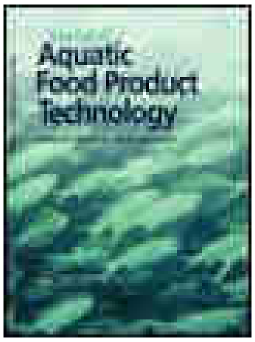

Journal of Aquatic Food Product Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wafp20

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To cite this article: Chakirath F. A. Salifou, Sabine Z. Vinankpon, Pascal S. Kiki, Raoul Agossa, Bernadette M. Konsaka & Issaka Youssao Abdou Karim (2021): Evaluation of the Physico-Chemical Characteristics and Sensory Qualities of Mackerel and Horse Mackerel Smoked with Fruit Peels and Rice Husk Residues in Benin, Journal of Aquatic Food Product Technology, DOI: 10.1080/10498850.2021.1988017

To link to this article: https://doi.org/10.1080/10498850.2021.1988017

Published online: 18 Oct 2021.

JOURNAL OF AQUATIC FOOD PRODUCT TECHNOLOGY
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Evaluation of the Physico-Chemical Characteristics and Sensory Qualities of Mackerel and Horse Mackerel Smoked with Fruit Peels and Rice Husk Residues in Benin

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ABSTRACT
Smoked fish quality depends on the fuel used for smoking. This study aimed to improve smoked fish quality using fruit peels, rice husks, and palm kernel charcoal (PCH) as fuels. Thirty fish (15 Atlantic mackerel and 15 horse mackerel) were smoked traditionally, while 75 horse mackerel and 75 Atlantic mackerel were smoked with experimental fuels. Physico-chemical characteristics and sensory quality of the smoked fish were assessed. The highest weight loss after smoking was found for the fish smoked with pineapple skin (32.79%), peanut shells (30.06%), and orange peel (29.84). The skin color of the fish smoked with rice husks was less white, redder, and more yellowish than the other fish. Those smoked traditionally had darker skin. The sensory quality of the fish smoked with rice husks, pineapple skin, and peanut shells was more acceptable. In summary, these fuels can be used to improve the appearance and quality of smoked products.

KEYWORDS
Fish; smoking; quality; fruit peelings and crop residues

Introduction

In developing countries and particularly in sub-Saharan Africa, fish is a major part of the meal, and the most accessible source of protein for low-income households. Fish is a very perishable foodstuff, especially in tropical environments, and can spoil in less than 12 hours between 25°C and 30°C (Djessouho 2015). In order to avoid losses due to deterioration of fresh fish, several techniques are used for preservation, including salting, drying, and smoking (Goueu 2006). Smoking is one of the oldest methods used in many parts of the world for preservation of foods, such as meat, fish, and cheese (Rivier et al. 2009). In Benin, about 10% of the fish obtained from local fishing at sea is processed (UEMOA 2014). Apart from the fish caught off the Beninese Coast, several other frozen fish species are also processed by smoking (Salifou et al. 2020). Fish smoking is traditional, as in other African countries (Chabi et al. 2014). There are two methods for fish smoking in Bénin: short smoking and long smoking. The first is generally of short duration, 2.4 hours on average; while the second lasts longer (5 to 96 h) (Assogba et al. 2019; Djessouho 2015). The short smoking is intended for fish to be sold in the following days on the local and national market. The shelf life of such smoked fish is generally between 2 and 3 days (Allagbé et al. 2020). The long smoking ensures a long-term preservation (up to one year) and is appropriate for regional market sale (Assogba et al. 2019; Djessouho 2015). Smoking equipment is generally composed of barrel ovens, and the main fuels used are wood, coconut shells, and cardboard (Assogba et al. 2019, 2018; Salifou et al. 2020). Other types of fuel are also used by the smoked fish processor. These are wood shavings, plastic, and kerosene (Assogba et al. 2019). Processed fish are stored at ambient temperature in a basket covered with cement paper or on a smoking

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rack covered with cardboard or old clothes (Assogba et al. 2019, 2018). Unfortunately, the traditional smoking process does not meet any safety standards regarding the work and hygienic conditions. The massive use of wood or wood shavings and the traditional smoking technique release a large quantity of smoke that causes respiratory and visual difficulties for the processors (Djessouho 2015). Moreover, the resultant fish product is of poor quality after smoking due to the use of corrugated and printed cardboard, kerosene, and plastic, which produce a very dense and harmful smoke (Assogba et al. 2019; Schoch 2015). In addition to the health conditions and the poor quality of traditionally smoked fish, the process brings about other issues. These are mainly the low quantity of fish to be smoked, the rapid dissipation of smoke, the high consumption of fuels, and very low income (Chabi et al. 2014). Faced with these challenges, the use of other smoking equipment using less fuel that can guarantee good quality of smoked fish and ensure good health for fish smoked processors is of paramount importance. The possibility of using other non-conventional fuels that are not hazardous to the consumer should also be explored. Rice husking residues and fruit peels exist in Benin, and their use as fuel for fish smoking should be studied given that climate change is affecting the whole planet, where there is an urgent need to protect the environment against deforestation. These potential fuels for fish smoking could therefore be a solution to the negative environmental, health, and socio-economic impacts caused by the traditional fish smoking practices in Benin. Some of these alternative fuels, such as dried orange peels and peanut shells, are used by very few smoked fish processors in southern Bénin (Assogba et al. 2019). Several studies have shown that agricultural by-products, such as rice husks and sugarcane bagasse, can be good alternatives to the use of wood and other harmful fuels for smoking fish (Bomfeh et al. 2019; Essumang et al. 2013; Ndakatu et al. 2012). In Benin, previous studies focused on the improvement of smoking conditions through the proposal of modern smokehouses (Chabi et al. 2014) on the quality and preservation of smoked fish (Degnon et al. 2013a, 2013b) but have not explored the impact of alternative fuels on the quality of smoked fish. The objective of this study is to evaluate the impact of the alternative fuels used in fish smoking on the smoked product quality. This work, therefore, evaluated the physico-chemical (pH, color, smoking weight loss, and moisture content) and sensorial quality of fish smoked with fruit peels (pineapple and orange), peanut shells, and rice husks.

Material and methods

Experimental site

The study was conducted in the experimental smoking workshop of the Animal Biotechnology and Meat Technology Laboratory of the Campus of Abomey-Calavi in the south of Bénin (Atlantique Departement, Abomey-Calavi). The climate is subequatorial, with two rainy (from April to July and from September to November) and two dry seasons. The temperature ranges between 27 and 31°C, and the average annual precipitation is around 1,200 mm. The main crops in the commune are maize, cassava, groundnut, and cowpea. Livestock farming is mainly focused on small livestock (poultry, small ruminants, rabbits) and unconventional rearing like aulacodes and achatines (INSAE 2016; Biaou 2006).

Fish sample

The fish species used for this sturdy were Atlantic mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*). Seventy-five fresh fishes of each species (average weight 189.5 g and 178.7 g, for horse mackerel and mackerel, respectively) were purchased from the fishmonger's shop in Abomey-Calavi. The fishes were divided into 5 groups of 30 fishes (15 horse mackerel and 15 Atlantic mackerel) and stored in the freezer for 2 days before the experimental smoking began.

In addition to fresh fish, 30 traditionally smoked fish (15 horse mackerel and 15 Atlantic mackerel) were purchased from smoked fish sellers in the local markets and were used as control.

Fuel collection

Five types of fuels were used for the smoking: peanut hulls, pineapple peel, orange peel, rice husk, and palm kernel charcoal. The rice husks were collected in a small rice-processing factory in the south of Bénin. The palm-nut husk charcoal was supplied by the manufacturer of the smokehouse. The other fuels were obtained from fruit sellers in Abomey-Calavi and then sun-dried (at 28–32°C) for 14 days. After drying, their water contents were 9.05 ± 0.89, 18.39 ± 1.16, 9.52 ± 0.42, and 10.05 ± 0.14 for rice husk, pineapple peel, orange peel, and peanut shell, respectively.

Smoking process

The smoking practice is a hot smoking process for cooking the fish (the core temperature of the product reaches at least 65°C). Before smoking, the fish were thawed by water soaking; fish were then drained and weighed using an Ohaus ® electronic scale (Ohaus Europe GmbH, Switzerland). A modern smokehouse (Atingan Solutions Sarl, Benin) was used for smoking (Figure 1). The smokehouse was equipped with a heat generator, which used palm kernel charcoal as fuel. The heat generated by the palm kernel charcoal was led by a chimney in the smoking chamber, which had 8 smoking racks arranged one on top of the other. A small cylindrical container was installed at the junction point of the chimney and the smoking chamber that was used to burn the other fuels mentioned in this study. The container was also provided with a metal filter to filter the smoke coming from the pyrolysis of fuels. The whole fish were smoked species by species and with one type of fuel only combined with palm kernel charcoal (3 kg of palm kernel charcoal and 0.75 kg of fuel). The smoking lasted 60 minutes for each specie. The palm kernel charcoal also was used alone for smoking. The internal temperature of the fish was measured 30 minutes after the smoking began and 60 minutes at the end of smoking using a Sunartis ® thermometer (Mingle Instrument GmbH, Germany). The physicochemical and sensory characteristics of the fish smoked with alternative fuels were compared with those of the Atlantic mackerel and horse mackerel that were traditionally smoked. For this purpose, smoked fish processors were made to smoke 15 horse mackerel and 15 Atlantic mackerel in a traditional smokehouse, using mostly wood (Acacia auriculiformis) as fuel. These processors were identified in advance, and fish were purchased immediately after smoking.

Physicochemical parameters evaluation

The physicochemical characteristics of each smoked fish were evaluated. Parameters included: temperature during smoking (T30) and temperature at the end of the smoking (T60); water loss during smoking; water content; the smoked fish pH; and color.

Water loss determination

The water loss during smoking was calculated by the difference in weight before and after smoking, following the formula:

$$\text{Weight loss} = \frac{\text{Weight before smoking} - \text{Weight after smoking}}{\text{Weight before smoking}} * 100$$

Moisture content determination

The moisture content of smoked fish was determined following the AOAC (1990) methods. Three samples of 5 grams of each smoked fish were placed in an oven (Memmert GmbH + Co, Germany) set at 105°C for 24 hours. Weight after drying was measured, and the moisture content was calculated using the formula:

$$\text{Moisture content} = \frac{\text{Weight before drying} - \text{weight after drying}}{\text{weight before drying}} * 100$$

Figure 1. Smokehouse ATINGAN® A: Heat generator, B: Closed smoking chamber, C: Open smoking chamber.

pH measurement

The pH was measured after cooling the fish (1 hour after the smoking) using a Hanna meat pH meter (Hanna Instruments, Smithfield, RI, USA). The probe of the device was inserted into the fillet of smoked fish at different places in order to have 4 measurements per fish. Before use, the pH-meter was previously calibrated with two standards: pH 4 and pH 7, following the procedure described by the manufacturer (Salifou 2013).

Color measurement

The color parameters of redness (a *), yellowness (b *), and lightness (L *) were measured on the skin and in the flesh of the smoked fish using reference system (L*, a*, b*) CIE 1976 with a Minolta CR 400® colorimeter (Konica Minolta Co Ltd., Japan). For each sample, 4 repetitions of each color parameter were made.

Sensory evaluation

A panel of 10 previously trained tasters was formed to evaluate the sensory quality. The smoked fish were cooled at room temperature (28.3°) in a basket covered with aluminium foil. Fish were then threaded and cut into pieces of 30 g. The assessment focused on flavor, juiciness, tenderness, and aroma of the smoked fish. The evaluation consisted of assigning scores ranging from 1 to 5 for each of the parameters. At the end, an overall acceptability score ranging 1 to 5 was assigned to each sample. For juiciness, score 1 corresponded to very dry, 2 to dry, 3 to moderate juiciness, 4 to juicy, and 5 to very juicy. Regarding the intensity of the flavor, 1 corresponded to very weak, 2 to weak, 3 to moderate intensity, 4 to high, and 5 to very high. The tenderness was very firm (1), firm (2), moderate tenderness (3), tender (4), and very tender (5). Regarding the intensity of the aroma, score 1 corresponded to no aroma, 2 to little aroma, 3 to moderate intensity, 4 to reasonably well, and 5 to strong aroma.

Statistical analysis

Statistical Analysis System software (SAS 2012, SAS Institute, Cary, NC, USA) was used for the data analysis. Proc means procedure was used to calculate the averages of the different variables. General linear model (GLM) procedure was used for the analysis of variance. Variation sources were the type of fuel and the species of fish smoked. The F test was used to determine the significance of the effect of each analysis model of variance, and the determined averages were compared by Student's t-test. The relation between fuel and species was determined through the statistical model with the following formula.

$$Y_{ijk} = \mu + E_i + C_j + EC_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} was the physico-chemical parameters of the fish k; μ was the value of the general average; E_i was the fixed effect of the species i (horse mackerel and Atlantic mackerel); Cj was fuel effect (orange peel, pineapple peel, groundnut husks, rice husks, palm kernel charcoal, and wood); EC was the interaction between fuels and species; and ε_{ijk} was the residual error.

Results

Physico-chemical characteristics of the smoked fish

Weight loss, internal temperatures, and moisture content of the fish during smoking

The effects of the interaction between fuel and species were significant for all physico-chemical parameters evaluated (Table 1). The weight loss was greater for the horse mackerel smoked with orange peel and pineapple peel (35.41% and 39.18%, respectively) compared to the Atlantic mackerel smoked with these same fuels (30.16% and 20.5%, respectively) ($p < .001$). The percentage of weight loss obtained with the fish smoked with peanut shells was similar for both the horse mackerel and Atlantic mackerel. The same trend was observed in the Atlantic mackerel and horse mackerel smoked with palm kernel charcoal and rice husks, which had the lowest percentages of weight loss (Table 1). The internal temperature measured at the end of the smoking (T60) was significantly higher for Atlantic mackerel (84.25°C) and horse mackerel (76.94°C) smoked with peanut shells ($p < .05$). However, the horse mackerel smoked with peanut shells showed an internal temperature similar to that obtained with the Atlantic mackerel smoked with orange peel. The lowest internal temperature of the fish at the end of the smoking was obtained in the horse mackerel smoked with palm kernel husk and rice husks as well as the Atlantic mackerel smoked with rice husks.

Overall, the different fuels influenced the smoking weight loss and the fish internal temperature during smoking (Figure 2). Smoked fish with pineapple peel, peanut shells, and orange peel led to the highest water loss during smoking (32.79%, 30.06%, and 29.84%, respectively) ($p < .001$). The lowest was found in fish smoked with rice husks (16.84%). The internal temperatures measured at 30 minutes of smoking were higher in the fish smoked with peanut shells (80.60°C) and in those smoked only with palm kernel husk (71.13°C). These temperatures were all higher than in the fish smoked with the other

Table 1. Interaction between fuel and species on the physico-chemical characteristics of smoked fish.

Parameters		Pineapple skin		Orange peel		PCH		Peanut shells		Rice husks		Tradi		RSD	Test of significance
		H.Mack.	A.Mack.	H.Mack.	A.Mack.	H.Mack.	A.Mack.	H.Mack.	A.Mack.	H.Mack.	A.Mack.	H.Mack.	A.Mack		
Weight loss (%)		35.41^{a}	30.16^{b}	39.18^{a}	20.5^{d}	20.87^{cd}	21.42^{cd}	30.12^{b}	30.01^{b}	17.23^{de}	16.44^{e}	-	-	5.44	***
T30 (°C)		49.69^{e}	49.1^{e}	49.14^{e}	51.35^{e}	64.14^{cd}	78.11^{ab}	76.94^{ab}	84.25^{a}	47.71^{e}	54.02^{de}	-	-	11.97	*
T60 (°C)		79.59^{def}	79.47^{def}	88.03^{cdef}	91.87^{bcd}	65.2^{g}	77.39^{efg}	97.37^{b}	117.29^{a}	68.83^{fg}	72.32^{fg}	-	-	14.42	*
Moisture content (%)		68.01^{de}	70.62^{abc}	68.68^{cde}	68.67^{cde}	72.68^{a}	72.51^{a}	70.43^{abc}	71.45^{ab}	67.94^{de}	71.3^{ab}	65.33^{f}	67.12^{e}	2.99	***
pH after smoking		5.97^{bc}	5.81^{de}	5.9^{cd}	5.94^{bc}	5.88^{cd}	5.81^{de}	5.94^{bc}	5.72^{ef}	5.67^{f}	5.76^{ef}	6.41^{a}	6.02^{b}	0.17	***
Skin color	L*	43.72^{de}	42.68^{de}	44.61^{de}	48.89^{bcd}	57.31^{a}	56.21^{a}	45.72^{cd}	51.04^{bc}	46.23^{cd}	47.03^{cd}	37.79^{e}	38.46^{e}	7.11	*
	a*	3.8^{cde}	3.75^{de}	5.3^{abc}	4.39^{bcde}	1.01^{g}	0.59^{g}	4.36^{bcde}	3.28^{de}	5.74^{ab}	4.75^{ab}	6.02^{a}	4.22^{cde}	1.70	*
	b*	15.37^{cde}	14.49^{de}	15.68^{cde}	16.41^{cd}	7.12^{f}	5.53^{f}	17.6^{bc}	19.48^{b}	23.63^{a}	24.49^{a}	14.66^{de}	13.59^{e}	2.93	*
Smoked fish meat color	L*	70.66^{ab}	59.86^{c}	68.82^{ab}	60.69^{c}	73.9^{a}	66.05^{bc}	74.85^{a}	65.82^{bc}	70.49^{ab}	64.66^{bc}	73.42^{a}	71.13^{ab}	7.47	*
	a*	2.59^{g}	6.01^{bcd}	4.2^{ef}	7.58^{a}	3.59^{fg}	5.76^{cd}	2.36^{g}	6.48^{abc}	5.09^{de}	7.29^{ab}	3.43^{fg}	5.28^{cde}	1.56	*
	b*	19.71^{a}	16.09^{cd}	17.21^{bc}	15.05^{d}	15.55^{d}	16.05^{cd}	20.14^{a}	17.71^{b}	17.34^{b}	17.00^{bc}	17.92^{b}	17.17^{bc}	1.74	***

H.Mack: Horse Mackerel; A.Mack: Atlantic Mackerel; PCH: palm kernel shell charcoal; Tradi: Traditionally smoking. RSD: residual standard deviation. T30: Temperature at 30 minutes of smoking; and T60: Temperature at the end of smoking; L*: Lightness; a*: Redness; b*: Yelloness. *p < 0.05; **: $p < 0.01$; ***: $p < 0.001$. Means of the same row followed by the same letters are not significantly different at the 5% level.

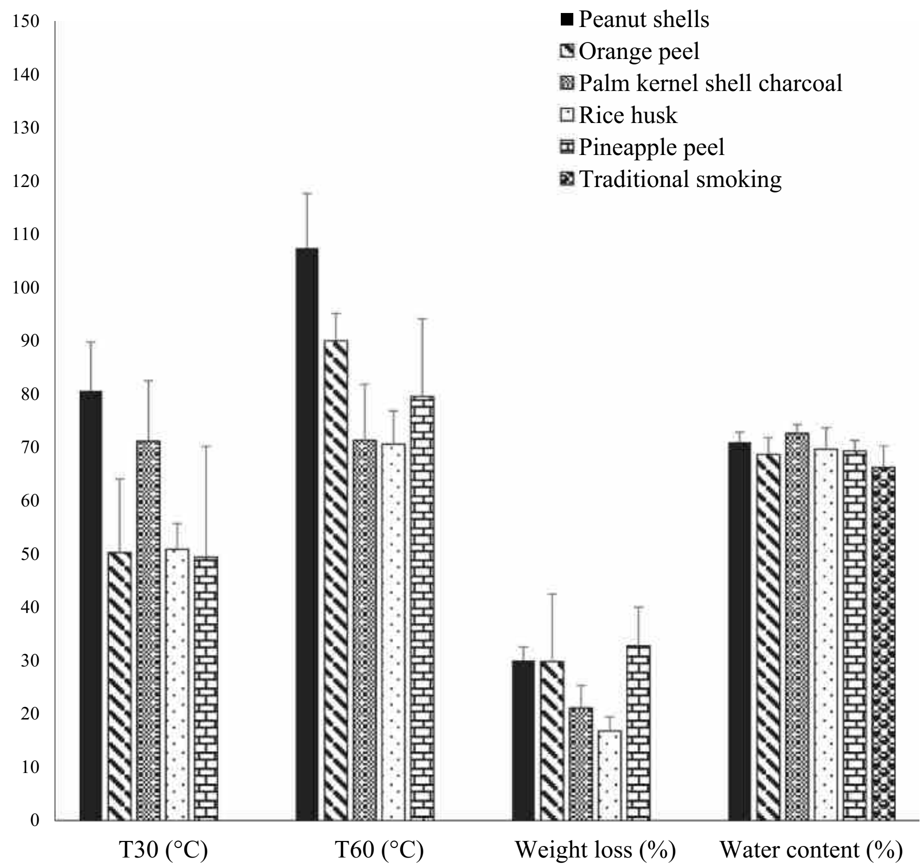

Figure 2. Temperature, weight loss, and water content of smoked fish.

fuels ($p < .001$). At 60 minutes of smoking, the internal temperature of the fish smoked with peanut shells (107.33°C) and orange peel (89.95°C) were significantly higher than those recorded for the fish smoked with other fuels ($p < .001$).

The fuel used also influenced the moisture content of the products obtained (Figure 2). Traditionally smoked fish had the lowest water percentage value (66.22%). The highest water percentage (72.59%) was obtained in the fish smoked with palm kernel charcoal. Fish smoked with orange peel, pineapple peel, and rice husks had similar moisture content.

Smoked fish pH

The two fish species (horse mackerel and Atlantic mackerel) smoked with peanut shells and palm kernel shell charcoal and the Atlantic mackerel smoked with rice hulls had higher moisture content than those smoked with other fuels (Table 1) ($p < .001$).

Overall, traditionally smoked fish showed the highest pH value (6.21), while the lowest pH value (5.71) was identified in the fish smoked with rice husks. The fish smoked with palm kernel shell charcoal, pineapple peel, and orange peel had similar pH values (Figure 3).

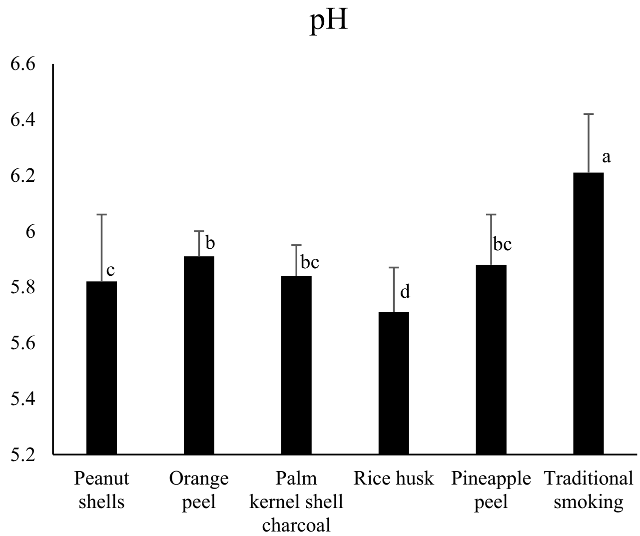

Figure 3. Smoked fish pH.

Color of the smoked fish

For the same fuel, the skin lightness did not vary significantly between smoked fish species. The highest skin lightness was obtained in fish smoked with palm kernel shell charcoal only (57.31 and 56.21 for horse mackerel and Atlantic mackerel, respectively) (Table 1). The lowest skin lightness was recorded for horse mackerel and Atlantic mackerel smoked with rice husks (37.79 and 38.46, respectively) ($p < .05$).

Like lightness, smoked fish skin redness and yellowness did not vary significantly between species for the same fuel. However, the use of rice husks as fuel resulted in the most golden smoked fish with the highest skin yellowness for both smoked horse mackerel (23.63) and Atlantic mackerel (24.49). The lowest redness and yellowness were obtained in horse mackerel (1.01 and 7.12, respectively) and Atlantic mackerel (0.59 and 5.53) smoked with palm kernel shell charcoal only ($p < .05$). Figure 2 illustrates the fish smoked with various fuels.

Figure 4 presents the color parameters of smoked fish skin and flesh according to different fuels used, and Figure 5 illustrates the presentation of the fish smoked with different fuels. All in all, fish smoked with palm kernel charcoal had skin with the highest lightness (56.76) and the lowest redness (0.80) and yellowness (6.32) ($p < .001$). However, fish smoked with the traditional smoking process were darker than those smoked with experimental fuel ($p < .001$) (Figure 4). This smoked fish had the lowest lightness (38.19) and the lowest yellowness (14.13). On the other hand, higher skin yellowness and redness was recorded in fish smoked with rice husks (24.06 and 5.25, respectively) ($p < .001$).

Smoked fish flesh color

The effects of the interaction between fuel and species were significant for all the color parameters (Table 1). The flesh of horse mackerel has a higher lightness than that of Atlantic mackerel smoked with the same fuel, except in the case of the fish smoked with the traditional process and those smoked with pineapple peels ($p < .05$). The horse mackerel with the highest brightness was smoked with peanut shells (74.84), palm kernel shell charcoal (73.9), and those smoked traditionally (73.42). For smoked Atlantic mackerel, the lightest flesh was obtained using the same fuels. The lowest flesh brightness was obtained for fish smoked with orange peel in both horse mackerel (68.82) and Atlantic mackerel (60.69).

Concerning the smoked fish flesh color, horse mackerel and Atlantic mackerel smoked with rice husks and with orange peel had the highest redness (5.09 and 7.29; 4.2 and 7.58, respectively). The lowest was recorded for both species smoked with the other fuels ($p < .001$). Overall, the Atlantic

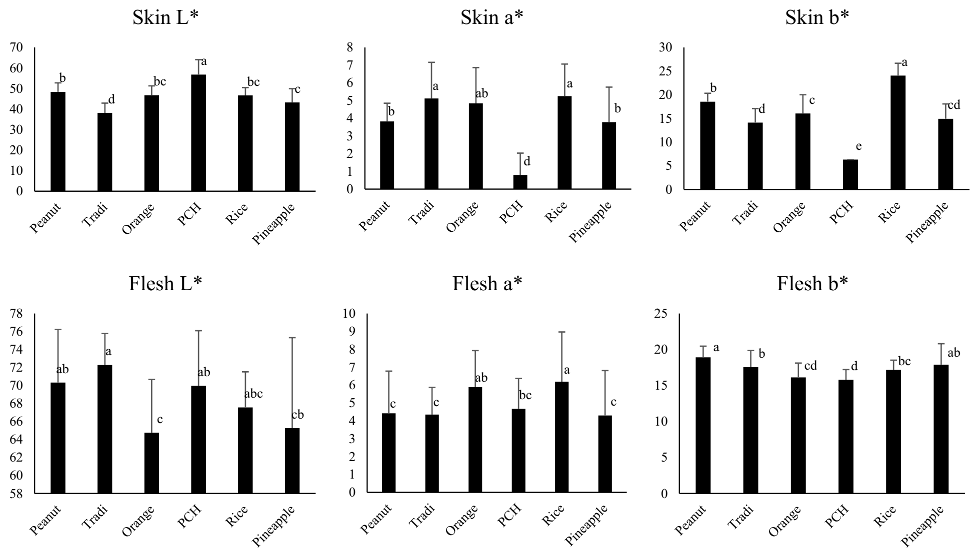

Figure 4. Skin and flesh color parameters of smoked fish. Pineap: Pineapple skin. Peanut: Peanut shells; Tradi: Traditionally smoking; Orange: Orange peel; PCH: palm kernel shell charcoal; Rice: Rice hulls

mackerel flesh had a higher redness than that of the smoked horse mackerel. Yellowness was higher for horse mackerel smoked with pineapple peel (19.71), peanut shells (20.14), and those smoked traditionally (17.92) compared to Atlantic mackerel smoked with the same fuels (16.09, 17.71, and 17.17, respectively) ($p < .001$). Among the horse mackerel, those smoked with peanut shell and pineapple skin had the highest yellowness (Table 1). Concerning Atlantic mackerel, the highest yellowness was recorded in fish smoked with peanut shells, rice husks, and traditionally smoked fish ($p < .001$). The lowest yellowness was obtained for horse mackerel smoked with palm kernel shell charcoal (15.55) and Atlantic mackerel smoked with orange peel (15.05).

Overall, the least redness in flesh was observed in fishes smoked with peanut shells and pineapple peel and fishes obtained in the traditional smoking process. However, fish smoked with orange and pineapple peel had a less light flesh than those smoked with the other fuels ($p < 0{,}001$) (Figure 4).

Sensory quality of smoked fish with various fuels

Atlantic mackerel and horse mackerel generally had the same flavor regardless of the fuel type (Table 2). Juiciness scores were similar and higher in fish (both species) smoked with rice husks and in horse mackerel smoked with peanut shells and pineapple skin ($p < .001$). The lowest juiciness score (1.9) was attributed to the horse mackerel smoked with palm kernel charcoal ($p < .001$). The most tender fish were horse mackerel and Atlantic mackerel smoked with rice husks. Overall, the lowest tenderness scores were assigned to the horse mackerel traditionally smoked and those smoked with orange peel and palm kernel charcoal ($p < .001$). The highest score for acceptability was attributed to the horse mackerel and the Atlantic mackerel smoked with pineapple skin, rice husks, and palm kernel charcoal ($p < .001$). For the same fuel, the aroma scores given by the judges did not vary from one species to another. The lowest aroma score was attributed to fish smoked with palm kernel shell charcoal (1.8 and 2.2 for horse mackerel and Atlantic mackerel, respectively) ($p < .05$).

Figure 5. Skin color of fish smoked with different fuels. **A**: fish smoked with pineapple skin; **B**: fish smoked with peanut shells; **C**: traditionally smoked fish; **D**: fish smoked with orange peel; **E**: fish smoked with palm kernel charcoal; **F**: fish smoked with rice husks. Smoked fish with **A**: Pineapple skin; **B**: smoked fish with Peanut shells; **C**: traditionally smoked fish; **D**: smoked fish with Orange peel; E: smoked fish with Palm husks coal; **F**: Rice hulls.

Table 2. Sensory quality of smoked fish with various fuels.

	Pineapple skin		Orange peel		PCH		Peanut shells		Rice husks		Tradi			
Parameters	H. Mack.	A. Mack.	H. Mack.	A. Mack.	H. Mack.	A. Mack.	H. Mack.	A. Mack.	H. Mack.	A. Mack.	H. Mack.	A. Mack	RSD	Test of significance
Flavor	3.8a	3.4a	3.2a	3.7a	2.2a	3.8a	3.3a	3.2a	3.6a	3a	3.3a	3.3a	5.44	NS
Jutosity	3.6abc	3.4bc	3.3bc	3 c	1.9d	3.4bc	3.5abc	3.2c	4ab	3.6abc	3.1c	3.3 c	11.97	***
Tenderness	3.4abc	3.3bc	2.5d	3.00 cd	2.1d	3.5abc	3.1 cd	3.2bc	3.9a	3.9a	2.6d	3.3bc	14.42	***
Acceptability	4a	3.5ab	2.8 cd	3.2 cd	2.1e	3.5ab	3.7ab	3.4b	3.7ab	3.4b	3.4b	3.4b	2.99	***
Aroma	2.5abc	2.4bc	3ab	2.5abc	1.8 c	2.2bc	3ab	2.6abc	3.1ab	2.6abc	2.9ab	3.3a	0.17	*

H.Mack: Horse Mackerel; A.Mack: Atlantic Mackerel; PCH: palm kernel shell charcoal; Tradi: Traditionally smoking. RSD: residual standard deviation. NS: $p > 0.05$; *: $p < 0.05$; ***: $p < 0.001$. Means of the same column followed by the same letters are not significantly different at the 5% level.

Discussion

Physico-chemical characteristics of the smoked fish

Weight loss, internal temperature of the fish during smoking, and moisture content of smoked product

This study did not determine the heating value of each fuel used. For discussion of our results, we referred to the calorific value reported in the literature (Table 3). The best smoking weight loss was obtained in fish smoked with peanut shells, pineapple, and orange peel. This could be related to the temperature (especially T60) taken on these fish, which were the highest. According to Werlich (2001), temperature is one of the parameters that can influence weight loss of smoked products. In this study, fish smoked with peanut shells and orange peel had the highest final temperature. Among the fuels used, peanut shell, pineapple peel, and orange peel had the highest calorific values, while rice husks had the lowest (Table 3). The results obtained here concerning the water loss during smoking and the internal temperature of the fish after one hour of smoking would thus be related to the intensity of the heat generated during the combustion of each fuel. The lowest calorific value of rice husk can also explain the lowest temperature recorded for both fish species. The weight loss during smoking is an important parameter, as it conditions, with the moisture content, the conservation of the final product (Gates 2015). The weight loss of the smoked fish in this study was lower than that reported by Salifou et al. (2020) for the horse mackerel (59.36%) and the Atlantic mackerels (62.07%) smoked traditionally in southern Benin. This difference can be explained by the smoking technique used. In the traditional smoking process, fish are directly exposed to the combustion chamber. In the present study, however, the combustion chamber was separated from the smoking chamber. Therefore, the fish smoked traditionally may have been exposed to a higher temperature, bringing about a higher weight loss compared to that obtained in the present study. Moreover, this difference can also be explained by the longer smoking time (2 hours) reported by this author.

In addition to the temperature and duration of smoking, fresh fish size and composition (especially water and lipid content) can also influence the weight loss during smoking (Arason et al. 2014). According to Aquimer (2020), horse mackerel has a higher water content (77% −78% of fresh fillet) than Atlantic mackerel (63.2% −71.8% fresh fillet). This specific composition of each species can explain the variations observed between the two smoked fish species for temperature (T30 and T60), weight loss during smoking, and water content. The moisture content of the smoked fish in this work was much higher than those reported by Adeyeye et al. (2015) for smoked fish (11.86% – 13.41%). The difference in the type of fish can explain such divergence as well as the relatively short smoking time in this study. On the other hand, these values are similar to that reported by Adeyemi et al. (2013), which ranged from 52.76 to 74.02. The lowest water content in the traditionally smoked fish may be related to the longer smoking time (2 hours) and the traditional process for fish smoking in southern Benin, as reported by Salifou et al. (2020).

pH and color parameters of the smoked fish

The pH value is an important factor in the preservation of smoked products (Fuentes et al. 2010). Overall, the pH values of the smoked fish in this study (5.71 to 6.27) were similar to those reported by Cardinal et al. (2004) for cold-smoked salmon (5.77–6.37). On the other hand, they are higher than those reported by Adebayo-Tayo et al. (2008) for various species of smoked fish sold in Nigeria. This difference may be due to the fact that these authors worked on dried smoked fish bought at the market. Meanwhile, Adeyemi et al. (2013) reported higher pH values (6.70) for smoked horse mackerel filets in Nigeria. This can be attributed to the smoking method used by these authors. They used wood and charcoal as fuel. The pH variation noted for the fish smoked with different fuels in this study must have bearings on the chemical composition of the smoke produced by each fuel type.

Table 3. Calorific value of fuels used in the study.

Fuel	Calorifique power (MJ/kg)	References
Pineapple skin	19.02	Arenas et al. (2019)
Orange peel	16.25–18.57	Chabel et al. (2015)
Palm kernel shell charcoal	18.72	Bonsu et al. (2020)
Peanut shells	18.547 − 19.2	Abe et al. (2007), Perea-Moreno et al. (2018)
Rice husks	13–16	An et al. (2010), Ríos-Badrán et al. (2020)
Wood	16.8–17.4	Marsoem and Irawati (2016)

Overall, fish smoked with palm kernel charcoal showed lighter skin compared to those smoked with other fuels. According to Varlet et al. (2007), the color of smoked fish depends on the chemical composition of the smoke. In fact, during smoking, the chemical compounds in the smoke cover the smoked products and gradually penetrate their flesh. These chemical compounds determine the specific color and the flavor of the smoked fish (Arvanitoyannis IS Kotsanopoulos KV 2012). However, the palm kernel shell charcoal, used as the only heat source for smoking fish, does not give off any smoke. This could therefore explain the difference in color observed. This has been noted by Rivier et al. (2009) regarding the color of the skin of the clarias smoked with charcoal in Senegal. Traditionally smoked fish are darker with low lightness compared to the fish smoked with the experimental fuel in the study. This could be justified by the types of fuels and the smokehouse used to perform traditional smoking. Fish smoked with rice husks had more golden skin color with higher yellowness and redness than other smoked fish in this study. The composition of the smoke depends on the nature of the fuel used (Varlet et al. 2007), which explains the difference noted for the skin color of the smoked fish and especially those smoked with rice husks. Rice husk are golden color, which could certainly be the basis for the best coloration obtained with this fuel. The consumer choice during purchase of smoked fish was primarily based on the color of the smoked fish. The best appearance of smoked fish is characterized by its external color, which is golden brown (Leksono and Ikhsan 2020). The color of the fish smoked with the rice husks suggests that this fuel could contribute to improving the appearance of the smoked fish sold in the market. However, the low calorific value of this type of fuel could be a limitation, since the loss of weight during smoking was lower for fish smoked with rice husks. The manufacture of rice husk briquettes alone or in combination with other more energetic fuels would favour a better valorisation of this type of fuel.

Unlike the skin color, the study revealed that the flesh of the traditionally smoked fish was brighter. This could be due to the smoking technique used. According to Varlet et al. (2007), in addition to the components of smoke, the color of smoked fish is also due to Maillard reactions, that is, the reactions between the amino acids of fish proteins and the compounds of smoke from the degradation of the polysaccharides of the fuel. Since the various fuels used in this study are not of the same nature, their chemical composition, as well as that of the smoke they produce, would also be different, which could explain the differences noted for the color parameters of the flesh of the smoked fish.

Sensory quality of the smoked fish with the various fuels

In general, the horse mackerel smoked with palm kernel charcoal showed a weak flavor and was tougher and drier than the fish smoked with other fuels. According to Jonsdottir et al. (2008) and Oduor-Odote and Odoli (2010), the sensory qualities of smoked fish are decisively influenced by the chemical composition of the smoke and the nature of the fuel used, but also by the specificities of each species. This would therefore confirm the jury's assessment of the sensory qualities of the horse mackerel smoked with palm kernel charcoal only. Moreover, unlike the horse mackerel, the Atlantic mackerel smoked with this same fuel were more appreciated by the panellists in terms of taste. This would certainly have bearing on the chemical composition of this species, which is different from that of the horse mackerel. Whatever the species, the fish smoked with pineapple skin, peanut shells, and rice husks showed the best sensory qualities. This could be due to the composition of the smoke from these fuels. Studies on the volatile compounds of the liquid smoke of rice husks, carried out by Pino (2014) and Sung et al. (2007), revealed a very high content of this smoke in phenolic compounds. These phenolic smoke compounds are said to be responsible for the sensory parameters of the smoked products such as smell, taste, and flavor (Martinez et al. 2007; Varlet et al. 2007). In general, traditionally smoked fish and those smoked with palm kernel charcoal have less pleasing appearance than other fish. This means that the fuels used in this study should be favored in the smoking of fish. However, more in-depth studies are needed to evaluate the chemical composition of the smoke produced as well as the polycyclic aromatic hydrocarbon levels of the fish being smoked.

Conclusion

This study revealed that the use of fruit peels and rice husk residues as fuel can improve the physico-chemical characteristics and sensory qualities of Atlantic mackerel and horse mackerel. Palm kernel charcoal used alone does not improve the quality of smoked fish. The fish smoked with rice husks had a good appearance given the values obtained for the skin color parameters. Furthermore, fish smoked with this fuel and those smoked with peanut shells and pineapple skin had the best sensory quality. However, due the low calorific value of rice husks and low weight loss during smoking, fish smoked with this fuel may have preservation difficulties. Other studies are needed to determine the impact of the fuel used in this study on the hygienic quality of the smoked fish, in particular the content of polycyclic aromatic hydrocarbons.

Acknowledgments

The authors would like to thank the Food Security Institute of the University of Abomey-Calavi (Bénin) for funding this research and Grace Oluwakemi Babarinde, Food Technology, Ladoke Akintola University of Technology (Nigeria) for proof-reading this article.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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