Assessment of the physicochemical characteristics, chemical and microbiological safety of two types of kilichi, a grilled meat produced in Niger

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Abstract
Production of kilichi, a grilled meat of West Africa, is a common method of meat preservation in Niger. Thirty samples of condiments-coated kilichi and uncoated kilichi collected in Niger, were analyzed for microbiological contamination, as well as NaCl, protein and lipid contents, using standard methods. Contamination with Polycyclic Aromatic Hydrocarbons (PAHs) was also assessed using a HPLC–FLD technique. Highly significant differences ($p < .001$) were observed between coated kilichi and uncoated kilichi, for NaCl content (2.56% and 1.40%), for proteins (51% and 72%) and lipids (18% and 13%), respectively. Water activity was low in both kilichi, showing a potential microbial stability. Among the 15 European Union (EU) priority PAHs, 12 were detected in the samples. About 56.3% of coated kilichi samples exceeded the EU maximal limit for BaP, and 75% exceeded the EU maximal limit for the sum of 4 PAHs (PAH4). For uncoated kilichi, 28.6% of samples did not meet the standards for BaP and PAH4. About 6% of coated kilichi samples were not compliant with standards related to Staphylococcus aureus, Bacillus cereus, Clostridium perfringens, and 31%, 50% for yeasts and fungi, respectively. Escherichia coli and Enterobacteria were below the detection limit in both kilichi, but Salmonella and Bacillus cereus were detected only in one coated kilichi. The noncompliant samples of uncoated kilichi were in the proportions varying between 7% –86% for S. aureus, C. perfringens, yeasts, and fungi. This study showed potential risks associated with the consumption of traditionally produced kilichi in Niger due to both PAHs and pathogen bacteria contamination.

KEYWORDS
microbiological contamination, polycyclic aromatic hydrocarbons, quality, risk assessment

1 | INTRODUCTION

Breeding plays a central role in the countries’ economy of the Sahelian zone of West Africa, where it constitutes an important source of income for millions of rural or periurban populations whose mean of existence is linked to pluvial agriculture (Kamuanga et al., 2008). Breeding has favored the development of a dynamic artisanal food processing sector producing and selling a number of meat products,
and providing substantial revenues for producers and animal proteins for populations.

Among these products, kilichi, a dried meat, coated with condiments or uncoated, then grilled, is well appreciated by consumers in local markets in Niger (Beidari & Mahamadou, 2014). Kilichi is a ready-to-eat meat product traditionally manufactured with bovine, camel, ovine, or goat fresh meat. Coated kilichi is produced by trimming meat, cutting into pieces of parallelepiped shape before slicing into flat thin sheets. The sheets are spread on millet or sorghum panicle mats for a first sun drying followed by marinating in a sauce made of complex blend of spices, before a second sun drying and briefly grilling at wood fire. For uncoated kilichi, the sun dried meat is slightly seasoned and grilled. Kilichi is generally packaged, only just before selling to consumers (Boubacar et al., 2019). The conditions of processing and distribution practices do not guaranty the safety of this product. Analyses conducted on this product in Chad and Cameroun showed high levels of contamination by pathogenic bacteria, in particular Salmonella, presenting a risk of acute intoxication for consumer (Kimassoum et al., 2017; Mbawala, Daoudou, & Cameroun showed high levels of contamination by pathogenic Salmonella bacteria, in particular Salmonella, presenting a risk of acute intoxication for consumer (Kimassoum et al., 2017; Mbawala, Daoudou, & Ngassoum, 2010). The problem of pathogenic bacteria seems to be the most worrying, but grilling step of the product shows risk of contamination by Polycyclic Aromatic Hydrocarbons (PAHs). In fact, PAHs are toxic chemical contaminants generated during the combustion of organic material. Food products mostly get chemical contamination through thermal processing such as smoking, roasting, grilling, frying, and drying where they are in direct contact with the combustion source (Farhadian, Jinap, Abas, & Sakar, 2010; Rose et al., 2015; Roseiro, Gomes, Patarata, & Santos, 2012). At high concentration, PAHs could be carcinogenic and genotoxic. Some respiratory, cardiologic, immunologic, reproductec, and genotoxic imperfections in human and animals are linked to the harmful effect of PAHs (EFSA, 2008; Olabemiwo & Ogunsola, 2014). The parameters like temperature, time, distance, biomass, relative humidity, and characteristics of the products have effect on the absorption and penetration of smoke components in product, and therefore, on its quality and stability (Akpambang et al., 2009; Santos, Gomes, & Roseiro, 2011).

The Scientific Committee on Food (SCF) of the European Commission (2002) identified 15 Polycyclic Aromatic Hydrocarbons (15 EU PAHs) as carcinogenic and genotoxic, which are Benzo[a]anthracene (BaA), Benzo[b]fluoranthene (BbF), Benzo[j]fluoranthene (BjF), Benzo[k]fluoranthene (BKF), Benzo(a)pyrene (BaP), Benzo[g,h,i]perylene (Bgp), Chrysene (CHR), Cyclopenta[c,d]pyrene (CCP), Dibenzo[a,h]anthracene (DHA), Dibenzo[a,e]pyrene (DPe), Dibenzo[a,h]pyrene (Dhp), Dibenzo[a,i]pyrene (DiP), Dibenzo[a]pyrene (Dip), Indeno[1,2,3-cd]pyrene (Icp), and 5-methylchrysene (5MC). On the recommendation of the Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2005) a 16th compound, Benzo[c]fluorene (BcF), has been added to the list. Little has been done on the characterization of kilichi in Niger, particularly on physicochemical, nutritional, and microbiological aspects, and to our knowledge, no study on the contamination by PAHs. Therefore, the aim of this work was to assess the nutritional, chemical, and microbiological characteristics of kilichi produced in Niger, and to estimate the risks associated with the consumption of PAHs contaminated kilichi for the purpose of improving its manufacturing process and quality.

2 | MATERIALS AND METHODS

2.1 | Sampling

The sampling was carried out in the regions of Agadez, Maradi, Niamey, Tahoua, & Zinder. About 30 samples of uncoated and coated kilichi were randomly bought at 17 manufacturing sites and markets of the regions as distributed in Table 1. The samples were composed of 14 uncoated samples (11 of beef and 3 of camel) and 16 coated samples (13 of beef and 3 of camel). Each collected sample was packaged in a sterile stomacher bag and stored in refrigerator for microbiological analysis and in freezer at −20°C for physicochemical analyses and determination of PAHs.

2.2 | Physicochemical analyses

The physicochemical parameters determined were: pH, moisture, water activity, protein, fat, ash, and NaCl contents. The pH was measured as described by Mgbemere, Akpapunam, and Igene (2011). The moisture of samples was determined using the ISO 1442/1997 standard. The water activity (a_w) was measured according to the method described by Anihouvi, Ayerno, Hounhouigan, and Sakyidawson, (2006) using a hygrometer (HygroLab, model Rotronic). The nitrogen content of samples was determined according to ISO 937/1978 standard, and the protein content was calculated by multiplying the nitrogen content by 6.25. The fat content was determined according to ISO 1444/1996. The determination of ash content was realized according to AOAC (1995) method 920.153. The NaCl content was assessed by measuring chloride concentration with a Chloride Analyzer, Model 926, Sherwood Scientific Ltd., 1997.

2.3 | Polycyclic aromatic hydrocarbons analyses

The 15 Polycyclic Aromatic Hydrocarbons (PAHs) were determined in the kilichi samples using a High-Performance Liquid Chromatography coupled with a fluorescence detector (HPLC-FLD) according to the method described by Brasseur et al., (2007). A Model 600 E solvent delivery system, equipped with a Model 717 automatic injector, a Mistral TM oven, and 2,475 Fluorescence detector (WATERS Corporation), was used. A C18 Pursuit 3 PAH (100 × 4.6 mm, 3 µm) equipped with a ChromGuard (10 × 3 mm) precolumn, both for Varian (Agilent Technologies) were used to separate the PAHs. The PAHs were extracted from the kilichi samples using the method described by Veyrand et al., (2007). The kilichi samples were frozen in liquid nitrogen and then freeze-dried for 36–48H. For the extraction, one g of lyophilized kilichi, was homogenized with a mixture of hexane/aceton (50/50, v/v) by using the Accelerated Solvent Extraction system (ASE 200; Dionex). Then the solvent was evaporated until 1 ml, and
then, reconstituted with 5 ml of cyclohexane. The reconstituted extract was then purified on a Chromatographic Column (Envi Chrom P Supelco), previously conditioned with 15 ml of ethyl acetate and 10 ml of cyclohexane. The extract was poured on the Column which was then washed two times with 3 ml of cyclohexane/ethanol (70/30, v/v) mixture. The PAHs were eluted three times using 4 ml of cyclohexane/ethyl acetate (40/60 v/v) mixture. The solvent was evaporated to dryness, then 90 µl of acetonitrile and 10 µl of the deuterated DiP-D14, used as internal standard (LGC Promochem, France), were added. Twenty-five (25) µl of this final extract was injected in the HPLC column. The limit of quantification (LOQ) corresponded to the first point of the calibration curve for each PAH and were 0.96 µg/kg pyrene and 0.24 µg/kg fresh weight for the rest of the PAHs.

2.4 | Microbiological analyses

Microbiological analyses were performed to determine the spoilage and pathogen germs like Aerobic Mesophilic Bacteria (AMB), Enterobacteriaceae, *Escherichia coli*, *Clostridium perfringens*, yeast and fungi, *Staphylococcus aureus*, *Bacillus cereus*, and *salmonella* spp. The analyses were performed on the primary dilution and its serial decimal dilutions according to ISO 6887-1/1999 by using the peptone buffer water solution as dilution liquid. The enumeration of Aerobic Mesophilic Bacteria, Enterobacteria, and *E. coli* was realized according to ISO 4833/2003, ISO 21528-2/2004, and ISO 16649-2/2001, respectively. *Clostridium perfringens* was enumerated according to ISO 7937/2004 while yeast and fungi load was enumerated using ISO 21527-2/2008. The enumerations of *Staphylococcus aureus* and *Bacillus cereus* were performed according to ISO 6888-1/2003 and ISO 7932/2004, respectively. *Salmonella* were investigated using ISO 6579/2002.

2.5 | Statistical analyses

The software SAS version 8 was used for statistical analysis of data. The means, medians, and standard deviations were calculated. The means comparisons were done with the test of Student at a threshold of 5% significance. The General Linear Model (GLM) was used for one-way analysis of variance (ANOVA). The Least Square Mean was used to compare the two types of *kilichi*.

3 | RESULTS AND DISCUSSION

3.1 | Physicochemical characteristics of the *kilichi*

The results obtained from physicochemical analysis of both types of *kilichi* samples are presented in Table 2. The means of moisture content of *kilichi* are close to that obtained by Kalilou (1997) and Yacoubu (2009), on both types of *kilichi* produced in Niger; and on coated *kilichi* produced in Nigeria and Cameroun (Apata, Osidibo, Apata, & Okubanjo, 2013; Jones, Tanya, Mboung, Fonkem, & Silverside, 2001; Mgbemere et al., 2011; Olusola, Okubanjo, & Omojola, 2012). However, these values are lower than those obtained on Nigerian uncoated *kilichi* (19%-26% moisture content) (Raji, 2006) and on dried Bitong (21.5%-25.3%) (Petit, Caro, Petit, Santchurn, & Collignan, 2014). They are also in agreement with the standard (at least 88% of dry matter) stipulated by the National Council of Normalization of Niger (Conseil National de Normalisation du Niger—CNNN, 2004). According to Prescott, Harley, and Klein (2002), the microbial growth would be impossible in food products with water activity values lower than 0.7. So, the mean water activity values registered in the studied samples are low enough to avoid the growth of pathogenic bacteria in both types of *kilichi*. These results are in agreement with those obtained by Jones et al., (2001) for Cameroun coated *kilichi* (0.59) but lower than those of Petit et al. (2014) on dried Bitong (0.65–0.68), and Ratsimba et al., (2017) on dried Kitoza (0.86) and smoked Kitoza (0.94). Bitong is a traditional meat product made from raw meat by salting, curing, and drying. There are two types, moist beef Bitong with high moisture content (higher than 40%) and dried Bitong. Kitoza is a traditional meat product from Madagascar, manufactured with strips of pork or beef. The process includes salting and mixing with spices followed by sun drying or smoking. Uncoated *kilichi* presents a mean pH lower than that of coated *kilichi*. The values found are similar to the results reported by Kalilou (1997), with a pH ranging between 5.7 and 6.2 for both types of *kilichi*, by Jones et al., (2001) for coated *kilichi* (5.81), by Petit et al., (2014) for dried Bitong (5.5–6.26) and by Ratsimba et al., (2017) for dry Kitoza and smoked Kitoza (5.67 and 5.87, respectively). These mean pH levels are lower than average value of 6.33 obtained by Eke et al. (2013) on *Dambu namma* (fried ground beef). The pH is an important parameter to control the sensory quality of meat. The average salt content in coated *kilichi* is higher than that in uncoated *kilichi*; this is justified by the addition of salt and bouillon cube in the seasoning sauce used to coat *kilichi*. The salt should play a role of preservative at short and average term but could be a source of disease. Petit et al., (2014) and Ratsimba et al., (2017) have reported salt contents of 5.5%–7.9%, 2.83%, and 3.61% in dried Bitong, dried Kitoza, and smoked Kitoza, respectively. The average protein content for both *kilichi* types are compliant with CNNN

**TABLE 1** Distribution of *kilichi* samples collected in different regions of Niger for analyses

| Sampling areas (Region) | Uncoated *kilichi* | Coated *kilichi* | Total |
|-------------------------|--------------------|-----------------|-------|
| Agadez                  | 3                  | 3               | 6     |
| Maradi                  | 3                  | 3               | 6     |
| Niamey                  | 2                  | 4               | 6     |
| Tahoua                  | 3                  | 3               | 6     |
| Zinder                  | 14                 | 16              | 30    |
TABLE 2  Physicochemical characteristics of uncoated and coated kilichi

| Compound       | Uncoated kilichi (n = 14) | Coated kilichi (n = 16) |
|----------------|---------------------------|-------------------------|
|                | Min | Max | Mean | Median | SD  | Min | Max | Mean | Median | SD  |
| pH             | 5.3 | 6.4 | 5.76 | 5.7   | 0.31| 5.60| 6.4 | 6.05 | 6.08   | 0.24|
| a_w            | 0.401 | 0.486 | 0.445 | 0.445 | 0.026| 0.427| 0.593 | 0.488 | 0.479 | 0.049|
| NaCl (% DM)    | 0.53 | 3.61 | 1.43 | 1.2   | 0.84| 1.37| 3.39 | 2.51 | 2.56   | 0.56|
| Moisture (%)   | 7.31 | 11.01 | 8.76 | 8.47  | 1.12| 7.24| 11.7 | 9.83 | 10.13  | 1.30|
| Protein (%)    | 62.74 | 84.48 | 72.32 | 72.48 | 5.83| 37.66| 62.1 | 51.23 | 50.71  | 6.63|
| Fat (%)        | 5.71 | 22.64 | 13.42 | 13.2  | 4.8 | 11.17| 24.73 | 17.53 | 18.74  | 3.43|
| Ash (%)        | 4.12 | 6.95 | 5.19 | 4.97  | 0.89| 5.12| 8.47 | 6.24 | 6.19   | 0.80|

Abbreviations: a_w, water activity; DM, dry matter basis; Max, maximum; Min, minimum; n, number of samples analyzed; SD, Standard deviation.

standard (50 to 70%) and the average coated kilichi protein content is similar to that obtained (49.8%) by Mgbemere et al., (2011). However, these results are lower than those obtained by Kalilou (1997), which are 64% protein content for coated kilichi and 74% for uncoated kilichi, and lower than those obtained by Jones et al., (2001), Olusola et al., (2012), and Apata et al., (2013), which are 61.95%, 62.33%, and 66.83% to 72.77% for coated kilichi, respectively. Also, the results showed that 06/16 (37.5%) coated kilichi had their protein content lower than the minimum (50%) recommended by the CNN.

The two types of kilichi are richer in protein than Dambu namma (fried ground beef) which values vary from 37.14% to 45.88% (Eke et al., 2013). Average values of fat content are compliant with CNNN standards (10 to 25%). However, 03/14 samples (21.43%) of uncoated kilichi are not compliant with CNNN standards, with a fat content lower than 10%. On one hand, fat contents of coated kilichi are higher than value (6.90%) reported by Olusola et al., (2012) and slightly higher than those obtained by Kalilou (1997), Mgbemere et al., (2011) and Apata et al., (2013); on the other hand, they are lower than value (25.39%) obtained by Jones et al., (2001). The difference between the two types of kilichi can be explained by use of many seasoning stuffs for coated kilichi. The fat content in kilichi should be low and of good quality; otherwise kilichi shelf life is short. Average ash values of the two types of kilichi are similar to that obtained by Yacouba (2009) (4.07% and 6.96%, respectively) and to that obtained by Mgbemere et al., (2011) and Jones et al., (2001) on the coated kilichi (5.2% and 6.2%, respectively) but lower than 10.31% reported by Olusola et al., (2012). These values on the other hand are higher than 3.70% obtained by Apata et al., (2013). The higher ash content of coated kilichi may be due to spices added.

The comparison of the two types of kilichi show a significant effect (p < .05) on moisture and fat, highly significant effects (p < .01) on pH and water activity, and very highly significant effects (p < .001) on salt, proteins, and ash contents (Table 3). The high value of the Mean standard error, shows the lack of standardization of the process. For Kilichi type production diverse types and quality of meat, different materials and practices, seasonings like spices which depend on producer are used (Boubacar et al., 2019).

3.2 | Contamination of Kilichi samples by PAHs

Upon 15 EU PAHs considered as cancerogenic and genotoxic, 12 were detected and quantified in the two types of kilichi: Benzo[a]Anthracène (BaA); Benzo[a]pyrene (BaP); Benzo[b]fluoranthene (BbF); benzo[c]fluorone (BcF); Benzo[ghi]perylene (BgP); Benzo[j]fluoranthene (Bf); Benzo[k]fluoranthene (BkF); Chrysene (CHR); Dibenzo [a, h]anthracene (DHA); Dibenzo [a, e]pyrene (DeP); 5-methylchrysene (5MC); and Indeno[1,2,3-cd]pyrene (ICP) (Table 4). Dibenzo[a, h]pyrene (Dhp), Dibenzo[a, e]pyrene (Dip), and Dibenzo[a, j]pyrene (DIP) have not been detected in the kilichi samples. Lorenzo, Purriños, Fontán, and Franco (2010) reported similar average values in smoked sausages including Androlla (36.45 µg/kg) and Botillo (29.39 µg/kg). Stumpe-Vīksna, Bartkevičs, Kukāre, and Morozovs (2008) on the other hand found higher average values in smoked meats (47.94 to 470.91 µg/kg). The lower average values of PAHs registered in kilichi samples collected from Niger compared to that of the literature is probably due to the fact that some samples are collected from localities of Maradi where grilling is not applied. The different types of kilichi are contaminated in decreasing order by BaA, CHR, BcF, BbF, BjF, BaP, BkF, BgP, ICP, DeP, DHA, and 5MC. The distribution of these contaminants in coated kilichi represents 22.44%, 18.73%, 20.39%, 8.83%, 7.01%, 6.86%, 5.30%, 4.42%, 3.22%, 1.40%, 0.91%, and 0.57% of the total sum of PAHs respectively, against 19.38%, 18.99%, 15.59%, 10.13%, 9.07%, 8.46%, 3.30%, 6.08%, 4.93%, 2.29%, 0.75%, and 0.93% for uncoated kilichi. This distribution is similar to the relative proportion of the 15 EU reported by EFSA (2008) on 1,375 grilled or smoked meat products of many countries of the European Union and Veyrand et al., (2013) on 725 food products consumed in France.

The adsorption of PAHs depends on several factors, in particular the wood species used to generate the smoke (Lorenzo et al., 2010). Boubacar et al., (2019) reported 20 types of wood used by processors in grilling kilichi in Niger. This difference of PAHs can also be due to drying/smoking procedures and climate conditions (temperature and humidity) in the regions (Roseiro et al., 2012).

There was a significant (p < .05) difference between both types of kilichi as far as DhA, BcF, and BaA concentrations were concerned. Also, significant (p < .1) differences of BkF and the sum of PAHs...
were observed between both types of kilichi (Table 5). Benzo[a] Anthracène, Benzo[c]fluorene, and Chrysene are the most abundant contaminants regardless the type of Kilichi. However, these contaminants concentrations are higher in coated kilichi (1.5 to 2 times) than in uncoated kilichi. Coating is generally done by covering meat surface with peanut paste-based sauce before grilling. The application of this sauce generally rich in fat on the meat before grilling could affect the level of contamination in PAHs which absorption is proportional to product fat content (Duedahl-Olesen et al., 2015; Farhadian et al., 2010; Santos et al., 2011). In fact, while grilling, the fat melts and falls on the combustible thereby causing their pyrolysis and leading to the formation of PAHs.

The European Commission (Rule n°835/2011) fixed maximal content of 2 µg/kg for Benzo(a)pyrene (BaP) and 12 µg/kg for PAH4 (sum of (BaP; BaA; BbF and Chrysene) in food commodities like meat and meat products (EFSA, 2008). BaP concentrations contribute at 8.46% and 6.86% to the formation of the total sum of PAHs in uncoated and coated kilichi, respectively. BaP concentrations registered on kilichi are similar to those obtained by Manda et al., (2012) on fried meat (2.32 µg/kg) and Husam et al., (2011) on Tikka meat (2.48). Smaller values (0.14 to 1.10 µg/kg) have been reported by EFSA (2008), Roseiro et al., (2012), Santos et al., (2011), Farhadian et al., (2010); Rozentāle et al., (2015) and Matorell et al., (2010) on 2,145 meat products of EU countries including smoked meat products of Spain; kebab: smoked meat of Latvia and meat products of Catalonia (Spain). However, previous studies have recorded higher values (7 to 91 µg/kg) on smoked and grilled meat (Satay). Hamburgers meat, smoked Gentile di maile in Italy, Suya, and smoked Shrimp (Manda et al., 2012; Farhadian et al., 2010; Rose et al., 2015; Carrabs et al., 2014; Akpambang et al., 2009 and Kpoclou et al., 2013). The average concentration of PAH4 represents 57% of the total sum of PAHs for both types of kilichi.

Table 6 represents PAHs profile in analyzed kilichi samples with a toxicity threshold fixed at 2 µg/ kg for BaP and at 12 µg/ kg for PAH4. 56.3% of coated kilichi samples pass the toxicity threshold for BaP and 75% exceed the limit for PAH4. Also 28.6% of uncoated

### Table 3: Comparison of the physicochemical characteristics of the two types of kilichi

| Compound | Uncoated kilichi (n = 14) | Coated kilichi (n = 16) |
|----------|--------------------------|----------------------|
|          | pH                       | a_w                  |
|          | 5.75                     | 0.446                |
|          | NaCl (%DM)               | 1.40                 |
|          | 8.77                     | 0.34                 |
|          | Protein (%)              | 72.43                |
|          | 13.40                    | 5.17                 |
|          | Ash (%)                  | 4.98                 |

**Abbreviations:** LS Mean, Least Squares Means; SE, Mean standard error.

**p value**

- .002**
- .008**
- .003***
- .034
- .001***
- .015
- .0002***

### Table 4: PAHs levels (µg/kg) in investigated kilichi samples collected in Niger

| PAHs | Uncoated kilichi (n = 14) | Coated kilichi (n = 16) |
|------|--------------------------|------------------------|
|      | Min | Max | Mean | Median | SD  | Min | Max | Mean | Median | SD  |
| BbF  | 0.85 | 8.16 | 2.30 | 1.62 | 1.88 | <LOQ | 8.9 | 3.40 | 2.43 | 2.65 |
| DhA  | <LOQ | 0.52 | <LOQ | <LOQ | <LOQ | <LOQ | 0.87 | 0.35 | 0.31 | 0.24 |
| BgP  | 0.47 | 4.54 | 1.38 | 1.12 | 1.02 | 0.26 | 4.4 | 1.70 | 1.44 | 1.29 |
| DeP  | <LOQ | 1.93 | 0.52 | <LOQ | 0.57 | <LOQ | 1.41 | 0.54 | 0.53 | 0.44 |
| BjF  | <LOQ | 6.56 | 2.06 | 1.39 | 1.52 | <LOQ | 6.52 | 2.70 | 2.2 | 1.95 |
| BcF  | 1.16 | 10.73 | 3.54 | 2.65 | 2.55 | <LOQ | 18.84 | 7.85 | 5.98 | 6.05 |
| BaA  | 1.66 | 10.64 | 4.40 | 3.91 | 2.36 | 1.98 | 23.13 | 8.64 | 6.62 | 5.92 |
| CHR  | 1.65 | 9.16 | 4.31 | 3.95 | 2.22 | 1.59 | 25.86 | 7.21 | 6.16 | 5.67 |
| SMC  | <LOQ | 1.48 | <LOQ | <LOQ | <LOQ | <LOQ | 0.94 | <LOQ | <LOQ | <LOQ |
| BkF  | 0.31 | 1.81 | 0.75 | 0.55 | 0.44 | <LOQ | 10.03 | 2.04 | 0.94 | 2.63 |
| BaP  | 0.67 | 6.59 | 1.92 | 1.3 | 1.63 | 0.32 | 7.06 | 2.64 | 2.27 | 1.94 |
| IpC  | <LOQ | 2.41 | 1.12 | <LOQ | <LOQ | <LOQ | 3.1 | 1.24 | 1.11 | 0.86 |
| Sum PAHs | 9.74 | 64.13 | 22.67 | 18.42 | 14.74 | 6.88 | 97.28 | 38.54 | 34.54 | 24.39 |
| PAH4 | 4.98 | 34.55 | 12.93 | 11.2 | 7.9 | 4.37 | 60.67 | 21.89 | 17.45 | 15.03 |

**Abbreviations:** LOQ, limit of quantification; Max, maximum; Min, minimum; PAH4, BbF + BaA+BaP + Chrysene; SD, Standard deviation.
kilichi samples are not in accordance with the standard for BaP as well as for PAH4. Therefore, a consumer has 75% chance to consume a coated kilichi contaminated by the PAH4 and 56% by BaP against 29% for uncoated kilichi. Considering the Bench Mark Limit dose (BMDL10), an adult of 60 kg is exposed to an intoxication risk by BaP if he consumes more than 210 g of uncoated kilichi per day, and for the PAH4, maximal ingestion level is 156 g. For coated kilichi, the daily maximal ingestion for an adult of 60 kg is 162 g and 90g for BaP and PAH4, respectively.

3.3 | Microbiological contamination of kilichi

The microbial counts in each type of kilichi and their compliance with CNNN (2004) and Public Health Laboratories (PHLS) (Gilbert et al., 2000) standards are given in tables 7 and 8. A total of 10/14 (71%) of uncoated kilichi samples are not compliant with standards against 100% of coated kilichi. For each type of kilichi, microbial load could come from a post-treatment contamination because of application of high temperature of grilling for most kilichi samples and their low postprocessing water activity. The AMB load is an important indicator of general hygiene. Boubacar et al., (2019) reported that processors used inappropriate packaging for storage and sale of kilichi. The results also showed that 1/16 (6%) of coated kilichi samples are not compliant with standards for S. aureus, B. cereus, C. perfringens, and 5/16 (31%) and 8/16 (50%) are not compliant for yeast and fungi, respectively. E. coli and enterobacteria were not detected; however, salmonella was detected in one sample. A consumer has a 6% chance to be exposed to an intoxication by pathogens bacteria by consuming coated kilichi. For uncoated kilichi, the noncompliant samples for S. aureus, C. perfringens, yeasts, and fungi are in the proportions 2/14 (14%), 1/14 (7%), 3/14 (21%), and 12/14 (86%), respectively. Neither, E. coli, nor B. Cereus and enterobacteria were detected in any uncoated kilichi samples. These mean values obtained are lower than those reported by Mbawala et al., (2010) for spicy coated kilichi and not spicy coated kilichi. Raji, (2006) also reported higher mean values for uncoated kilichi. However, Jones et al., (2001) reported a lower value of AMB for coated kilichi. Averages of AMB, E. coli, S. aureus load counted on the two types of kilichi are lower that than counted on Balangu (grilled meat) (Moshood, Tengku, & Ibrahim, 2012) and on Dambun nama (fried ground beef) (Salihu et al., 2010).

For all germs investigated, coated kilichi present higher loads than uncoated kilichi. This difference could be due to germs carried by seasonings spices. Shamsuddin (2009), Frazier and Westhoff (2006), have reported that some spices do not have antimicrobial activity, so that the meat treated with spices could have high microbial load. In the same logic, Price and Schweigert (1971) stated that unless the spices are treated to reduce their microbial load, they can be a source of high number of undesirable germs in the product to which they are added. The presence of S. aureus, Enterobacteria, C. perfringens, E. coli, and Salmonella in the products is an indication of poor hygienic practices during processing. Edema, Osho, and Diala (2008) detected in spices used in the preparation of Suya (grilled meat product) the following microbial flora: AMB 3.42–3.50 × 10^5 cfu/g, yeast and fungi 1.27–1.43 × 10^5 cfu/g, Coliforms 0.37–0.47 × 10^5 cfu/g, Staphylococcus 0.37 × 10^5 cfu/g, Bacillus cereus 0.02 × 10^5 cfu/g, Salmonellas 0.37–0.43 × 10^5 cfu/g. These results confirm the high AMB load obtained in coated kilichi.

### TABLE 5 Comparison of PAHs profiles (µg/kg) in the two types of kilichi investigated in Niger

| PAHs | Uncoated kilichi | Coated kilichi | p value |
|------|-----------------|----------------|---------|
|      | LS mean | SE  | LS mean | SE  |        |         |
| BbF  | 2.40     | 0.66 | 3.31     | 0.62 | .330   |
| DhA  | 0.18     | 0.05 | 0.34     | 0.05 | .034   |
| BgP  | 1.43     | 0.33 | 1.66     | 0.31 | .615   |
| DeP  | 0.54     | 0.14 | 0.52     | 0.13 | .906   |
| BjF  | 2.15     | 0.49 | 2.63     | 0.46 | .480   |
| BcF  | 3.78     | 1.32 | 7.64     | 1.24 | .044   |
| BaA  | 4.72     | 1.20 | 8.36     | 1.13 | .038   |
| CHR  | 4.42     | 1.28 | 7.12     | 1.20 | .139   |
| SMC  | 0.20     | 0.10 | 0.23     | 0.10 | .872   |
| BkF  | 0.74     | 0.51 | 2.05     | 0.48 | .074   |
| BaP  | 1.99     | 0.51 | 2.57     | 0.48 | .419   |
| IcP  | 1.15     | 0.21 | 1.22     | 0.20 | .803   |
| Sum PAHs | 23.70 | 5.72 | 37.64 | 5.35 | .089 |
| 4 PAHs | 13.54 | 3.43 | 21.35 | 3.20 | .110   |

Abbreviations: LS Mean, Least Squares Mean; SE, Mean standard error. *p < 0.05: significance.

4 | CONCLUSION

This study on the physicochemical characteristics and safety of kilichi produced in five regions of Niger reveals that the microbiological quality of the studied samples is generally not satisfactory. The pathogen bacteria responsible for the food intoxication (B. cereus, S. aureus, and Salmonella spp) and germs indicators (100% coated kilichi and 70% uncoated kilichi) of nonrespect of hygiene practices were detected despite the unfavorable conditions (aw < 0.7) for their growth. Coated kilichi has a level of contamination higher than uncoated kilichi. As far as chemical contamination is concerned, to our knowledge, this preliminary study reports for the first time the level of aromatic polycyclic hydrocarbons contamination of kilichi in Niger. High levels of BaP (7.06 µg/kg) and PAH4 (60.67 µg/kg) contamination recorded in coated kilichi, indicators of PAHs toxicity, showed potential health risks for consumers. Nutritional, uncoated kilichi is richer in proteins than coated kilichi. However, coated kilichi is richer in lipids and in salt which high level can cause public health problems. The study showed that the manufacturing of the product is not standardized for each type of kilichi. Based on these results, future studies should be conducted for the implementation of an improved and standardized process of traditional kilichi. This will enable to obtain a product of better quality and safety.
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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

TABLE 6  Occurrence of kilichi types meeting the BaP and PAH4 standards in the market

| kilichi types          | BaP (concentration) | Sum PAH4 (concentration) |
|------------------------|---------------------|--------------------------|
|                        | ≤2 µg/kg*           | >2 µg/kg ≤12 µg/kg        | ≤12µg/kg**          | >12 µg/kg     |
| Uncoated kilichi       | 71.43%              | 28.57%                   | 71.43%              | 28.57%        |
| (n = 14)               |                     |                          |                      |               |
| Coated kilichi         | 43.75%              | 56.25%                   | 25.00%              | 75.00%        |
| (n = 16)               |                     |                          |                      |               |

*Maximum limit of BaP set by European Union Commission Regulation N. 1881/2006.
**Maximum limit of sum 4PAHs set by European Union Commission Regulation N. 1881/2006.

TABLE 7  Microbial load (Log_{10} CFU/g) of uncoated kilichi samples and compliance with standards (n = 14)

| Germs           | Positive samples | Min | Max | Median | Mean ± SD | Acceptable limit | Noncompliant samples |
|-----------------|------------------|-----|-----|--------|-----------|------------------|---------------------|
| AMB             | 14 (100%)        | 3.5 | 6.2 | 5      | 4.8 ± 0.8 | 4^a              | 10 (71%)            |
| S. aureus       | 2 (14%)          | 3.7 | 4.2 | 3.9    | 3.9 ± 0.38| 2^b              | 2 (14%)             |
| E. coli         | 0 (0%)           | <1  | <1  | <1     | <1        | 2^b              | 0 (0%)              |
| Enterobacteriaceae | 1 (7%)  | <1  | 1.8 | <1     | <1        | 4^b              | 0 (0%)              |
| Molds           | 12 (86%)         | <1  | 4.6 | 3      | 3.1 ± 1.2 | 2^a              | 12 (86%)            |
| Yeast           | 3 (21%)          | <1  | 4   | <1     | 1.3 ± 1.2 | 2^a              | 3 (21%)             |
| B. cereus       | 0 (0%)           | <1  | 1   | <1     | <1        | 4^b              | 0 (0%)              |
| C. perfringens  | 5 (36%)          | 1.7 | 2.4 | 1.9    | 1.9 ± 0.3 | 2^b              | 1 (7%)              |
| Salmonella spp  | Abs              | Abs | Abs | Abs    | Abs       | Abs/25g^a        | 0 (0%)              |

Abbreviations: Abs, Absence in 25 g; AMB, Aerobic Mesophilic Bacteria; Maxi, Maximum; Mini, Minimum; N, number of samples analyzed; Positive samples, Samples in which colonies are detected; SD, Standard deviation.
^aAccording to CNNN standard.
^bAccording to HPLS, 2000.

TABLE 8  Microbial load (Log_{10} CFU/g) of coated kilichi samples and compliance with standards (n = 16)

| Germs           | Positive samples | Min | Max | Median | Mean ± SD | Acceptable limit | Noncompliant samples |
|-----------------|------------------|-----|-----|--------|-----------|------------------|---------------------|
| AMB             | 16 (100%)        | 4.6 | 6.8 | 5.2    | 5.3 ± 0.6 | 4^a              | 16 (100%)           |
| S. aureus       | 1 (6%)           | <1  | 3.6 | <1     | <1        | 2^b              | 1 (6%)              |
| E. coli         | 1 (6%)           | <1  | 1   | <1     | <1        | 2^b              | 0 (0%)              |
| Enterobacteriaceae | 4 (25%) | 1   | 2.2 | 2      | 1.8 ± 0.6 | 4^b              | 0 (0%)              |
| Molds           | 10 (63%)         | <1  | 4.6 | 2.5    | 2.4 ± 1.6 | 2^b              | 8 (50%)             |
| Yeast           | 5 (31%)          | <1  | 3.7 | <1     | 1.5 ± 1.2 | 2^b              | 5 (31%)             |
| B. cereus       | 1 (6%)           | <1  | 3.4 | <1     | <1        | 4^b              | 1 (6%)              |
| C. perfringens  | 5 (31%)          | <1  | 2.2 | <1     | 1.1 ± 0.6 | 2^b              | 1 (6%)              |
| Salmonella spp  | 1 (6%)           | Abs | 1   | -      | -         | Abs/25g^a       | 1 (6%)              |

Abbreviations: Abs, Absence in 25 g; AMB, Aerobic Mesophilic Bacteria; Maxi, Maximum; Mini, Minimum; N, number of samples analyzed; Positive samples, Samples in which colonies are detected; SD, Standard deviation.
^aAccording to CNNN standard.
^bAccording to HPLS, 2000.

ETHICAL APPROVAL

This study does not involve any human or animal testing.

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REFERENCES

Akpambang, V. O. E., Purcaro, G., Lajide, L., Amoo, I. A., Conte, L. S., & Moret, S. (2009). Determination of polycyclic aromatic hydrocarbons (PAHs) in commonly consumed Nigerian smoked/grilled fish and meat. Food Additives & Contaminants: Part A, 26, 1096–1103.

Anihouvi, V. B., Ayerho, S. G., Honhouin, D. J., & Sakyi-Dawson, E. (2006). Quality characteristics of Lanhoun: A traditional processed fermented fish product in the Republic of Benin. African Journal of Food, Agriculture, Nutrition and Development, 6(1), 1–5.

Association of Official Analytical Chemists (1995). Official methods of analysis. Official methods 985.14. Gaithersburg, MD: AOAC.

Aptate, E., Osidibo, O., Aptate, O., & Okubanjo, A. O. (2013). Effects of different solar drying methods on quality attributes of dried meat product (Kilishi). Journal of Food Research, 2, 0887–0895.

Beidari, S., & Mahamadou, M. (2014). Rapport de l’étude pour la réalisation des indications géographiques et du cahier de charges du kilichi du Niger. 38.

Boubacar, R. S., Anihouvi, V., Mamadou, A., Marichatou, H., Scippo, M.-L., & Honhouin, D. J. (2019). Indigenous practices and quality perception in the production of kilichi, a grilled dried meat in Niger. Food Chain, 8(1), 1–17.

Brasseur, C., Brose, F., Pinlot, A., Douny, C., Eppe, G., Maghuni-Roger, G., & Scippo, M.-L. (2007). Validation of the analytical procedure for the determination of polynuclear hydrocarbons in smoke flavourings using high performance liquid chromatography coupled to an ultraviolet, diode array or fluorescence detector. Accreditation and Quality Assurance, 12, 535–542.

Carrabs, G., Marrone, R., Mercogliano, R., Carosielli, L., Vollano, L., & Anastasio, A. (2014). ‘Polycyclic aromatic hydrocarbons residues in Gentile di maiale, a smoked meat product typical of some mountain areas in Latina province (Central Italy). Italian Journal of Food Safety, 3(1681), 102–104. https://doi.org/10.1016/j.foodcont.2009.09.002

Conseil National de Normalisation du Niger—CNNN (2004). Viande séchée ou kilichi (spécifications). Norme nigérienne (p. 6, 1ère édn).

D quam, N. J. (2004). Rapport de l’étude du kilishi au Nigeria. Thèse de doctorat en génie des procédés, p. 137. Ecole Nationale Supérieure des Industries Agricoles et Alimentaires, (Massy, Essonne, France)

EFSA (2008). Scientific opinion of the panel on contaminants in the food chain on a request from the European commission on polycyclic aromatic hydrocarbons in Food. EFSA Journal, 724, 1–114.

Eke, K., Opudu, M., Ariahu, A., Chukwuma, C., Abu, A., & Onoh, J. (2013). Sensory and chemical evaluation of beef based dambe-nama (BBBD). Advance Journal of Food Science and Technology, 5(10), 1271–1274.

European Commission (2002). Opinion of the Scientific Committee on Food on the risks to human health of polycyclic aromatic hydrocarbons in food. SCF/CNS/NTM/PAH/29/Final. 84.

European Commission (2006). Regulation (EC) N. 1881/2006 setting maximum levels for certain contaminants in foodstuffs. Official Journal, L346, 20/12/2006, 5–24.

European Commission (2011). Regulation (EC) N. 835/2011 amending Regulation (EC) N. 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs. Official Journal, L215, 20/08/2011, 4–8.

Farhadian, A., Jinap, S., Abas, F., & Sakar, Z. I. (2010). Determination of polycyclic aromatic hydrocarbons in grilled meat. Food Control, 21, 606–610. https://doi.org/10.1016/j.foodcont.2009.09.002

Frazier, W. C., & Westhoff, D. C. (2006). Food microbiology, (3rd ed. pp. 163–165, 223–236, 419–543). New York, NY: McGraw Hill Publishing Company Limited.

Gilbert, R. J., Louvois, J., Donovan, T., Little, C., Nye, K., Ribeiro, C. D., ... Bolton, F. J. (2000). Guidelines for the microbiological quality of some ready-to-eat foods sampled at the point of sale. Communicable Disease and Public Health, 3, 163–167.

Husam, A., Sameer, A., Suad, A., Sahar, Z., Wajih, S., Nisar, A., & Kurunthachalam, K. (2011). Concentrations and dietary exposure to polycyclic aromatic hydrocarbons (PAHs) from grilled and smoked foods. Food Control, 22, 2028–2035.

ISO 1442 (1997). Meat and meat products. Determination of moisture content (Reference method).

ISO 1444 (1996). Meat and meat product. Determination of fat content (Reference method).

ISO 16449-2 (2001) Microbiology of food and animal feeding stuffs. Horizontal method for the examination of β-glucuronidase positive Escherichia coli. Part 2: Colony. count technique at 44°C using 5-bromo-4-chloro-3-indolyl β-D-glucuronide.

ISO 21528-2 (2004). Microbiology of food and animal feeding stuffs. Horizontal method for the detection and enumeration of Enterobacteriaceae. Part 2: colony-count method.

ISO 21527-2 (2008). Microbiology of food and animal feeding stuffs. Horizontal method for the determination of yeasts and moulds. Part 2: Colony count technique in products with water activity less than or equal to 0.95.

ISO 4833 (2003). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of microorganisms. Colony count technique at 30°C.

ISO 6579 (2002). Microbiology of food and animal feeding stuffs. Horizontal method for the detection of Salmonella spp.

ISO 6887-1 (1999). Microbiology of food and animal feeding stuffs. Preparation of test samples, initial suspension and decimal dilutions for microbiological examination.

ISO 6888-1 (2003). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of coagulase positive Staphylococci (Staphylococcus aureus and other species). Part1: Technique using Baird-Parker agar medium.

ISO 7932 (2004). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of presumptive Bacillus cereus. Colony count technique at 30°C.

ISO 7937 (2004). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of Clostridium perfringens. Colony count technique.

ISO 937 (1978). Meat and meat products. Determination of nitrogen content (Reference method).

Join FAO/WHO Expert Committee on Food Additives (2005). Evaluation of certain food contaminants. Report of the 64th meeting. 47.

Jones, M. J., Tanya, V. N., Mbofung, C. M. F., Fonkem, D. N., & Silverside, D. E. (2001). A microbiological and nutritional evaluation of the west african dried meat product, Kilishi. Journal of Food Technology in Africa, 6(4), 126–129.

Kalloul, S. (1997). Transformation traditionnelle de la viande en kilishi au Niger: Optimisation du procédé. Thèse de doctorat en génie des procédés, p. 137. Ecole Nationale Supérieure des Industries Agricoles et Alimentaires, (Massy, Essonne, France)

Kamwanga, M. J. B., Somda, J., Yacouba, S., Sanon, Y., Kagoné, H., Zoundi, J. S., & Hitimana, L. (2008). Elevage et marché régional au Sahel et en Afrique de l’Ouest. Potentialités et défis. CEDEAO, p. 182.

Kimassoum, D., Sado Kamdem, S. L., Ngando, B. N., Fatou, K. C., Njii, A. M., Bawe, N. M., ... Mbacham, W. F. (2017). Evaluation of microbial adverse effects on fresh and processed bovine meat in N’Djamena (Chad) and Yaoundé (Cameroon). African Journal of Microbiology Research, 11(16), 637–643. https://doi.org/10.5897/AJMR2017.8455

Kpocolou, E. Y., Anihouvi, V. B., Azokpota, P., Soumanou, M. M., Daube, G., Douny, C., ... Houhouignou, D. J. (2013). Microbiological and
physico-chemical quality of smoked shrimp, an expanding food condiment in beninese local markets. *Food and Public Health*, 3(6), 277–283.

Lorenzo, J. M., Purriños, L., Fontán, M. C. G., & Franco, D. (2010). Polycyclic aromatic hydrocarbons (PAHs) in two Spanish traditional smoked sausage varieties: Androlla and botillo. *Meat Science*, 86, 660–664. https://doi.org/10.1016/j.meatsci.2010.05.032

Manda, P., Dano, D. S., Ehile, E. S., Koffi, M., Amani, N., & Assi, Y. A. (2012). Evaluation of polycyclic aromatic hydrocarbons (PAHs) content in foods sold in Abobo market, Abidjan, Côte d’Ivoire. *Journal of Toxicology and Environmental Health Sciences*, 4(6), 99–105. https://doi.org/10.5897/JTEHS11.085

Martorell, L., Perello, G., Martí-Cid, R., Castell, V., Llobet, J. M., & Domingo, J. L. (2010). Polycyclic aromatic hydrocarbons (PAH) in foods and estimated PAH intake by the population of Catalonia, Spain: Temporal trend. *Environment International*, 36(5), 424–432. https://doi.org/10.1016/j.envint.2010.03.003

Mbawala, A., Daoudou, B., & Ngassoum, M. B. (2010). Qualité microbiologique du kilishi (produit carné séché) produit dans la ville de Ngaoundéré (Cameroun). *Tropicultura*, 28(3), 153–160.

Mgbemere, V. N., Akpapunam, M. A., & Igene, J. O. (2011). Effect of groundnut flour substitution on yield, quality and storage stability of kilishi – A Nigerian indigenous dried meat product. *African Journal of Food, Agriculture, Nutrition and Development*, 11, 4718–4738.

Moshood, A. Y., Tengku, H. A. T. A. H., & Ibrahim, H. (2012). Isolation and identification of bacteria associated with balango (roasted meat product) sold in Bauchi, Nigeria. *IOSR Journal of Pharmacy*, 2(6), 38–48.

Olabemiwo, O. M., & Ogunsola, A. D. (2014). Polycyclic aromatic hydrocarbons in smokes of two biomasses used for domestic cooking in Nigeria. *Chemistry and Materials Research*, 6(1), 101–106.

Olusola, O. O., Okubanjo, A. O., & Omojola, A. B. (2012). Nutritive and organoleptic characteristics of Kilishi as affected by meat type and ingredient formulation. *Journal of Animal Production Advances*, 2(5), 221–232.

Petit, T., Caro, Y., Petit, A. S., Santchurn, S. J., & Collignan, A. (2014). Physicochemical and microbiological characteristics of biltong, a traditional salted dried meat of South Africa. *Meat Science*, 96, 1313–1317.

Prescott, L. M., Harley, J. P., & Klein, D. A. (2002). *Microbiology* (5th edn, pp. 963–9710). London: McGraw-Hill.

Price, J. F., & Schweigt, B. S. (1971). *The science of meat and meat products* (2nd edn, p. 289). New York, NY: W. H. Freeman and Company.

Raji, A. I. (2006). Bacteriological quality of dried sliced beef (Kilishi) sold in Ilorin Metropolis. *Journal of Applied Sciences and Environmental Management*, 10(1), 93–96.

Ratsimba, A., Leroy, S., Chacornac, J. P., Rakoto, D., Arnaud, E., Jeannoda, V., & Talon, R. (2017). Staphylococcal ecosystem of kitoza, a traditional malagasy meat product. *International Journal of Food Microbiology*, 246, 20–24.

Rose, M., Holland, J., Dowding, A., Petch, S. R. G., White, S., Fernandes, A., & Mortimer, D. (2015). Investigation into the formation of PAHs in foods prepared in the home to determine the effects of frying, grilling, barbecuing, toasting and roasting. *Food and Chemical Toxicology*, 78, 1–9. https://doi.org/10.1016/j.fct.2014.12.018

Roseiro, L. C., Gomes, A., Patarata, L., & Santos, C. (2012). Comparative survey of PAHs incidence in Portuguese traditional meat and blood sausages. *Food and Chemical Toxicology*, 50, 1891–1896.

Rozentāle, I., Stumpe-Vīksna, I., Začs, D., Siksni, I., Melgaile, A., & Bartkevičs, V. (2015). Assessment of dietary exposure to polycyclic aromatic hydrocarbons from smoked meat products produced in Latvia. *Food Control*, 54, 16–22.

Salihu, M. D., Junaidu, A. U., Magaji, A. A., Aliyu, R. M., Yakubu, Y., Shittu, A., & Ibrahim, M. A. (2010). Bacteriological quality of traditionally prepared fried ground beef (Dambun namu) in Sokoto, Nigeria. *Advance Journal of Food Science and Technology*, 3(4), 145–147.

Santos, C., Gomes, A., & Roseiro, L. C. (2011). Polycyclic aromatic hydrocarbons incidence in Portuguese traditional smoked meat products. *Food and Chemical Toxicology*, 49, 2343–2347.

Shamsudddeen, U. (2009). Microbiological quality of spice used in the production of kilishi a traditionally dried and grilled meat product. *Bayerno Journal of Pure and Applied Sciences (Bajopas)*, 2(2), 66–69.

Stumpe-Vīksna, I., Bartkevičs, V., Kukāre, Å., & Morozovs, A. (2008). Polycyclic aromatic hydrocarbons in meat smoked with different types of wood. *Food Chemistry*, 110, 794–797.

Veyrand, B., Brossaude, A., Sarcher, L., Varlet, V., Montea, F., Marchand, P., ... Le Bizec, B. (2007). Innovative method for determination of 19 polycyclic aromatic hydrocarbons in food and oil samples using gas chromatography coupled to tandem mass spectrometry based on an isolate dilution approach. *Journal of Chromatography A*, 1149, 333–344.

Veyrand, B., Sirot, V., Durand, S., Pollono, C., Marchand, P., Dervilly-Pinel, G., ... Le Bizec, B. (2013). Human dietary exposure to polycyclic aromatic hydrocarbons: Results of the second French Total Diet Study. *Environment International*, 54, 11–17. https://doi.org/10.1016/j.envint.2012.12.011

Yacouba, I. (2009). Analyse des techniques traditionnelles de transformation de la viande en kilichi dans la commune urbaine de Madaoua (Rép. du Niger) (p. 45). Mémoire d’Ingénieur. Katibougou, Mali: Institut Polytechnique Rural de Formation et de Recherche Appliquée (IPR/IFRA).

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