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Meat Science 59 (2001) 377–389

MEAT SCIENCE

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Characterization of traditional processing of pork meat into *boucané*

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Received 11 December 2000; received in revised form 19 March 2001; accepted 19 March 2001

Abstract

Boucané is a traditional meat product from Réunion that is obtained by salting, drying and hot smoking pork belly. One-step unit operations give rise to a stable product with remarkable colour and flavour qualities. Smoking the product directly over embers, however, leads to benzo(a)pyrene contamination. Mass transfers (salt gain, water loss) stabilize the end product, which has a 28.5% water content and 5.6% salt content. Lipid oxidation and Maillard reactions are the main mechanisms involved in the *boucané* production process. The molecules derived from these two reactions are — along with smoke compounds — responsible for the flavour and colour of the end product.

Keywords: Meat; Salting; Drying; Smoking; Transfers; Process; Quality; Colour; Volatile compounds

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1. Introduction

Boucané is a traditional salted/dried/smoked pork-belly product from Réunion (Poligné, Collignan, Trystram, & Pieribasttesti, 2000). Traditional small-scale industries produce around 900 t of *boucané*/year in Réunion, all of which is targeted for domestic consumption.

This cured product differs from commercially successful European sliced smoked pork belly and bacon, which have a mild smoked taste and are obtained by accelerated industrial production techniques (Pearson & Gillett, 1999; Poma, 1998). Traditional *boucané* is drier, saltier and smokier than these industrial products, and it is more like *unam inung*, a salted/smoked pork belly product from tropical Nigeria (Egbunike & Okubanjo, 1999).

Smoked pork belly, bacon and *unam inung* are usually processed through a series of salting, drying, smoking and/or cooking operations. Traditional *boucané* production is unique in that the unit operations are done in a single step, and gives rise to a product that meets Réunion consumers' specific organoleptic quality and stability requirements (Poligné et al., 2000).

Many studies have been carried out to assess the impact of drying on the quality of meat products in the tropics (Chang, Huang, & Pearson, 1991; Kalilou, 1997), or even physicochemical, microbiological and/or ultrastructural modifications of meat products processed in the tropics (Bennani, Zenati, Faid, & Ettayebi, 1995; Biscontini, Shimokomaki, Oliveira, & Zorn, 1996; Shimokomaki, Franco, Biscontini, Pinto, Terra, & Zorn, 1998). Other authors have studied the impact of curing agents on the development of flavour compounds in meat (Mottram, Croft, & Patterson, 1984; Ramarathnam, Rubin, & Diosady, 1991), and the impact of different technologies on product flavour (Chakurov, Miteva, Trendafilova, & Gadjeva, 1989; Andersen & Hinrichsen, 1995; Cardinal, Berdagué, Dinel, Knockaërt, & Vallet, 1997).

The present study was designed to assess the unique *boucané* production process. As the unit operations are achieved in one step, we had to set up a special assessment method to focus on transfers and reaction mechanisms.

First, a field study was conducted to obtain an in-depth analysis of traditional small-scale *boucané* production processes. The sanitary and organoleptic qualities of the product were assessed. An analytical framework was developed, based on three parameters (mass transfers, and product colour and flavour), to identify the mechanisms involved.

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0309-1740/01/$ - see front matter
PII: S0309-1740(01)00090-0

2. Materials and methods

2.1. Raw material

Boucané is made on a small scale with fresh local pork belly. Meat obtained from the island's main slaughterhouse (Sica Viande Pays, Saint Pierre, France) is stored at 4°C and then manually trimmed into rectangular chunks. These pork belly chunks are subsequently sliced (8–10 cm slices). Each slice, which includes two ribs, is partially cut between the ribs and split open lengthwise to obtain a long piece that varies according to the size of the pork belly (60±10) cm. These pieces are of equal width and thickness, i.e. (6±1) cm and (4±1) cm, respectively.

2.2. Boucané *production process*

The cut pieces of meat are immersed, for about 30 s, in salt-saturated brine (46.2 kg salt/100 kg brine) containing suspended salt crystals that cling to the surface of the product after immersion. The product is set aside for 2–5 min following this salting operation and the meat is then smoked in a *boucan*, which is a chamber measuring around 36 m^3 (6×2×3 m). Wood logs obtained locally, e.g. tamarind (*Acacia heterophylla*) and Australian pine (*Casuarina equisetifolia*), are burned to generate smoke in the *boucan*. The product is hung directly over the burning embers, at a height of (125±25) cm. Four to five hours after the beginning of the smoking process, fresh logs are set on the fire which subsequently flares up. Smoking time is visually determined by the producer. This operation lasted 21.5 h in the present study. The processed meat is stored in a storehouse adjacent to the *boucan* before marketing.

2.3. Study method

Boucané samples (around 200 g) were obtained during the production process and stored in airtight plastic bags prior to analysis, which were carried out within 24 h of sampling. All measurements (colour, weights, chemical and physicochemical analyses) were performed on the raw material (RM), the product after salting (S), and the product during smoking (SS) at time $t = 1.25$ ($SS_{1.25}$), 4 (SS_4), 5.75 ($SS_{5.75}$), 8 (SS_8), 11.5 ($SS_{11.5}$), 20 (SS_{20}) and 21.5 ($SS_{21.30}$) h, except for the benzo(a)pyrene assay and the flavour analyses which were only carried out on the end product.

The surface colour measurements were done on two specific areas since pork belly is a heterogeneous product composed of successive lean protein and intermuscular fat layers. Measurements were performed in the field, immediately following sampling, to avoid potential product colour modifications linked with light exposure and the presence of oxygen during sample storage (Hunt et al., 1991).

Temperature, air velocity, relative humidity, and product temperature (core and surface) were continuously recorded at the production site. Product temperatures were recorded 1 m above the burning embers, with the thermocouples placed at the core and on the surface of the meat pieces. Dry-bulb and wet-bulb air temperatures and velocities were recorded 1.5 m above the fire.

2.4. Measurements and analyses

Water content was determined by oven drying the sample at (103±1)°C to constant weight (AFNOR, 1968a). Water activity (Aw) was measured using an Aw-meter (FA-st/1, GBX, France) maintained at (24±1)°C. Sodium chloride content was measured using a chloride analyser (Corning, model 926) after extraction in 0.3 N nitric acid (Bohuon, 1995). Fat was extracted from dried samples with a Soxterm apparatus (Gerdardt) using petroleum ether as solvent (AFNOR, 1968b). Phenolic compounds were extracted in an alcohol-chloroform solution and their absorbance measured at $\lambda = 455$ nm (AFNOR, 1996). Benzo(a)pyrene content was determined as described by Salagoity, Gaye, Tricard, Desormeaux, and Sudraud (1990).

Product colour was measured with a Minolta CR-300 colorimeter (Osaka, Japan) after gauging the instrument against a solid-white standard (vitrolite), with standardized diffuse lighting D_{65}, at a constant angle relative to the sample. The results were recorded in the $L^*a^*b^*$ measurement mode. Saturation C^*, which represents the colour intensity (Chizzolini et al., 1996), is given by the equation [Eq. (1)]:

$$C^* = \sqrt{a^{*\,2} + b^{*\,2}} \tag{1}$$

Volatile compounds were separated by gas chromatography (GC) and identified by mass spectrometry (MS). Volatile compounds were extracted by the dynamic headspace technique ($T = 18$°C; helium flow $= 64$ ml min^{-1}; $t = 60$ min) using 5 g of ground meat sample placed in a cylindrical glass extractor ($H = 70$ mm; Ø = 25 mm). The volatile meat compound desorption and trapping conditions, and the chromatography conditions were as described by Cardinal et al. (1997). Separation was performed with a Supelco capillary column (60 m×0.32 mm i.d.) coated with SPB5 (film thickness 1 μm). Carrier gas was helium (velocity, 1 ml min^{-1}), and the oven was programmed from 40 to 200°C at a rate of 3°C min^{-1}. Splitless injection was used and volatile compounds were identified by comparing experimental spectra with reference database spectra (NIST Standard Reference Database; Wiley 138). Retention indices were calculated using the method described by Tranchant (1982) and compared to those compiled by Kondjoyan and Berdagué (1996). The chromatogram peaks were integrated with the

MSChemstation software program (Hewlett Packard, 1992). For pure compounds, the chromatogram peak areas were calculated on the basis of the total ionic current. For coelution products, peak areas were calculated by estimating the ionic current from integration results obtained for specific ions. Only the main compounds that are characteristic of *boucané* processing were taken into account in this study and are referenced by peak number in Table 1.

Air temperature, velocity and relative humidity and product temperatures were recorded with a CR21X Micrologger (Campbell Scientifique Ltd, England). Temperatures were recorded using Chromel-Alumel thermocouples, air velocity using a revolving vane anemometer (Casella, London) and relative humidity by measuring the dry- and wet-bulb air temperatures.

Meat mass variations were monitored during the smoking process, which enabled us to plot the water content kinetics of the product X = f(t), from which we could derive the drying patterns dX/dt = f(X). The results are given in kg water per kg dry matter of the product (db) per second, denoted kg/kg s^{-1}.

2.5. Data presentation — calculation methods — uncertainties

Mass transfers that occurred during the *boucané* salting, drying and smoking process can be represented by salt gain (StG), water loss (WL) and fat loss (FL), expressed as follows (Collignan & Raoult-Wack, 1992):

$$\mathrm{StG} = \left(\frac{m_{t+1}}{m_t}\right) S_{t+1} - S_t \tag{2}$$

$$\mathrm{WL} = X_t - X_{t+1}\left(\frac{m_{t+1}}{m_t}\right) \tag{3}$$

$$\mathrm{FL} = F_t - F_{t+1}\left(\frac{m_{t+1}}{m_t}\right) \tag{4}$$

with StG, salt gain between t and $t+1$ [kg/100 kg of product]; 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]; S_t, salt content at t [kg/100 kg of product] (wb); S_{t+1}, salt content at $t+1$ [kg/100 kg of product] (wb); 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].

The calculations were carried out between steps t and $t+1$.

The colour variations are illustrated on a 2D graph, where $L^* = f(C^*)$. This enabled us to monitor colour patterns during the *boucané* production process.

The chemical analyses were carried out in triplicate, except for the phenol content measurements which were done in duplicate. The flavour analysis was conducted on one sample. The colour index results $L^*a^*b^*$ were averaged (15 replicate measurements for each analysed fraction). Temperatures, air velocity and relative humidity were measured with accuracies of 0.5°C, 0.2 m s^{-1} and 3%, respectively.

3. Results and discussion

3.1. Heat and mass transfers

3.1.1. Variations in boucané characteristics

Fig. 1 shows the mass results recorded at the test site, the operational conditions, and the chemical and physicochemical characteristics of the product during the production process. The raw material had a water content of (51.7±0.6) kg/100 kg and a fat content of (32.4±3.8) kg/100 kg.

An overall mass gain of 5.7 kg/100 kg was noted after salting. This was due to a salt gain of 5.3 kg/100 kg, which mainly corresponded to the quantity of salt crystals deposited on the meat surface, along with a water gain of 0.5 kg/100 kg. A fat loss of 0.1 kg/100 kg corresponded to the experimental error. The salted product thus had water and salt contents of (49.3±3.7) and (5.0±0.3) kg/100 kg respectively, corresponding to a total Aw of 0.94±0.03. Salt transfers during this unit operation were low due to the very short salting times.

A total weight loss of 38.3 kg/100 kg was obtained after smoking, as a result of the high water loss (31.0 kg/100 kg), fat melting (6.2 kg/100 kg) and salt loss (1.4 kg/100 kg). The end product was stable, with a water content of (28.5±0.6) kg/100 kg and Aw of (0.83±0.02), indicating that it was an intermediate moisture food product (Leistner & Rödel, 1976).

This latter operation involved water transfer, which was mainly associated with drying of the *boucané* product, and fat melting, associated with the heat treatment. Drying leads to fat cell dehydration, thus damaging the cell walls and prompting a flow of fused fats (Sheard, Wood, Nute, & Ball, 1998). Salt crystals on the product surface could have been dragged away by the flow of fused fats, thus explaining the minor salt loss observed. The high water loss linked with the fat melting resulted in a low processing yield (67%).

3.1.2. Variations in air conditions during the smoking process

Because of field constraints, air temperature (Fig. 2) and product temperature (Fig. 3) were recorded at different heights in the smoking chamber. The results are presented and discussed separately.

Table 1
Main volatile compounds and their relative abundance (unregistered compounds are not discussed in this study)[a]

Peak No.	Chemical name	Reliability of identification	Retention index	Relative abundance	Odour characteristics of volatile compounds in meat
	Hydrocarbons — aliphatic				
14	Heptane	A	700	Middle	
34	Octane	A	800	Middle	
40	Heptane, 2,4-dimethyl	A	823	Weak	
	Decane	A	1000	Trace	
	Undecane	A	1100	Trace	
	Tridecane	A	1300	Middle	
	Tetradecane	A	1400	Weak	
	Pentadecane	A	1500	Trace	
	Hexadecane	A	1600	Trace	
	Heptadecane	A	1700	Weak	
	Hydrocarbons — cyclic				
8	Benzene	A	661	High	
29	Benzene, methyl (*toluene*)	A	769	High	
48	Benzene, ethyl	A	865	Middle	
49	Benzene, 1,3-dimethyl	A	873		
	Benzene, 1,4-bis (1,1-dimethylethyl	B	1264	Middle	
	Aldehydes — aliphatic				
13	Pentanal	A	698	High	
33	Hexanal	A	798	Very high	Rancid, pungent, sickly[b], green[c]
57	Heptanal	A	900	Middle	
75	Octanal	A	1003	Middle	
92	Nonanal	A	1104	Middle	Very rancid[c]
98	Decanal	A	1206	Middle	
100	Undecanal	A	1308	Middle	
103′	Dodecanal	A	1409	Weak	
109	Tridecanal	A	1514	Middle	
Ill	Tetradecanal	A	1616	Weak	
	Aldehydes — cyclic				
72′	Benzaldehyde	B	967	High	Oil of almond[d]
	Phenylacetaldehyde	A	1050	Trace	
	Alcohol				
7	Butanol, 3-methyl	A	650	Middle	
	Ketones — aliphatic				
5	2-Butanone	B	?	Middle	
12	2-Pentanone	B	?	Middle	
53	2-Heptanone	A	888	Weak	Spicy[e]
	2,5-Hexanedione	B	925	Weak	
	5-Hepten-2-one, 6-methyl	B	985	Weak	
	Ketones-cyclic				
32	Cyclopentanone	B	789	Middle	
	2-Cyclopenten-l-one, 2,3-dimethyl	B	1043	Middle	
89′	Acetophenone	B	1074	Middle	Sweet floral[d]
	Phenols				
73	Phenol	A	978	Middle	Pungent characteristic[d]
84	Phenol, 2-methyl (o-cresol)	B	1053	Middle	Pungent characteristic[d]
88	Phenol, 3-methyl (m-cresol)	B	1071	Weak	Pungent characteristic[d]
90	Phenol, 2-methoxy (gaiacol)	A	1095	High	Sweet smoky and somewhat pungent[d]
	Phenol, 2,4-dimethyl	B	1149	Weak	
	Phenol, 2,3-dimethyl	B	1167	Trace	
97	Phenol, 2-methoxy-4-methyl	B	1200	Weak	Sweet smoky[d]
nd	Phenol, 2-methoxy-4-ethyl	B	1288	Weak	Sweet smoky[d]
	Phenol, 4(1,1-dimethylethyl)	B	1291	Weak	
	Carboxylic acids				
6	Acetic acid	B	?		Weak
	Furans				
6′	Furan, 2-methyl	A	605	Weak	Pleasant, meaty[f]

(*continued on next page*)

Table 1 (*continued*)

Peak No.	Chemical name	Reliability of identification	Retention index	Relative abundance	Odour characteristics of volatile compounds in meat
	Furan, 2-ethyl	A	702	Weak	
15	Furan, 2,5-dimethyl	A	707	Middle	
42	Furfural	B	833	High	Caramel, fruity[e]
46	2-Furanmethanol	B	853	Middle	
72	Furfural, 5-methyl	B	966	Middle	Burnt, caramel[c]
74	Furan, 2-pentyl	A	996	Weak	Licorice-like, beany-greenish[g]
76	Benzofuran	A	1006	Middle	
	Nitrogen compounds				
18	Pyrazine	B	730	Weak	Roasted[h], Nutty, grilled[i]
23	Pyrrole, 1-methyl	B	740	Weak	
nd	Pyridine	A	743	Weak	Vile (concentrated), bitter pleasant roasted (dilute)[j]
25	Pyrrole	B	755	Middle	
38	Pyridine, 2-methyl	A	815	Weak	Astringent, hazelnut-like[k]
	Benzothiazole	A	1244	Weak	Slightly sweet, nutty, roasted-brown, slightly popcorn like[l]
	Other compound				
3	Carbon disulfide	B	?	Very high	

[a] The reliability of the identification is indicated by the following symbols : A = mass spectrum and retention index in agreement with Kondjoyan and Berdagué (1996); B = tentative identification by mass spectrum. The Kovats indices are calculated for the DB5 capillary column of the GC–MS System.

[b] Shahidi (1989).

[c] Berdagué et al. (1993).

[d] Hollenbeck (1994).

[e] Mottram (1991).

[f] Macleod and Coppock (1976).

[g] Peterson and Chang (1982).

[h] Mottram (1998).

[i] Pittet and Hruza (1974).

[j] Peterson et al. (1975).

[k] Ho et al. (1983).

[l] Chang and Peterson (1977).

Fig. 2 shows dry-bulb temperature and relative humidity patterns recorded at 1.5 m height in the *boucan*. The air velocity measured during the smoking process was less than 0.2 m s^{-1}. The temperature in the smoking chamber at the beginning of the smoking process was (44.5±0.5)°C. It gradually decreased to (38.0±0.5)°C after 3.75 h due to a decrease in combustion intensity, and then increased after 4 h of smoking, i.e. when new logs were added to the fire, causing it to flare up substantially. After 6 h of smoking, the peak temperature recorded was (54.0±0.5)°C. From 6 to 21.5 h of smoking, the temperarure gradually declined in the chamber to a final temperature of (31.0±0.5)°C.

The mean relative humidity during the smoking operation was (64±16)%. The humidity increased steadily over the first 4 h of smoking, from (57±3)% to (77±3)%. From 4 to 7 h of smoking, the relative humidity results decreased to a minimum of (42±3)%. This decrease occurred concomitantly with a temperature rise in the smoking chamber after 4 h of smoking because fresh logs were added to the fire. From 7 to 21.5 h of smoking, the relative humidity curve rose again and peaked at (90±3)%. The relative humidity decreased with a rise in the dry-bulb temperature in the *boucan* and vice-versa.

3.1.3. Variations in the product temperature during the smoking process

Fig. 3 shows the temperature kinetics on the surface and at the core of the product at 1 m height. The product core and surface temperatures at the beginning of the smoking process were 25 and 29°C, respectively, and rose to 47 and 62°C, respectively, after 6 min of smoking. This sharp temperature increase could be explained by the very rapid combustion of logs in the fire. From 0.25 to 4 h of smoking, the temperatures progressively decreased because of the lower combustion intensity. From 4 to 5 h of smoking, adding fresh logs to the fire led to a rise in the product core temperature from 42 to 57°C and in the surface temperature from 49 to 77°C. From 5 h to the end of smoking, the product surface and core temperatures both gradually declined to an asymptotic value of (30.0±0.5)°C, corresponding to the ambient air temperature. *Boucané* is thus subjected to high fluctuating temperatures during processing.

Heat transfers were not quantified in this study, but they could be extrapolated from the product temperature kinetics. Fig. 3 highlights that the product surface temperature can reach 77°C after 4–5 h of smoking. During the smoking process, *boucané* thus also undergoes a cooking-type heat treatment which, at these temperatures, leads to protein denaturation (Martens, Stabursvik, & Martens, 1982).

3.1.4. Drying kinetics

Boucané drying kinetics could be divided into two phases (a) and (b) (Fig. 4). The isenthalp phase (a) corresponds to a quick and almost constant drying rate, reaching a mean 29.10^{-6} kg/kg s^{-1} for a water content ranging from 1.20 to 0.83 kg water/kg dry matter. The product Aw remained constant at (0.94±0.2) during the first hour of the smoking process.

During the drying period in the declining phase (b), the drying rate decreased from 28.10^{-6} to 1.10^{-6} kg/kg s^{-1} for water contents ranging from 0.83 to 0.40 kg water/kg dry matter. The free water supply to the product surface was exhausted and water mobility thus became a limiting factor. The product Aw gradually decreased to reach 0.83 at the end of the smoking process. The high product surface and core temperatures promoted water loss. This could be explained by temperature-induced activation of transfers (Arrhenius law), and by the effect of cooking on *boucané* protein structures. In meat products, water is retained by protein charges and by steric effects in myofibrillar networks. Protein solubility and charges, and consequently their hydration, are modified by heat. This results in a

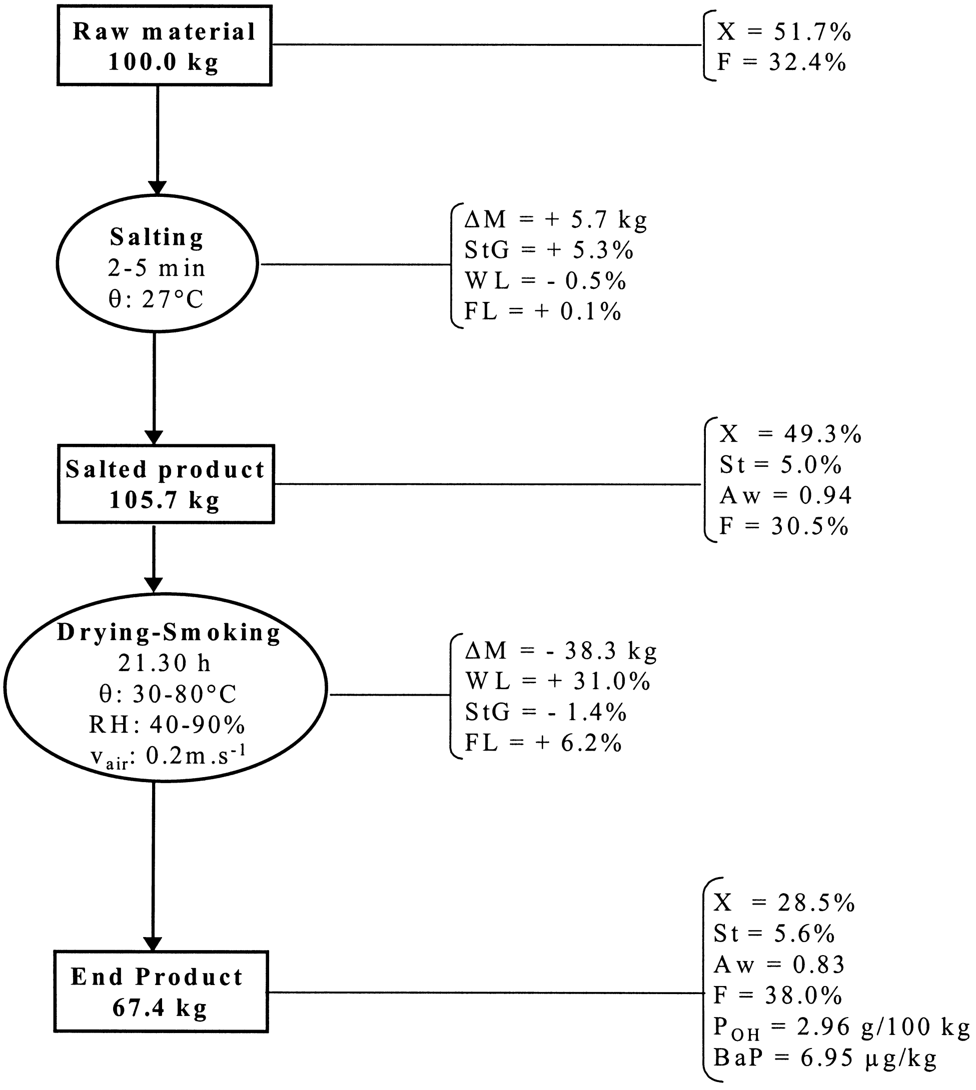

Fig. 1. Variations in chemical and physicochemical characteristics during *boucané* processing. With %, kg/100 kg of product (wb); X, water content; St, salt content; F, fat content; P_{OH}, phenol content; BaP, benzo(a)pyrene content; ΔM, mass variation; WL, water loss; StG, salt gain; FL, fat loss; θ: temperature; RH, relative humidity; V_{air}, air velocity.

decline in the water retention potential at 40°C and above (Laroche, 1988). There is a concomitant increase in cell membrane permeability, which also promotes water loss.

By comparison, the drying rate of Chinese pork (*zousoon*) is as high as 17.10^{-5} kg/kg s^{-1} for water contents ranging from 1.0 to 0.5 kg water/kg dry matter (Chang et al., 1991). This is tenfold higher than noted in *boucané*. The two main factors responsible for this difference are the drying rate (*zousoon*: $v_{air} = 1$ m s^{-1}; *boucané*: $v_{air} < 0.2$ m s^{-1}) and the fat content of the

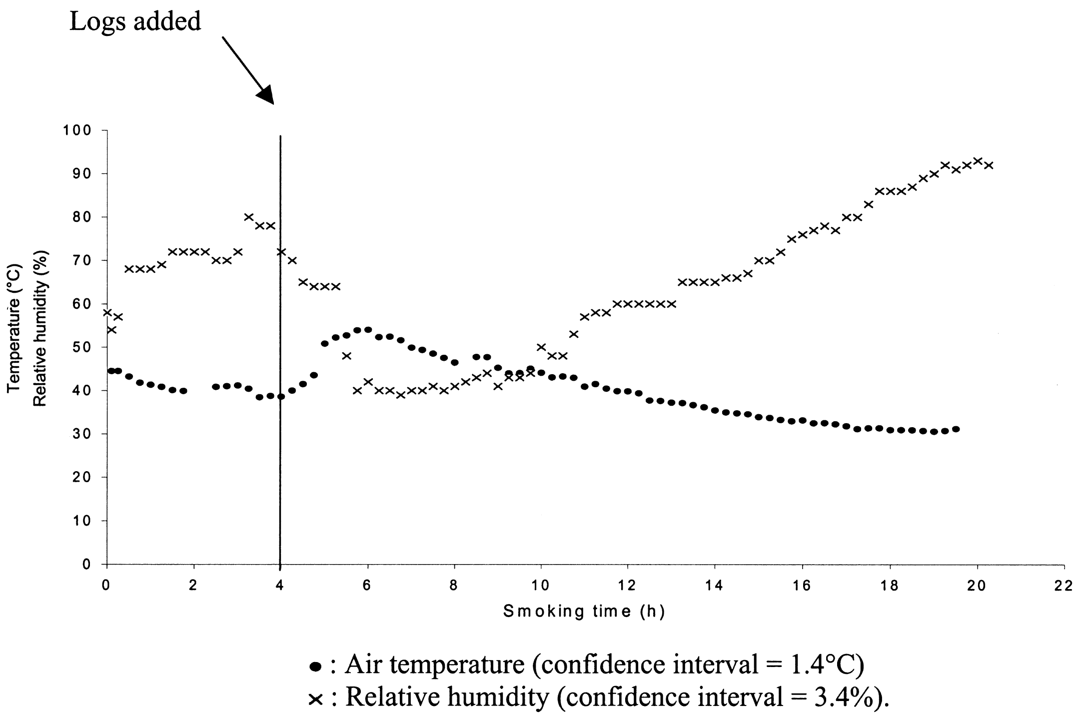

Fig. 2. Air temperature and relative humidity in the smoking chamber recorded 1.5 m from the fire. ●, air temperature (confidence interval = 1.4°C); X, relative humidity (confidence interval = 3.4%).

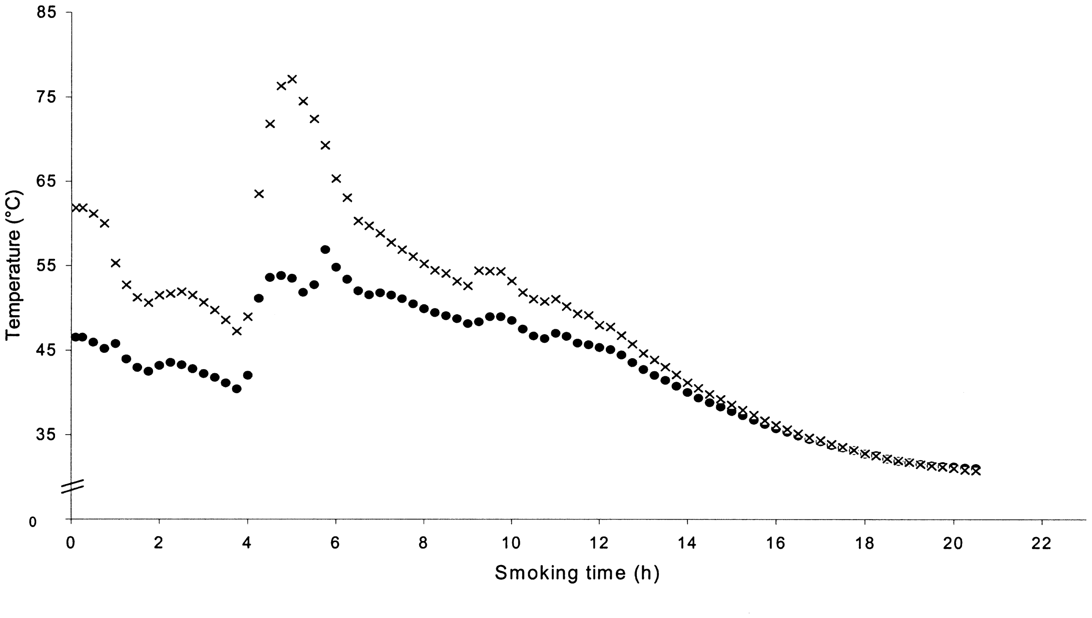

Fig. 3. Temperatures at the core (depth = 1 cm) and surface of the product recorded 1 m from the fire during the smoking process. ●, product core temperature (confidence interval 1.5°C); X, product surface temperature (confidence interval = 2.6°C).

products (*zousoon*: $F=12\%$; *boucané*: $F=38\%$). The drying rates of thin slices of Nigerian beef (*kilishi*) are also tenfold higher than those of *boucané* at the same water contents (Kalilou, 1997). In addition, salt crystals on the surface of *boucané* cause surface crusting and thus limits air-product exchanges.

After a very quick superficial salting process, the meat product is smoked for a long period during which it is simultaneously dried, cooked and smoked. *Boucané* drying is purposely slow in comparison to rates for other intermediate moisture meat products, which enables the development of the typical colour and flavour compounds of this product.

3.2. Analysis of boucané *flavour compounds*

3.2.1. Identification of volatile compounds of the end product

The substances identified by GC–MS in the *boucané* samples are given in Table 1. This table lists the peak number of volatile compounds, the identification reliability, the retention indices, the relative abundance of each component and the odour characteristics of some volatile compounds with bibliographical references. The 46 main substances, considered to be characteristic of *boucané* processing, are three aliphatic hydrocarbons, four cyclic hydrocarbons, eleven aldehydes, one alcohol, five ketones, five phenols, one carboxylic acid, seven furans, one pyrazine, one pyridine, two pyrroles, and carbon disulfide. The volatile compounds were grouped according to their endogenic (lipid oxidation, Maillard reactions) or exogenic (smoke) origins.

3.2.2. Volatile compounds derived from lipid oxidation

Aliphatic hydrocarbons, aldehydes, aliphatic ketones and carboxylic acid identified in *boucané* are mainly derived from lipid oxidation (Shahidi, 1989). They accounted for 26% of the entire chromatogram area.

Hexanal, the main scission product of linoleic acid (Barbieri et al., 1992; Mottram, Edwards, & MacFie,

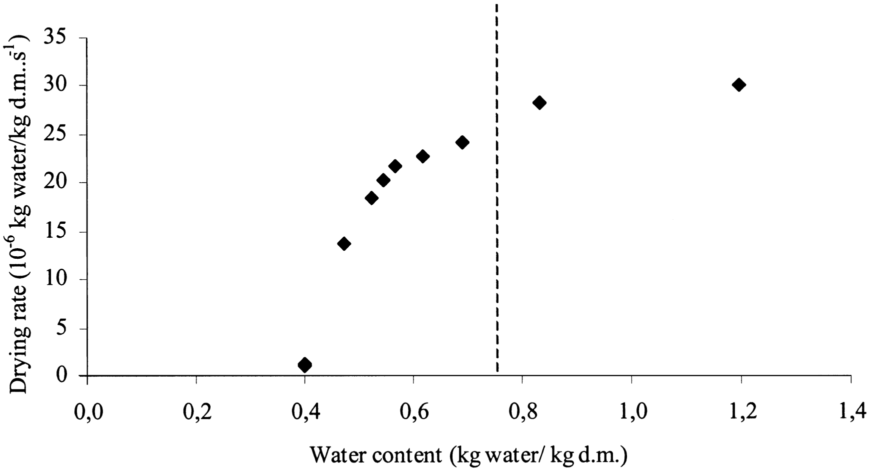

Fig. 4. *Boucané* drying kinetics.

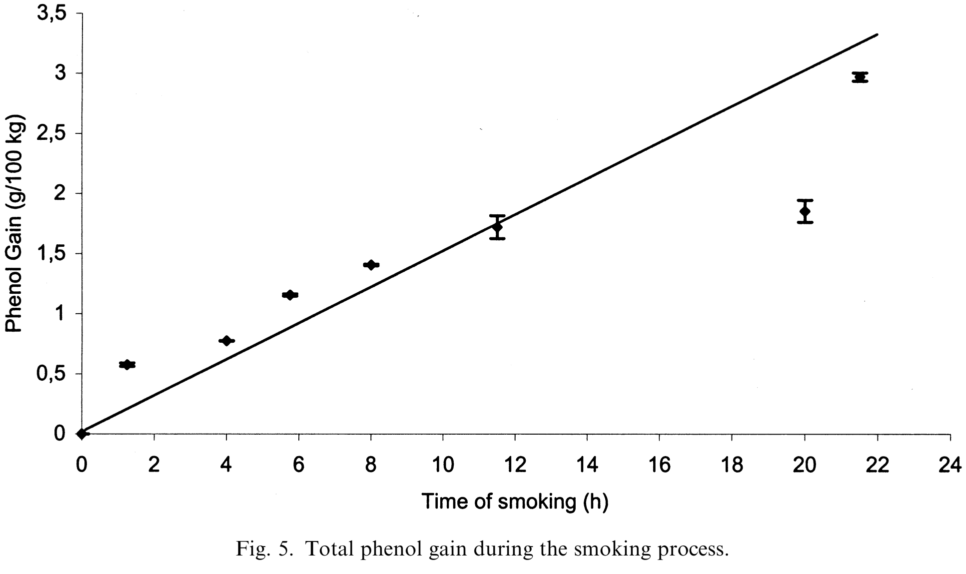

Fig. 5. Total phenol gain during the smoking process.

1982), was the main compound noted on the *boucané* chromatogram. This is in line with the results reported by Shahidi, Yun, Rubin, and Wood (1987) and Ramarathnam et al. (1991), which indicated that hexanal is a key compound in cooked meats containing no nitrates or nitrites. Hexanal, whose content is directly proportional to the quantity of 2-thiobarbituric acid (TBA index), is a good indicator of the extent of product oxidation (Shahidi et al., 1987). Pentanal levels were found to be high. Hexanal and to a lesser extent nonanal give meat an unpleasant rancid pungent odour (Berdagué, Bonnaud, Rousset, & Touraille, 1993; Shahidi, 1989). The formation of these volatile compounds is linked with pork belly processing conditions (presence of salt crystals and oxygen, absence of antioxidants, high temperatures, high treatment times). At cooking temperatures below 100°C, volatile compounds derived from lipid oxidation are predominant in *boucané*, particularly aldehydes (including hexanal). This is in agreement with the results reported by Ho, Oh, and Bae-Lee (1994) in a study on cooked pork.

Benzene, ethylbenzene and 1,3-dimethylbenzene are unsaturated hydrocarbon products derived from lipid oxidation (Min, Ina, Peterson, & Chang, 1977) and are commonly detected in cooked meats (Mottram, 1991). These compounds have been identified in pork fat heated at 70–80°C for 10 min (Yasuhara & Shibamoto, 1990).

3.2.3. Volatile compounds derived from Maillard reactions

Furans and sulphur and nitrogen compounds represented 9% of the entire chromatogram area. These heterocyclic compounds are mainly derived from Maillard reactions and indicate that the meat has been cooked (Mottram, 1985; Vernin, 1980). For instance, pyridine and pyrrole are compounds detected in pork that has been grilled for 1 h at 70°C (Mottram, 1985). Pyrazine formation is mainly associated with heat treatment of meat since these molecules appear after 2 h of cooking a meat product at 70°C (Shibamoto & Bernhard, 1976). In addition, salting leads to an Aw of 0.94 and promotes

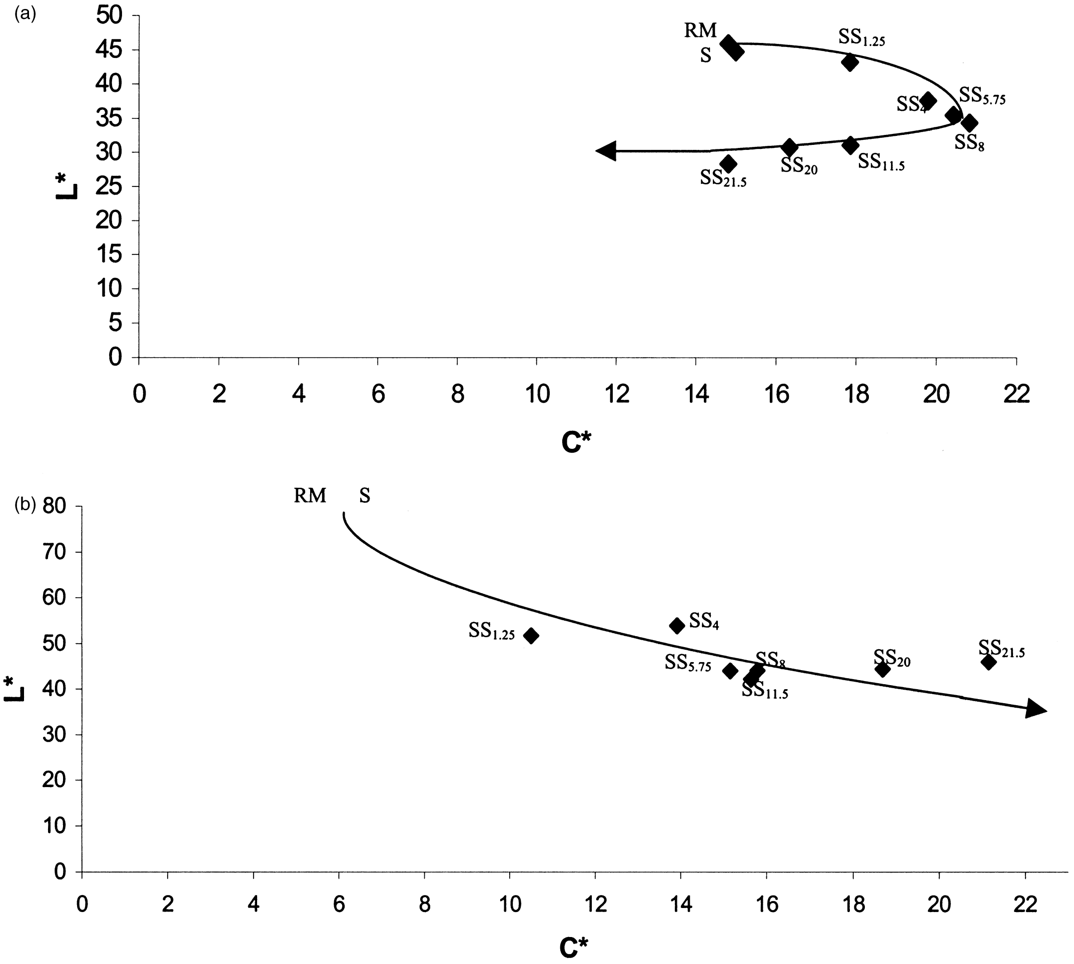

Fig. 6. (a) Variations in lightness L^* relative to the saturation C^* of the lean protein fraction during *boucané* production. (b) Variations in lightness L^* relative to the saturation C^* of the fat protein fraction during *boucané* production. With RM, raw material; S, salted product; SS_x, (SS) smoked product per (x) smoking time (h).

pyrazine development (Maga, 1982). These latter molecules give meat a characteristic grilled (Pittet & Hruza, 1974) and roasted (Mottram, 1998) odour. Furfural, 2-furanmethanol and 5-methylfurfural are also molecules detected often in cooked meats, giving them caramel and grilled odours (Mottram, 1991).

3.2.4. *Volatile compounds derived from smoke*

The main compounds derived from smoke are phenolic. The nature of these phenolic compounds varies according to the type of wood used. *Boucané* chiefly contains 2-methoxyphenol (guaiacol), 2-methylphenol (*o*-cresol) and phenol — three compounds that account for 90% of the phenol fraction. These results contrast with those reported by Lesimple et al. (1995) who reported that at high vapour pressure phenol compounds such as *o*-cresol and guaiacol are only found during cold smoking of meat products.

Phenols in general were found to give an incomplete "smoke cured aroma" and it was suggested that for whole smoke aroma a complex mixture of substances was necessary (Daun, 1972). According to Daun (1979), phenols are adsorbed onto smoked meat by formation of hydrogen bonds between their hydroxyl groups and components of collagen. Phenols are known to inhibit bacterial growth and oxidative degradation of fatty products.

3.2.5. *Total phenol assay during the production process*

The spectrophotometric total phenol assay highlights the extent of smoking of a meat product (Bratzler, Spooner, Weatherspoon, & Maxey, 1969). Fig. 5 shows a classical linear curve for total phenol gain during the *boucané* smoking process. This agrees with the results obtained by Chan, Toledo, and Deng (1975) with fish under nil air velocity conditions in the smoking chamber. The final phenol gain was (2.95±0.03)g/100 kg *boucané*. Phenols are deposited on the product surface and migrate very slowly to the core (Chan et al., 1975), which gives the product antioxidant and antimicrobial properties that are essential for its stability.

The mean total phenol content of *kundi*, a Nigerian meat product that is salted and hot smoked directly over embers, is 0.9 g/100 kg of product (Alonge, 1987). *Boucané* has a final phenol content of 2.95 g/100 kg, which means that it is three times more smoked than *kundi*.

The smoked flavour is strengthened by hints of caramel, grilled, rancid or green flavours given by Maillard reaction and lipid oxidation derivative compounds.

3.3. *Product colour variations during the production process*

Fig. 6a and b show the colour patterns of lean and fat parts of the product, respectively, during processing.

3.3.1. *Lean protein fraction*

The lean protein fraction was not very light coloured ($L^* = 44.8 \pm 7.5$). Saturation, which is indicative of the colour intensity of the meat fraction, was 15.0±2.8, corresponding to an a^* index of 13.4±2.5 and a b^* index of 5.8±2.7. Chizzolini et al. (1996) stated that these values correspond to a DFD (dark firm dry) raw material. Due to the speed of the pork belly salting process, no variations in the L^* index were noted between RM and S. The lightness then gradually decreased from 43.3±6.1 to 30.8±4.3 during the smoking process. The high water loss (31 kg/100 kg) could explain this decrease in the L^* index since dehydration processes determine colour changes in red meats (Chizzolini et al., 1996). Moreover, high treatment temperatures lead to heat denaturation of myoglobin and hemoglobin, which darkens the meat (Martens et al., 1982). Colour variations could also be explained by the appearance of brown reaction products produced by rearrangement and polymerization reactions of carbonyl compounds present in the smoke gas phase and amine groups of meat proteins (Clifford et al., 1980; Ruiter, 1979). Furfural (Table 1, peak no. 43) is a flavour compound that is also involved in meat colour modifications (Hollenbeck, 1994). During smoking, compounds derived from the particulate phase can then be deposited on the meat surface, thus giving it a colour that varies from yellowish (HR < 60–70%) to pale to dark brown (HR > 60–70%).

Fig. 6a shows the saturation patterns of the lean protein fraction at two times. An increase in the C^* index from 17.9±3.0 to 20.8±3.6 was noted during the first 8 h of the smoking process, followed by a progressive decline (reaching 16.3±3.8) over the last 13 h of the smoking process. It is difficult to explain this phenomenon.

3.3.2. *Lipid fraction*

The lipid fraction of the raw material was twofold lighter ($L^* = 81.0 \pm 1.6$) than the lean fraction, and was yellowish ($b^* = 5.6 \pm 0.8$; $a^* = 2.5 \pm 0.6$). Due to the short salting time, no colour modifications were noted between the two RM and S. The marked decrease in lightness was measured during the first hour of the smoking process ($L^* = 51.7 \pm 7.2$). From 1.25 to 21.5 h, L^* gradually decreased from 51.7 to 46.0. The saturation C^* increased from 1.5 to 21.1±2.9 during the smoking process. This saturation variation was due to a progressive increase in the b^* index between the salting operation (5.6±0.8) and the end of the smoking process (20.9±2.9), with a^* being constant (1.5). The results indicated a darkening of the lipid fraction and a strengthening of the yellow colour, with a greyish tint. These colour variations were probably caused by oxidation of the lipid fraction and the deposit of phenolic compounds. These molecules, which are mainly lipophilic, are generally taken up by the lipid fraction of the meat product (Ruiter, 1979).

3.4. Sanitary quality of the end product

Benzo(a)pyrene (BaP) is a good indicator of carcinogenic compound contamination of cooked and smoked meat products. At the end of the smoking process, the benzo(a)pyrene content in *boucané* was found to be (6.9 ± 2.4) μg/kg of product, which is higher than the 1 μg/kg level recommended by the French Conseil Supérieur d'Hygiène Publique (Salagoity et al., 1990).

The high BaP contamination of *boucané* could be explained by the fact that it is smoked directly over embers (Larsson, Sahlberg, Eriksson, & Busk, 1983), the high temperatures on the product surface (Alonge, 1988), the long smoking time and the high fat content of the product (Noll & de Toledo, 1995). There is considerable published evidence (Alonge, 1988; Chen & Lin, 1997; Noll & de Toledo, 1995) that products smoked over embers have higher BaP contents than permitted by legislation in different countries (Salagoity et al., 1990; U.S.EPA, 1975; Walker, 1977). One explanation put forward by Lijinsky & Ross (1967), and later by other authors (Adrian, 1987; Alonge, 1988; Gomaa, Gray, Rabie, Lopez-Bote, & Booren, 1993), is that fatty acids (and probably other lipid molecules) contained in fat droplets that fall on the burning embers undergo pyrolysis and then cyclization. The polycyclic molecules formed — including benzo(a)pyrene — are smoke-borne and are subsequently deposited on the product surface.

Bories, Tchimbakala, and Tchimbakala (1978) reported BaP levels of 0.4 μg/kg for pork belly smoked by an indirect process, i.e. not directly over smouldering embers, demonstrating that contamination of hot smoked pork belly can be substantially reduced by separating the fire from the smoking chamber.

4. Conclusion

Boucané is still produced by traditional empirical techniques with very little control of the processing conditions. Processing yields are low and the sanitary quality of the end product is generally unsatisfactory.

The high temperatures in the *boucan* and the long smoking time results in a very cooked and dehydrated end product, thus promoting the formation of heterocyclic compounds. When cooking temperatures are kept below 100°C, these latter compounds give the end product a slight roasted and grilled taste. The salting and smoking conditions promote the development of volatile compounds (aldehydes, ketones) derived from lipid oxidation of the product. The smoked flavour is produced by several phenolic compounds present in the product. Maillard reactions that occur during cooking and deposits of smoke compounds on the product surface are responsible for the typical colour of *boucané*.

The current *boucané* production process simultaneously involves reaction mechanisms and mass transfers which stabilize the product and give it its typical flavour and colour. These one-step operations are probably necessary for the development of product quality. A further laboratory study should now be carried out to determine the specific roles of each process variable and each mass transfer with respect to the flavour and colour characteristics of the end product.

Acknowledgements

We would like to thank the Laboratoire Flaveur-SRV at INRA in Theix for enabling us to carry out the *boucané* flavour analysis via dynamic headspace techniques/gas chromatography combined with mass spectrometry. We are also grateful to the Laboratoire de la Répression des Fraudes at Saint-Denis, Réunion, for their help with the benzo(a)pyrene analyses.

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