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Effects of Boiling and Smoking on the Proximate Composition and Oil Quality of a Commercially Important Freshwater Fish (*Chrysichthys nigrodigitatus*) from Nkam River in Cameroon

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Abstract

The effects of boiling and smoking on the proximate composition and lipids quality of a freshwater fish (*Chrysichthys nigrodigitatus)* collected from Nkam River in Cameroon were investigated. Fresh fish was filled, boiled or smoked and then, aliquoted for analyses. One portion was dried at 50 ℃ and ground into flour for the proximate composition determination. The other portion was served for lipids extraction using the Bligh and Dyer method. The extracted oil was characterized physico-chemically using chemical indexes and GC/FID. Moisture, protein, ash and lipid contents of raw fish were 80.67 ±4.18, 64.42 ±1.51, 10.90 ±0.42 and 22.06 ±5.40 % dm respectively. The changes in dry matter, protein and ash contents were found to be statistically significant ($P<0.05$) after smoking. The most important mineral of this fish was the Potassium (7017.54-8771.93 mg/kg). Except the calcium and phosphorus contents which decreased with the treatments, the amount of the other detected minerals was significantly increased. It was also found that these technological treatments significantly increased ($P<0.05$) the free fatty acids and hydroperoxides formation in oil, while it decreased its iodine value. The fatty acid profile of untreated and treated fish revealed her richness in Palmitic (22.91-34.76%), Oleic (12.83-23.55%), Stearic (11.29-14.81%), Linoleic (LA) (ω6) (2.83-6.75%), Arachidonic (ω6) (2.50-6.64%) and Docosahexaenoic (DHA) (ω3) (1.56-12.31%) acids. The ratio PUFA/SFA of raw fish (0.47) was severely reduced by the smoking (0.26) while it increases after boiling (0.61). This fish contain appreciable levels of Omega-6 PUFA, suggesting that it could be used as a source of healthy diet for human beings. These findings may also be beneficial for the fish industry, nutritionists and researchers who were striving to improve the nutritive value, processing and marketing of selected fish species.

Keywords: *Chrysichthys nigrodigitatus*, chemical composition, fatty acids, fresh fish, smoking, boiling, Nkam river

1. Introduction

Fishes are very important animal proteins source which can be exploited for preventing food insecurity in both rural and urban areas of Cameroon. They serve as feeds for livestock, poultry and carnivorous fish. Apart from being the richest source of high quality protein, vitamins and essential minerals, they are virtually a unique and good source of n-3 and n-6 long-chain poly-unsaturated fatty acids (PUFAs). The nutritional importance of seafood, fats and oils has increased substantially because of their health benefit effects (Azamand & Ali, 2004). Fish containing high n-3/n-6 PUFAs ratios is important for human health and it has been proven that regular fish consumption reduces the risk of cardiovascular diseases, enhances neurodevelopment of infants, leads to improvement in learning ability and prevents cancers (Suzuki *et al.*, 1998; Mozaffarian *et al.*, 2005). PUFAs are also essential in maintaining the functions of living cell membranes. Moreover, they are useful in making

prostaglandins which regulate many body processes, notably the inflammation and blood clotting. Fish fats are equally needed to absorb fat soluble vitamins A, D, E and K from food and for regulating body cholesterol metabolism (Connor, 2000; Kris-Etherton *et al.*, 2003). Clinical results of an epidemiological research suggest that, eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids, found only in fish and seafood, possess extremely beneficial properties for human coronary artery disease prevention. Additionally, fish oil helps in preventing brain aging and Alzheimer's disease (Conner, 1997). Many health experts recommend the consumption of seafood 2 or 3 times a week. This is mostly recommended for pregnant women, children and elderly people (Krauss *et al.*, 2000). Consumption of EPA and DHA may reduce the risk of mortality due to cardiovascular diseases (Conner, 1997; Krauss *et al.*, 2000). Although the hydrographic network of Cameroon is wide with an abundant and diversified aquatic fauna (Vivien, 1991), very few studies on their nutritional quality have been addressed in the literature. *Chrysichthys nigrodigitatus* is a species of fish in the family of claroteidae (Hopkins et al., 2007). This freshwater fish is of great commercial value at Yabassi and is interesting for consumption after boiling or smoking. However, very few studies have been done in Cameroon from this species. Previous works on this species include Tenyang *et al.* (2016) and Mouokeu *et al.* (2018). The first studied the proximal, mineral and fatty acid composition of raw *C. nigrodigitatus*, from the Maga Lake in Far North region. The second analyzed the chemical composition and antibacterial activity of oil of *C. nigrodigitatus* from Nkam River at Yabassi, extracted hot by pressing and maceration in hexane. Furthermore, no study made mention of the effects of boiling and smoking generally applied on their nutritional potential and the quality of their lipids. These effects are not yet been reported and remain unknown in this species of fish. Studies of nutrient intake from fish in relation to health are frequently carried out with data obtained from raw food. But, chemical contents in raw fish tissue might not provide explicit information on the nutritive value of the species after technological treatments. The objective of this study is to assess the influences of smoking and boiling on the proximate composition and fat quality of *C. nigrodigitatus* from Nkam River at Yabassi.

2. Material and Methods

2.1 Sample Preparation and Cooking

Fish samples *(Chryschsthys nigrodigitatus)* were obtained from the landing stages of the Nkam River at Yabassi-Cameroon, located at Titina: 4° 45' North latitude and 9° 97' East Longitude, former River Port 4° 27' North Latitude and 9° 57' East Longitude and Bodiman 4° 24' North latitude and 9° 53' East longitude. The fishes were harvested, transferred into ice containing boxes and transported to the laboratory. Identification was made by ichthyologists of the Laboratory of Ecosystem and Fisheries Resources of the Institute of Fisheries and Aquatic Sciences.

2.2 Boiling Procedures

Fresh fishes were washed with tap water to remove adhering blood and slime. They were prepared using a handling process, i.e. eviscerating, beheading, washing, and then cooked by boiling. The fishes were dipped into boiling water at the ratio of 1:1.5 (w/v) for 20 minutes at 98 ℃ (water temperature).

2.3 Smoking Procedures

The traditional heat smoking methods was used in the "banda chorhor" room for smoking. Firewood was set up in the combustion chamber and then lighted. The smoking temperature was monitored in the smoking chamber using a thermometer. Fish samples were then placed on the mesh in the kiln after weighing. The burning wood was adjusted continuously to maintain the required temperature in the chamber during the three smoking periods. During the pre-drying phase, the temperature was kept low between 32 and 50 ℃ for 2 h. During cooking-smoking, the temperature was between 60 and 80 ℃ for 2h30minutes and in the final phase smoking-drying, the temperature was decreased and maintained between 50 and 60 °C for 2h30minutes.

2.4 Sample Collection

After boiling or smoking, the bones of fishes were removed; meanwhile the fresh samples were filled in parallel. These samples of raw, boiled and smoked fish were then aliquoted for analysis. After evaluating their moisture content, a portion of the aliquots was dried at 50 ℃ and ground into flour in which proximal and mineral composition has been determined. For lipids analysis, the extraction was done in the other portion using a mixture of solvent chloroform, methanol, according to the Bligh and Dyer (1959) method.

2.5 Proximate Composition Analysis

The moisture content of *C. nigrodigitatus* was determined by drying the meat in an electric air dried oven at 105 ℃, until a constant weight was obtained as described by AOAC method (AOAC, 1990). Crude protein (CP) content was calculated by converting the nitrogen content determined via Kjeldahl's method (6.25xN). Fat (F)

was determined by the method described by the AOAC (1990) using the Soxhlet system apparatus, with a non-polar solvent hexane. Ash (A) content was evaluated by dry-aching in a furnace at 550 ℃ for 24 h (AOAC, 1990). Total carbohydrates (C) were determined by subtracting the sum of % F, % CP and % A contents from 100 g of fish dry matter (Onyeike *et al.*, 2000). Gross energy value of each sample was calculated, by multiplying the percentage CP, F and total Carbohydrate (C) contents with their respective energy values of 4, 9 and 4 kcal per 100 g of fish dry matter (dm).

2.5.1 Mineral Analysis

For mineral determination, the samples were digested in $HNO_3/HClO_4$ (Pauwels *et al.*, 1992)**.** The elements Fe, Zn and P were determined using a spectrophotometer. While Sodium (Na) and potassium (K) were measured by flame photometry, calcium (Ca) and magnesium (Mg) were measured by titration, using EDTA-complex metric method (AOAC, 2000).

2.5.2 Chemical Analysis for Lipids Quality

The extracted oils of samples were characterized through the assessment of their Iodine (I_2), Peroxide (PV) and free fatty acid (FFA) values as per the AFNOR official methods (AFNOR, 1981).

2.5.3 Fatty Acids Profile of Fish Oil Analysis

Fatty acids profiles of oils samples were investigated following the conversion of their fatty acids into fatty acids methyl esters (FAMEs). Then they were prepared by trans-esterification using 2% of sulfuric acid in methanol (Christie, 1993). The FAMEs were extracted into ethyl acetate and thoroughly washed with water to make them free of acid and dried over anhydrous sodium sulfate. The dried esters were analyzed in Gas chromatography flame ionize detector (GC-FID). The GC-FID analyses were performed with an Agilent (Agilent Technologies, Palo Alto, CA, USA) 7890A series gas chromatograph equipped with a FID detector using a DB-225 capillary column (30 m × 0.25 mm, 0.25 μm of film thickness). The column temperature initially maintained at 160°C for 2 minutes, was subsequently increased to 220 ℃ at 5 ℃/minutes and maintained for 10 min at 220 ℃. The carrier gas utilized was nitrogen at a flow rate of 1.5 ml/min. The injector and detector temperatures were maintained at 230 and 250 ℃, respectively with a split ratio of 50:1. The identification of fatty acid was based on the comparison of retention time with that of standard reference fatty acid methyl esters performed under same conditions.

2.5.4 Statistical Analysis

Completely Randomized Design (CRD) was adopted in carrying out the experiment. Experimental trials on evaluation of the physicochemical properties of each sample were conducted at least three times. One-way analysis of variance (ANOVA) with a level of significance $P< 0.05$ was applied to the different sample values obtained. The differences among the means were characterized by the multiple comparison test of Tukey Kramer. Graph Pad InStat Software Inc (C) 1992-2000 version 3.05, 32 bit for Win 95/NT was used for the data analysis.

3. Results and Discussions

3.1 Proximate composition

Results of the proximate analysis carried out on fresh, smoked and boiled *C. nigrodigitatus* are presented in Table 1. The average values obtained on the raw flesh of this fish were 80.67 % fw for the water content, 64.42 %dm for the crude protein, 22.06 % dm for the crude lipid, 10.90 % dm for the crude ash and 2.62 % dm for the crude carbohydrates. These values differ from the 78.46% fw, 39.73, 30.34, 7.32 and 22.61 % dm found by Tenyang *et al.* (2016) respectively on the same fish species in the Maga Lake in Far North. However, this proximate composition was not far from the one found by Tenyang *et al.*, (2013). These authors found 76.48 % fw, 64.24, 23.02, 10.98 and 1.76 % fw respectively on a catfish *Arius maculatus* from Wouri. It is clear that the flesh of *C. nigrodigitatus* is dominated by water. This result is in agreement with Tenyang *et al.* (2014) and (2016) on the catfish. Also, value of water content of this fish is in the range of 70-85 g / 100 g FW described by Yeannes and Almandos (2003) on the fresh fish. The fat content of our fresh samples is lower than that found by Tenyang *et al.* (2016) on the same species in the Far North-Cameroon. This fat value is similar to that of *A. maculatus* from Wouri (Tenyang et al., 2014) and fall within the range of 17.16 - 39.06 % dm found by Olele (2012) on *C. nigrodigitatus* from Niger River between September and February. Protein of raw *C. nigrodigitatus* of this study is similar to that of *A. maculatus* from Wouri (Tenyang *et al.*, 2014), but remains very high than the same species collected in the Maga Lake in the far North (Tenyang *et al.*, 2016). This value is also very high compared to the range 0.86 - 14.15% found by Olele (2012) on *C. nigrodigitatus* of Niger. The carbohydrate content of our raw sample is very small compared to that found (22.61 %DW) by Tenyang *et al.* (2016) and the range (4.23 - 14.11%) recorded by Olele (2012). The high protein levels recorded is proving that this fish could

be used to enrich the basic food rations and prevent its deficiency-related diseases. To be healthy, the FAO (Food and Agricultural Organization) and WHO (World Health Organization) (2007) recommend a protein intake of 0.66 g/kg of weight body/day. Overall the differences observed in the nutritional composition of *C. nigrodigitatus* could be explained by some variation of the extrinsic factors (geographic areas, quality of water (temperature, salinity and turbidity), quality and availability of food, migration) and intrinsic factors (species, breeding period, age, sex and size at capture) (Ackman, 1990; Argen *et al.*, 1991; Rao *et al.*, 1995 and Sargent *et al.*, 2002).

Table 1. Proximate composition of raw, smoked and cooked *C. nigrodigitatus*

Parameters	Raw	Smoked	Boiled
Moisture (%)	$80.67 \pm 4.18_a$	$15.89 \pm 0.01_{b**}$	$76.47 \pm 1.77_a$
Dry matter (%)	$19.33 \pm 4.1_a$	$84.11 \pm 0.01_{b**}$	$23.53 \pm 1.77_a$
Moisture of flour (%)	$7.67 \pm 0.46_a$	$7.47 \pm 0.34_a$	$8.13 \pm 0.12_a$
Dry mater of flour (%)	$92.33 \pm 0.46_a$	$92.53 \pm 0.34_a$	$91.87 \pm 0.12_a$
Ash (%DM)	$10.90 \pm 0.42_a$	$27.45 \pm 0.31_b^{**}$	$11.30 \pm 3.54_a$
Lipides (%DM)	$22.06 \pm 5.40_a$	$26.79 \pm 2.3_a$	$19.08 \pm 4.6_a$
protein (%DM)	$64.42 \pm 1.51_a$	$38.75 \pm 7.19_b^{*}$	$60.27 \pm 1.11_a$
carbohydrates (%DM)	$2.62 \pm 2.46_a$	$7.01 \pm 3.28_a$	$9.35 \pm 3.10_a$
Energy (kcal/100gDM)	$466.70 \pm 64.48_a$	$424.15 \pm 62.58_a$	$450.2 \pm 58.24_a$
Calcium (mg/kg)	$7.92 \pm 0.22_a$	$5.68 \pm 0.84_a$	$5.23 \pm 0.61_a$
Magnesium (mg/kg)	$12.98 \pm 6.7_a$**	$37.12 \pm 1.13_b$	$38.46 \pm 6.12_b$
Sodium (mg/kg)	$923.15 \pm 0.01_a$	$1384.72 \pm 0.00_b$*	$923.15 \pm 0.01_a$
Potassium (mg/kg)	$7017.54 \pm 0.00_a$*	$8187.13 \pm 1654.05_b$	$8771.93 \pm 827.02_b$
Phosphorus (mg/kg)	$406.25 \pm 44.20_a$	$343.75 \pm 44.20_a$	$375 \pm 0.01_a$
Iron (mg/kg)	$1.70 \pm 0.01_a$	$1.20 \pm 1.17_a$	$2.70 \pm 0.01_a$
Zinc (mg/kg)	Trace	Trace	Trace
Na/K	0.13	0.17	0.11

Values are shown as mean ± standard deviation of triplicates. N=3. Within the same line, values with different letters (a,b) are significantly different (*P<0.05; **P<0.01).

The effects of treatments on the proximate composition showed a drastic moisture decrement with the smoking. This dehydration concentrates the dry mater of fish, as well as its nutrient contents. This result is in agreement with those of Kumolu-Johnson *et al.* (2010) who reported the same observations. With respect to the dry matter, while value of ash content significantly (P<0.01) increases with the smoking process, the amount of proteins significantly decreases (P<0.01). The augmentation in ash content of smoked fish could be due to the loss of water during the process as explained in previous studies (Salan *et al.*, 2006**).** Likewise, the observed statistically significant decrease of proteins amount in the present study during the smoking process, may affect the quality of food as stated in previous studies (Salan *et al.*, 2006). The loss in available lysine may vary from 6-33% at 25 ℃ to 53-56 % at 40 ℃ during hot smoking (Dvorak & Vognarova, 1965); 25 % loss of available lysine on the surface and a 12% loss at the center of hot smoked fish (Clifford *et al*., 1980). Akande *et al.* (1998) observed that lysine reduction was directly proportional to the temperature and duration of smoking. However, the present study showed that boiling does not significantly (P>0.05) affect the proximate composition of *C. nigrodigitatus*.

The mineral contents of *C. nigrodigitatus* carried out in fresh, smoked and boiled are also shown in Table 1. In this fish, potassium content was higher (7017.54-8771.93 mg/kg), followed by sodium (923.15-1384.72 mg/kg), phosphorus (343.75-406.25 mg/kg), magnesium (12.98-38.46 mg/kg) and calcium (5.23-7.92 mg/kg). Iron was reported to be the least represented (1.20-2.70mg/kg), while zinc was observed in traces. The ratio Na/K, increases (from 0.13 to 0.17) with smoking and decrease (from 0.13 to 0.11) with boiling. This report is very interesting in nutrition insofar as consumption of foods with high Na/K ratio is often associated with high blood pressure (Liu, 1996). The P, Ca and Mg are the essential components of the bones. Calcium and magnesium plays a significant role in photosynthesis, carbohydrate metabolism, nucleic acids and binding agents of cell walls (Russel, 1973). Calcium assists in teeth development (Brody, 1994). Magnesium is an essential mineral for enzyme activity; like calcium and chloride, magnesium also plays a role in regulating the acid-alkaline balance in the body (Fallon & Enig, 2001). The order of predominance of these minerals from raw *C. nigrodigitatus* is different from the one obtained by Tenyang *et al.* (2016) on the same species collected in the Maga Lake. These last authors had found the order of predominance of *C. nigrodigitatus* minerals as Ca, P, K, Mg, Na, Zn and Fe with respective values of 82938.9, 35394.8, 6117.5, 1797.8, 1072.3, 122.8 and 77.2 mg/kg dm. Thus, *C.*

nigrodigitatus from Nkam River at Yabassi is less rich in minerals than the Maga Lake. The differences could be explained as previously by the variation in environmental factors (geographic areas, quality of water (temperature, salinity), availability of natural food and migration) and intrinsic (species, period of reproduction, age, sex and size at capture) (Ackman, 1990; Argen *et al.*, 1991; Rao *et al.*, 1995 & Sargent *et al.*, 2002).

Processing methods like smoking and boiling significantly ($P<0.05$) and positively affect the content in some minerals. For example, it is clearly noted in the table 1 that, it leads to an increment of potassium (16-25%), magnesium (185-196%) and sodium (50%) content of fish. This corroborates the findings of Akinwumi (2014), who demonstrated that smoking of *Clarias gariepinus* increased its phosphorus, iron and potassium content. Similarly Effiong & Fakunle (2012) observed high values of phosphorous and low iron contents in the three tropical smoked freshwater fishes studied. However, Eyo (2014) reported low phosphorous and iron contents, but high potassium and vitamin C contents in frozen fish. The current study is in contradiction with the report of Gokoglu *et al.*, (2004) in regard to the effect of boiling on minerals contents. These authors observed a significant decrease in minerals Na, K, Mg, P, Zn and Mn after smoking. Flesh of freshwater fish is a particularly valuable source of minerals calcium and phosphorous as well as iron (FAO, 2014).

3.2 Chemical Analyses for Lipids Quality

The table 2 shows the effect of smoking and boiling on the oxidation parameters of *C. nigrodigitatus* oil. From this table, it is clearly observed that compared to extracted oil from raw fish, boiling and smoking have significantly affected the oil quality. The oil extracted from boiled fish has exhibited the highest peroxide and acid values, and the lowest iodine values in comparison to smoked and raw fishes. The index value of acid (10.25% oleic acid which corresponds to 20.4 mg KOH/g) obtained in this work with the raw fish is at the limit ($\leq$ 20 mg KOH/g) granted by the *Codex Alimentarius* for Virgin oils of fish rich in phospholipids. This value is greater than 7.33 mg KOH/g obtained by Mouokeu *et al.* (2018) in *C. nigrodigitatus* dried and macerated into hexane. This difference could be justified by the extraction technique. The increase in acid value observed in fish oil after treatment might be attributed to the hydrolysis of lipid compounds (triglycerides, phospholipids, etc.) due to the effect of heating and water. At high temperature, water can catalyze the hydrolysis of lipids, leading to free fatty acids, which result in the increment of oil acidity and in the susceptibility of the released fatty acids easily oxydable especially if they are unsaturated. These results are in agreement with those of Labuza (1974) who observed an increment of free fatty acids in food during dehydration and storage processes.

Table 2. Oxidation parameters of oil extracted from raw, smoked and boiled *C. nigrodigitatus*

Parameter	Raw	Smoked	Boiled
Acid value (% oleic acid)	$10.25 \pm 0.01_a$	$18.80 \pm 0.01_b$	$29.96 \pm 0.01_c$
Iodine value (g of I_2/100g)	$56.37 \pm 0.22_a$	$52.66 \pm 0.01_a$	$51.60 \pm 4.59_a$
Peroxyde value (meq O_2/Kg)	$22.02 \pm 4.21_a$	$29.54 \pm 3.21_{ab}$	$35.00 \pm 0.01_b$

Values are shown as mean ± standard deviation of triplicates. N=3.

In the same line, values with different letters (a, b) are significantly different ($P<0.05$).

The iodine value of the raw samples was 56.37 g I_2 /100 g of oils. This value was lower than 82.64 and 93g I_2 /100g obtained respectively by Mouokeu *et al.* (2018) in the same fish and Tenyang (2015) in *Arius maculatus.* Smoking and boiling have not significantly affected ($P>0.05$) this parameter. These effects are not in the same line as those observed by Tenyang (2015). This author showed a significant decrease in the iodine value of *Arius maculatus* lipids after smoking and boiling. However, this result is in agreement with those of Onyeike and Oguike (2003) who found similar effects during heating of peanut oil. The observed variations could be explained by the inactivation of exogenous lipoxygenase responsible of oxidation (Eymard, 2003) and which depend on intrinsic factors of the samples, mainly, duration and temperature of the heat treatment (Franckel, 1998).

Table 2 also illustrates the changes in peroxide value of the tested fish oil before and after treatments. It is clearly observed that these treatments have significantly increased the peroxide value of oil. The highest value was noted in boiled fish oil samples, showing that boiling might accelerate the primary oxidation of fish oil as compared to smoking. This result is related to the result of acid value, because the same sample has exhibited the highest acid value. It is well known that hydrolysis of lipids leads to free fatty acids, which, if unsaturated, can rapidly undergo oxidation. The highest peroxide value obtained in boiled fish oil sample is contradictory to the observed findings of Tenyang (2015) during cooking by boiling and smoking of *Arius maculatus* fish. The observed increment in peroxide value is associated to the formation of primary oxidation products, mainly

hydroperoxides. In fact, during heating, unsaturated fatty acids of oil can undergo auto oxidation, which can lead to the formation of these compounds. So these parameters strengthen on the primary oxidation status of oil. The peroxide value of the oils extracted from raw *C. nigrodigitatus* was 22.02 meq O_2/kg. This result was greater than 4.49 meq O_2/Kg and smaller than 72 meq O_2/Kg found respectively by Mouokeu *et al.* (2018) in the same fish and Tenyang (2015) in *Arius maculatus* oil.

3.3 Changes in Fatty Acid Profile of Fish Oil during the Process

The fatty acid profiles of raw, smoked and boiled samples of *C. nigrodigitatus* are presented in Table 3.

Table 3. Fatty acid profiles of raw, smoked and boiled fish oils

Fatty acids	Raw	Smoked	Boiled
C10:0, Capric	$0.09 \pm 0.01_a$	$0.06 \pm 0.01_b$	$0.10 \pm 0.01_a$
C11:0, Undecanoate	$0.27 \pm 0.04_a$	$0.24 \pm 0.03_a$	$0.85 \pm 0.11_b$
C12:0, Lauric	$0.66 \pm 0.02_a$	$1.22 \pm 0.03_b$	$0.23 \pm 0.00_c$
C13:0, Tridecanoate	$0.16 \pm 0.03_a$	$0.33 \pm 0.04_b$	$0.11 \pm 0.03_a$
C14:0, Myristic	$2.91 \pm 0.06_a$	$3.60 \pm 0.07_b$	$2.05 \pm 0.06_c$
C15:0, Pentadecanoic	$0.70 \pm 0.01_a$	$0.75 \pm 0.04_a$	$1.17 \pm 0.03_b$
C16:0, Palmitic	$27.61 \pm 0.50_a$	$34.76 \pm 0.41_b$	$22.91 \pm 0.10_c$
C17:0, Heptadecanoic	$1.58 \pm 0.03_a$	$2.07 \pm 0.03_b$	$2.58 \pm 0.01_c$
C18:0, Stearic	$11.29 \pm 0.21_a$	$12.29 \pm 0.14_b$	$14.81 \pm 0.03_c$
C20:0, Arachidic	$0.52 \pm 0.04_a$	$0.32 \pm 0.01_b$	$0.68 \pm 0.02_c$
C21:0, Heneicosanoic	$0.17 \pm 0.01_a$	$0.16 \pm 0.09_a$	$0.32 \pm 0.13_a$
C22:0, Behenic	$0.42 \pm 0.08_a$	$0.46 \pm 0.15_a$	$0.91 \pm 0.32_a$
C23:0, Tricosanoic	$0.87 \pm 0.07_a$	$0.71 \pm 0.00_b$	$1.64 \pm 0.01_c$
C24:0, Lignoceric	$0.18 \pm 0.02_a$	$0.27 \pm 0.01_a$	$0.43 \pm 0.05_b$
C14:1 Myristoleic	$0.09 \pm 0.03_a$	$0.56 \pm 0.49_a$	$0.50 \pm 0.29_a$
C16:1, Palmitoleic	$5.88 \pm 0.10_a$	$5.68 \pm 0.06_a$	$3.00 \pm 0.04_b$
C17:1, cis-10 Heptadecanoic	$0.41 \pm 0.21_a$	$0.58 \pm 0.04_a$	$0.67 \pm 0.05_a$
C18:1, Elaidic			4.17 ± 0.10
C18:1, Oleic	$23.55 \pm 1.16_a$	$21.15 \pm 0.25_a$	$12.83 \pm 0.05_b$
C20:1, cis-11 Eicosenoic	$0.42 \pm 0.02_a$	$0.29 \pm 0.05_{ab}$	$0.20 \pm 0.01_b$
C22:1, Erucic	$0.07 \pm 0.02_a$	$0.37 \pm 0.33_a$	
C24:1, Nervonic	0.09 ± 0.04		
C18:2, Linolelaidic	$0.24 \pm 0.01_a$	$0.20 \pm 0.04_a$	
C18:2, Linoleic (LA) (ω6)	$6.75 \pm 0.17_a$	$3.62 \pm 0.10_b$	$2.83 \pm 0.10_c$
C20:2, cis-11,14 Eicosadienoic (ω6)	$0.82 \pm 0.02_a$	$0.46 \pm 0.02_b$	$0.79 \pm 0.02_a$
C22:2, cis 13,16 Docosadienoic (ω6)	$0.05 \pm 0.01_a$	$0.11 \pm 0.02_a$	
C18:3, γ-linolenic (GLA) (ω6)	$0.56 \pm 0.06_a$	$0.48 \pm 0.12_a$	$0.45 \pm 0.11_a$
C18:3, α-linolenic (ω3)	$1.32 \pm 0.04_a$	$2.37 \pm 0.05_b$	$1.47 \pm 0.04_a$
C20:3, cis-8,11,14 Eicosatrienoic (hGL) (ω6)	$1.43 \pm 0.05_a$	$1.07 \pm 0.02_b$	$0.87 \pm 0.07_b$
C20:3, cis-11,14,17 Eicosatrienoic (ω3)	$0.65 \pm 0.01_a$	$0.84 \pm 0.08_b$	$0.54 \pm 0.05_a$
C20:4, Arachidonic (ω6)	$4.53 \pm 0.11_a$	$2.50 \pm 0.10_b$	$6.64 \pm 0.22_c$
C20:5, Eicosapentaenoic (EPA) (ω3)	$1.41 \pm 0.02_a$	$0.95 \pm 0.03_b$	$3.92 \pm 0.06_c$
C22:6, Docosahexaenoic (DHA) (ω3)	$4.33 \pm 0.04_a$	$1.56 \pm 0.00_b$	$12.31 \pm 0.17_c$
Σ Total Fatty acids	**100**	**100**	**100**
Number of fatty acids	**32**	**31**	**29**
Σ Saturated Fatty acids (SFA)	$\mathbf{47.41 \pm 1.11_a}$	$\mathbf{57.23 \pm 1.06_b}$	$\mathbf{48.8 \pm 0.88_a}$
Σ Unsaturated Fatty acids (UFA)	$\mathbf{52.59 \pm 2.14_a}$	$\mathbf{42.77 \pm 1.80_b}$	$\mathbf{51.20 \pm 1.39_a}$
Σ Monounsaturated fatty acids (MUFA)	$\mathbf{30.51 \pm 1.59_a}$	$\mathbf{28.63 \pm 1.21_a}$	$\mathbf{21.37 \pm 0.55_b}$
Σ Polyunsaturated fatty acids (PUFA)	$\mathbf{22.08 \pm 0.55_a}$	$\mathbf{14.14 \pm 0.59_b}$	$\mathbf{29.83 \pm 0.8_c}$
Σn-3	$\mathbf{7.7 \pm 0.12_a}$	$\mathbf{5.72 \pm 0.17_b}$	$\mathbf{18.25 \pm 0.32_c}$
Σn-6	$\mathbf{14.14 \pm 0.43_a}$	$\mathbf{8.23 \pm 0.38_b}$	$\mathbf{11.59 \pm 0.52_c}$
n-3/n-6	**0.54**	**0.69**	**1.57**
PUFA/SFA	**0.47**	**0.25**	**0.61**

Values are shown as mean ± standard deviation of triplicates.

In the same line, values with different letters (a, b) are significantly different ($P<0.05$).

Thirty two fatty acids were identified in raw samples of fish oil *C. nigrodigitatus*. This number is very high compared to 20 and 17 obtained by Mouokeu *et al.* (2018) on oil of the same fish species collected at Yabassi and extracted respectively by press after boiling and maceration into hexane. This number is also higher than 23 obtained by Tenyang *et al.* (2016) on *C. nigrodigitatus* from Lake Maga and 22 recorded by Tenyang *et al.* (2014) on *A. maculatus* from Wouri. These differences could be explained by some extrinsic factor and the extraction method used. The oil of raw fish of this study contains 47.41±1.11, 30.51±1.59, and 22.08±0.55 % of saturated, monounsaturated and polyunsaturated fatty acids respectively. These proportions are also different from those of Tenyang *et al.* (2016) who recorded 43.52, 42.53 and 11.62 percent, respectively in the same fish from Lake Maga and Mouokeu *et al.* (2018) who also registered 50.09 - 51.72; 30.5 - 33.9 and 18.4 - 12.92 % respectively on the same fish species.

The most abundant fatty acids were Palmitic acid (C16:0) and Oleic acid (C18:1) with 27.61±0.50 % and 23.55±1.16 % respectively. These results corroborate with those of previous authors on *C. nigrodigitatus*. Tenyang *et al.* (2016) found an abundance of 22.75 and 32.96% while Mouokeu *et al.* (2018) found 27.5 - 34.0 % and 23.9 - 26.3% of these two fatty acids respectively. Oleic acid is n-9 fatty acids which plays a moderate role in the body. The n-6 fatty acids cannot be synthesized by humans and are therefore considered as essential fatty acids (Watanabe *et al*., 1989; Osborn & Akoh, 2002; Bell & Sargent, 2003). Linoleic (C18:2, ω6), Arachidonic (C20:4, ω6) and Docosahexaenoic (DHA) (C22:6, ω3) acids were in general, the polyunsaturated fatty acids found in the largest percentages of 6.75±0.17 %, 4.53±0.11 % and 4.33±0.04 % respectively. These findings are in line with previous studies conducted in catfish samples (Mouokeu *et al.*, 2018; Tenyang *et al.*, 2016; Tenyang *et al.*, 2013**;** Weber *et al.*, 2002; Sharai *et al., 2002)*. DHA are the fatty acids predominant in n-3 series of *C. nigrodigitatus*. This fatty acid has been considered as important for brain, eyes development and good cardiovascular health (Conner, (1997). *C. nigrodigitatus* had low level of n-3 PUFA when compared to the sum of n-6. However, the value 0.54 recorded on the n-3/n-6 ratio in this study is very high when compared to 0.3 and 0.2 obtained by Weber *et al.* (2002) and Sharai *et al.* (2002) respectively. These differences could be attributed to their diet. Several authors have concluded that FA profiles in fish reflect the diets of the animals (Zenebe *et al.*, 1998a; 1998b, Ahmed *et al*., 2010; Tenyang *et al.*, 2016; Osibona, 2011). Also, feeding of fish depend on the environmental conditions, including temperature, salinity, prey composition and types of metabolism (Sargent *et al*., 2002).

As shown in the table 3, smoking has significantly increased ($P<0.05$) the amount of saturated fatty acids, meanwhile it has significantly reduced ($P<0.05$) the amounts of unsaturated ones (n-3 and n-6 polyunsaturated fatty acids). The increase in saturated fatty acids concerns Lauric, Tridecanoic, Myristic, Palmitic, Heptadecanoic and Stearic acids. Nervonic (C24:1) acid disappeared with this treatment. The decrease of polyunsaturated fatty acids concerns Linoleic, Cis-11, 14-Eicosadienoic, cis-8,11,14-Eicosatrienoic, Arachidonic, Eicosapentaenoic and Docosahexaenoic acids. The ratio PUFA/SFA regressed from 0.47 to 0.25. Similar effects have been recorded in our precedent research in smoking of *Oreochromis niloticus* in the same zone (Djopnang *et al.*, 2017). The decreased of this quality index could be related to the fat oxidation, which was confirmed by the previous results on the indices of acids and peroxides. From this effect, Julie (2002) concluded that Fat oxidation can decrease the level of essential fatty acids in the diet and can lower the overall food quality by introducing free radicals and other oxidized products. It is well known in the literature that a ratio of 0.2 is associated with hypercholesterolemia, while the oils with 0.8 ratios are recommended to prevent cardiovascular diseases (Rahman *et al*., 1995).

Boiling also affects the fatty acid profile. In general, the loss of four fatty acids with boiling is observed: Nervonic, Linolelaidic, Erucic and Docosadienoic (ω6). A new Elaidic acid was generated during cooking. The cooking processes did not significantly influence ($P>0.05$) the total saturated fatty acids, but, a significant ($P<0.05$) decrease in monounsaturated fatty acids is registered. In Contrast, a significant ($P<0.05$) increase in polyunsaturated fatty acids was registered with the increase of n-3 fatty acids. This process increased the nutritional status of n-3 PUFA like the n-3/n-6 and PUFA/SFA ratios at 1.57 and 0.61 respectively, which are necessary for cardiovascular diseases prevention. These results are in agreement with our previous research in boiling of *O. niloticus* (Djopnang *et al.*, 2017). The increase in PUFA concerns Docosahexaenoic (DHA, ω3), Eicosapentaenoic (EPA, ω3), and Arachidonic (ω6), while the decrease of MUFA and PUFA concerns Palmitoleic, Oleic, cis-11 Eicosenoic, Linoleic (LA, ω6) and cis-8,11,14 Eicosatrienoic (hGL, ω6) respectively. The increase in PUFA and different quality oils ratio of *C. nigrodigitatus* could be justified by extraction. Indeed, during extraction, fine grinding of the skin in raw samples was difficult unlike in boiled samples. Boiling has the role of weakening the cell membranes, and in turn facilitates the extraction of oils. The only source of higher fatty acids could reside in the subcutaneous fat deposit. Similar effects were observed by Kaitaranta (1980) on

the *Coregonus albula*.

4. Conclusion

The present study consisted in an evaluation of the influence of smoking and boiling processes of a selected freshwater fish *C. nigrodigitatus* commercialized in Yabassi-Cameroon on the chemical composition and lipids qualities. This fish was found to be a good source of protein, minerals and fatty acids. It is equally rich in essential PUFAs, such as EPA and DHA, which are good for health. Processing by smoking and boiling methods applied to this fish influenced significantly its composition. Smoking concentrates ash value and decreases the amounts of water, protein, PUFA such as Docosahexaenoic (DHA), Eicosapentaenoic (EPA), Arachidonic, cis-8,11,14-Eicosatrienoic (hGL) and cis-11,14-Eicosadienoic and PUFA/SFA ratio. Thus, the drastic decline of this last parameter would indicate that oil of *C. nigrodigitatus* smoked could expose the consumer to cardiovascular diseases. Both processes led to an increase of potassium, sodium and magnesium. Lipid oxidation was revealed by the increase of free fatty acids and peroxide value. Moreover, boiling improved the values of the ratio Omega-3/Omega-6 and PUFA/AGS, which upgrade their nutritional status. Another advantage of this treatment resides in the fact that nutrients lost in the cooking water could be recovered by consuming its juice. Thus, boiling would be the best way for their nutritional valorization.

Conflict of Interests

The authors declare to do not have any conflict of interest.

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