5210–5218.

EFSA. (2008). Polycyclic aromatic hydrocarbons in food: Scientific opinion of the panel on contaminants in the food chain. *The European Food Safety Authority (EFSA) Journal*, *724*, 1–114.

Egbunike, G. N., & Okubanjo, A. O. (1999). Effects of processing upon the quality of Nigerian meat products. *Livestock Production Science*, *59*, 155–163. https://doi.org/10.1016/S0301-6226(99)00024-X

European Commission. (2002). *Opinion of the Scientific Committee on Food on the risk to human health of polycyclic aromatic hydrocarbons in food*. SCF/CS/CNTM/PAH/29/Final.

FAO. (2012). *West African Food Composition Table*. Rome: Food and Agricultural Organization of the United Nations. 171 p.

FAO. (2018). *Bilan des disponibilités alimentaires* [en ligne]. Retrieved from www.fao.org/faostat/en/#data/FBS

Folch, J., Lees, M., & Stanley, G. H. S. (1957). A simple method for the isolation and purification of total lipides from animal tissues. *Journal of Biological Chemistry*, *226*, 497–509.

Hajaligol, M., Waymack, B., & Kellogg, D. (1999). American chemical society. *Division of Fuel Chemistry*, *44*, 251–255.

Hajaligol, M., Waymack, B., & Kellogg, D. (2001). Low temperature formation of aromatic hudrocarbon from pyrolysis of cellulosic materials. *Fuel*, *80*, 1799–1807.

Horne, P. A., & Williams, P. T. (1996). Influence of temperature on the products from the flash pyrolysis of biomass. *Fuel*, *75*, 1051–1059. https://doi.org/10.1016/0016-2361(96)00081-6

Houndonougbo, M., Adjolohoun, S., Aboh, B., Singbo, A., & Chrysostome, C. (2012). Caractéristiques du système d'élevage porcin au Sud-Est du Bénin. *Bulletin de la Recherche Agronomique du Bénin (BRAB) Numéro spécial Elevage & Faune*, 15–21.

Idah, P. A., & Nwankwo, I. (2013). Effects of smoke-drying temperatures and time on physical and nutritional quality parameters of Tilapia (*Oreochromis niloticus*). *International Journal of Fisheries and Aquaculture*, *5*, 29–34.

Iko Afé, O. H., Saegerman, C., Kpoclou, Y. E., Anihouvi, V. B., Douny, C., Igout, A., … Scippo, M.-L. (2020). Polycyclic aromatic hydrocarbons contamination of traditionally grilled pork marketed in South Benin and health risk assessment for the Beninese consumer. *Food Additives & Contaminants: Part A*, *37*(5), 742–752. https://doi.org/10.1080/19440049.2020.1726502

Kpoclou, E., Anihouvi, V., Azokpota, P., Soumanou, M., Douny, C., Brose, F., … Scippo, M.-L. (2014). Effect of fuel and grill type on the polycyclic aromatic hydrocarbon (PAH) levels in smoked shrimp, a Beninese food condiment. *Food Additives and Contaminants: Part A*, *31*, 1212–1218.

Martens, C., Fanning, K. A., & Manheim, F. T. (1982). La production, la consommation et le transport du méthane dans les eaux interstitielles des sédiments marins côtiers. *in THE DYNAMIC ENVIRONMENT OF THE OCEAN FLOOR; USA; LEXINGTON, MA:D. C. HEATH AND CO.; DA. 1982, BIBL. 27 REF.; ISBN 0-669-02809-6; ILL*, 187–202. Retrieved from https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=PASCALGEODEBRGM8320467062

Marti, K. (2002). *Catalogue d'éléments de construction avec calcul de la valeur U*. Office fédéral de l'énergie OFEN. 80 p.

Mopate, Y., & Kabore-Zoungrana, C. (2013). Production, commerce et consommation de la viande porcine dans quelques villes d'Afrique de l'Ouest et du Centre. 37 p.

Oz, F., & Yuzer, M. O. (2016). The effects of cooking on wire and stone barbecue at different cooking levels on the formation of heterocyclic aromatic amines and polycyclic aromatic hydrocarbons in beef steak. *Food Chemical*, *203*, 59–66. https://doi.org/10.1016/j.foodchem.2016.02.041

PAFILAV. (2014). Etude des filières Lait et Viandes. In *Rapport définitif sur la filière bétail et viande*. Projet d'Appui aux filières Lait et Viande, editor, p. 85.

Pana, M. (2012). Impact des traitements thermiques sur la structure des protéines de lentilles et leur digestibilité. Mémoire pour l'obtention de grade de Maîtrise ès sciences (M.Sc.), Faculté des Sciences de l'Agriculture et de l'Alimentation, Université de LAVAL, Quebec, 84 p.

Pearson, A., & Gillett, T. (1999). *Processed meats* (3rd ed.). New York, NY: Aspen Publishers Inc.

Poligné, I. (2001). Etude des transferts et des mécanismes réactionnels lors du salage, séchage, cuisson et fumage de pièces de viande: cas du porc boucane à la Réunion. (Thèse de doctorat en génie des procédés de l'Université de la Réunion).

Poligné, I., Collignan, A., Trystram, G., & Pieribattesti, J. C. (2000). Traditional techniques for processing boucane, a salted/dried/smoked meat product from Reunion. *Tropical Science*, *41*(2), 90–94.

Poma, J. P. (1998). *Le jambon sec et les petites salaisons*. Paris: Erti.

Ratsimba, A., Rakoto, D., Arnaud, E., Goli, T., Ricci, J., Jeannoda, V., … Rivier, M. (2014). Improving the smoking process of kitoza, a traditional Malagasy meat product. *Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux*, *67*(3), 99–100.

Ratsimba, A., Rakoto, D., Jeannoda, V., Andriamampianina, H., Talon, R., Leroy, S., … Arnaud, E. (2019). Physicochemical and microbiological characteristics of kitoza, a traditional salted/dried/smoked meat product of Madagascar. *Food Science & Nutrition*, *7*(8), 2666–2673. https://doi.org/10.1002/fsn1003.1122

Ravindra, K., Sokhi, R., & Vangrieken, V. R. (2008). Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmospheric Environment*, *42*, 2895–2921. https://doi.org/10.1016/j.atmosenv.2007.12.010

Rivier, M., Kebe, F., & Goli, T. (2009). *Fumage de poissons en Afrique de l'Ouest pour les marchés locaux et d'exportation*. Rapport de l'Agence Universitaire de la Francophonie, 19.

Ruiter, A. (1979). Color of smoked foods. *Food Technology*, *33*, 54–63.

Sebastian, P., Bruneau, D., Collignan, A., & Rivier, M. (2004). Drying and smoking of meat: Heat and mass transfer modeling and experimental analysis. *Journal of Food Engineering*, *70*, 227–243. https://doi.org/10.1016/j.jfoodeng.2004.10.002

Solomon, I. P., Ekanem, E. O., & Okubanjo, A. O. (1994). Effects of salt (NaCl) level and smoke application on chemical and sensory characteristics of unam inung, a cured Nigerian pork product, Der tropenlandwirt. *Zeitschrift fûr die landwirtschaft in den tropen und Subtropen*, *95*, 157–169.

Stołyhwo, A., & Sikorski, Z. E. (2005). Polycyclic aromatic hydrocarbons in smoked fish-a critical review. *Food Chemical*, *91*, 303–311. https://doi.org/10.1016/j.foodchem.2004.06.012

Toth, L., & Blaas, W. (1972). Einfluss det Ra¨uchertechnologie auf den Gehalt von gera¨ucherten Fleischwaren an cancerogenen KohlenWasserstoffen. II. Einfluss der Glimmtemperatur des Holzes sowie der Ku¨ hlung, Wa¨sche und Filtration des Ra¨ucherrauches. *Fleischwirtschaft*, *52*, 1422–1429.

Vautier, A. (2006). *Les valeurs nutritionnelles de la viande de porc: analyses sur 9 pièces uvc*. p. 82.

Viegas, O., Novo, P., Pinto, E., Pinho, O., & Ferreira, I. M. P. L. V. O. (2012). Effect of charcoal types and grilling conditions on formation of heterocyclic aromatic amines (HAs) and polycyclic aromatic hydrocarbons (PAHs) in grilled muscle foods. *Food Chemical and Toxicology*, *50*, 2128–2134. https://doi.org/10.1016/j.fct.2012.03.051

Williams, P. T., & Horne, P. A. (1995). Analysis of aromatic hydrocarbons in pyrolytic oil derived from biomass. *Journal of Analytical and Applied Pyrolysis*, *31*, 15–37. https://doi.org/10.1016/0165-2370(94)00814-H

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