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Research Article

Fatty Acid Profile, Physicochemical Composition, and Sensory Properties of Atlantic Salmon Fish (*Salmo salar*) during Different Culinary Treatments

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This study was conducted to assess the effects of boiling, steaming, and oven-cooking on the fatty acid profile, physicochemical composition, and sensory properties of Atlantic salmon fish. The protein content of steamed (18.90%) and oven-cooked (20.59%) salmon was significantly higher than that of boiled (16.69%) and raw fish (14.73%). Analysis of the fatty acids profile revealed that steaming significantly ($p < 0.05$) influenced the fatty acid contents of Atlantic salmon by recording the lowest SFA and the highest omega-3, omega-6, and PUFA contents. Textural properties such as hardness, gumminess, and chewiness were significantly higher ($p < 0.05$) in oven-cooked salmon, with steamed salmon having significantly lower and higher values of hardness (75.32 ± 4.73) and springiness (90.56 ± 3.94), respectively. Also, volatile organic compounds, including aldehydes, ketones, and alcohol, were significantly higher ($p < 0.05$) in oven-cooked and steamed salmon. Additionally, the E-nose sensors analysis showed that S2 and S7 were significantly correlated during oven-cooking and steaming. Furthermore, low-field NMR analysis showed that the values of T_{21} and T_{22} relaxation characteristics of raw and cooked samples fluctuated, with steamed salmon having the highest peak values indicating reduced proton mobility and increased freedom of the protons compared to other treatments. Therefore, steaming resulted in the best quality salmon when considering the fatty acid profile, physicochemical composition, and sensory properties of Atlantic salmon fish, suggesting further studies to ascertain its effectiveness compared to modern treatments.

1. Introduction

Atlantic salmon fish (*Salmo salar*) is considered an exquisite source of nutrients due to its rich protein, lipids, vitamins, and mineral contents [1] and other beneficial nutrients, such as long-chain (LC) n-3 polyunsaturated fatty acids (PUFA) [2, 3]. The consumption of Atlantic salmon fish takes place after various traditional treatments such as steaming, frying, roasting, grilling, boiling, and oven-cooking. Omega-3 fatty acids, especially in fish oils, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are recognized for their therapeutic roles and antibacterial properties. Besides, the composition of fatty acids in fish can vary according to various parameters as well as the size zones of peaches undergoing several cooking processes before being consumed [4]. Cooking processes, such as cooking time, temperature, and water use, affect the fish's product quality, physicochemical properties, and sensory attributes due to the high temperatures produced [2, 5]. Several physicochemical reactions occur in fish during culinary treatments, causing lipid oxidation, protein denaturation, and apparent water loss, thus contributing to texture characteristics and product quality [6]. Complex reactions involving numerous nutritional components are activated when fish tissues are

subjected to heat treatments, which are the most common technique to boost product safety and shelf life, eliminate antinutritional material, and increase protein digestibility [7].

Myofibrillar proteins (myosin and actin), connective tissue proteins (primarily collagen and elastin), and intrafiber water are the components of fish muscle that determine toughness. Moreover, different fish proteins denature during heating, causing structural changes in the fish such as cell membrane damage, fiber shrinkage, aggregation, gel formation of myofibrillar, sarcoplasmic proteins, and connective tissue shrinkage and solubilization. Tenderizing is caused by heat-induced changes in connective tissue, whereas toughening is caused by the hardening of myofibrillar proteins during cooking [8].

Fish, especially salmon, is commonly consumed when cooked and frequently steamed, boiled, or oven-cooked, according to consumer preferences [9]. Numerous studies have examined the effect of different culinary treatments on salmon's proximate composition and fatty acids profile [10, 11]. However, information is still lacking on the effect of different culinary treatments on the physicochemical and sensory properties of Atlantic salmon [7, 12, 13]. Moreover, little or no data about the use of modern technologies in determining the sensory properties and product quality of Atlantic salmon fish are available. However, the states of protons within fish products are significantly associated with their physical properties, and water is an essential component in fish, comprising about 80 percent of the total mass, and plays a vital role in the texture properties and quality of fish products [6, 14]. As a result, impervious and rapid technologies are used to ensure the quality and safety of fish because they preserve the quality of the original attributes, such as texture, taste, and flavor [15].

The aim of the study was to investigate the fatty acid profile, physicochemical and sensory properties of Atlantic salmon fish during different culinary treatments such as boiling, steaming, and oven-cooking in comparison with other conventional and modern methods. In addition, we used computer tools, such as a sensor-array system and analytical data processing, to perform extensive physicochemical and sensory analysis by the electronic nose and proton states from water by the LF-NMR.

2. Materials and Methods

2.1. Fish Procurement and Treatment Methods. Fresh Atlantic salmon fish (*Salmo salar*) ($n = 40$) was procured according to the sizes (3.5–5.5 kg) regularly consumed directly from a major distributor in the Chinese Mainland (Metro, Zhenjiang, China) in ice-packed boxes and then stored at $4 \pm 1^{\circ}$C until analysis. Because of the various fat distributions throughout the salmon body, only the middle portion of the fillet was utilized for testing [2, 12], with an average weight of 184 ± 15 g. The salmon fillets were subjected to different culinary treatments (boiling, steaming, and oven-cooking), and double-distilled water was used for washing and cooking the samples. Table 1 outlines the properties of the various heat treatments following the preliminary panel decision.

2.2. Proximate Composition Analysis. The proximate composition analysis was carried out following the Association of Official Analytical Chemists' standard protocol [16]. After cutting the fish samples to a uniform size, they were analyzed for moisture, protein, fat, and ash. AOAC 930.15 and AOAC 938.08 methods were used to determine moisture and ash content, respectively. The Soxhlet extraction procedure (AOAC 948.15) was used to determine fat content, while the Kjeldahl method was used to determine the protein content (AOAC 954.01). All proximate components were examined in triplicate based on a percentage dry weight basis.

2.3. Sensory Characteristics. Thirty semitrained panelists comprising students from the Department of Food Science and Biological Engineering, Jiangsu University, China, were chosen to assess the sensory attributes of the fish samples using a 7-point hedonic scale following the approval of the Jiangsu University's School of Food and Biological Engineering Authority, Zhenjiang, China. The panelists were given pretesting orientation on the descriptive profile of sensory characteristics in terms of flavor, taste, texture, odor, appearance, and overall acceptability to enable each participant to interpret the rated qualities [17]. The experiments were conducted in a room with a constant temperature, appropriate lighting, and no odors. Panelists were instructed to give numerical ratings between 1 and 7 after each sample was evaluated. After the sample evaluation, each panelist was requested to rate the overall acceptability of the sample on a scale of 1 (dislike extremely) to 7 (like extremely).

2.4. Texture Profile Analysis. The determination of the texture profile of the fish samples was performed using Mercadante et al. [18] protocols with minor changes. The fish samples were sliced into 2.0 cm length sections and subjected to various cooking methods (boiled, steamed, and oven-cooked), with a raw fish sample serving as a control. The fish samples were placed immediately into a Food Properties Tester (TA-XT Plus, Physical Property Meter, UK) and measured using the force induced by compressing 50% of the sample with t-probe under the following settings: pretest speed 2 mm/sec, test speed 1 mm/sec, posttest speed 2 mm/sec, target mode strain 50%, time 5 s, and trigger type auto force 5 g. Hardness, resilience, cohesiveness, gumminess, and chewiness were used to describe the textural features of the various samples.

2.5. Scanning Electron Microscopy (SEM). Fragments of fish meat were excised from raw and cooked Atlantic salmon and dehydrated in 25, 50, 70, 95%, and absolute ethanol (three times), 10–15 min in each solution. Fish samples were frozen in liquid nitrogen, and the dried samples were placed on holders with a brass stub before coating with gold under vacuum (0.5 mbar) using as sputter-coating/glow discharge to make them conductive. The microstructure of the fish

Table 1: Properties of the Atlantic salmon treatment methods.

Treatment	Procedure/equipment	Parameters
Raw	NA	NA
Boiled	Fillets were heat-treated with adequate amount of distilled water in a stainless cooking pot (SUPOR-145, Beijing, China)	Temperature (°C) = 90 ± 1; time (min) = 10 ± 1.5
Steamed	Fillets were heat-treated with adequate amount of distilled water in a stainless-steel steaming pot (SUPOR-304, Beijing, China)	Temperature (°C) = 120 ± 0.25; time (min) = 6 ± 1.5
Oven-cooked	Fillets were heat-treated in an electric heating constant temperature drying oven (DHG-9050A, Shanghai, China)	Temperature (°C) = 180 ± 1.3; time (min) = 8 ± 1.5

NA, not available.

samples was examined using a scanning electron microscope (Zeiss Supra 55) at a magnification of 6.8 mm and an accelerating voltage of 5.0 kV. The samples were photographed at a 90-degree angle to the surface such that the cross section of the film could be seen.

2.6. Free Amino Acid (FAA) Analysis. The FAA content of various cooked salmon fillets was determined using an Amino Acid Automatic Analyzer (Hitachi L-8900, Tokyo) equipped with a UV detector and a Bio Basic SCX cation exchange column (4.6 mm × 60 mm, 5 μm). A 3% (w/v) concentration of 5-sulfosalicylic acid (30 mL) was mixed with 8 grams of fish, homogenized for 5 minutes with ultrasonic cleaners, and centrifuged for 10 minutes at 4000 rpm at 4°C. The supernatant was collected and mixed with 3 mL n-hexane. Afterward, the nonorganic layer was extracted and filtered using 0.22 μm membranes. Subsequently, an automated amino acid analyzer was used to determine FAA using 20 liters of the filtered solution.

2.7. Analysis of Volatile Organic Compounds

2.7.1. Extraction Procedure of Volatile Organic Compound Using Headspace-Solid-Phase Microextraction (HS-SPME). Volatile organic compounds (VOCs) extraction was carried out according to Wang et al. [19] with minor adjustments. To facilitate the progression of the chemical from the sample to the gaseous phase, 3 g of fish sample (boiled, steamed, oven-cooked, and raw) was mixed with 10 μL of 4-methyl-2-pentanol (807 μg/L) and 6 mL of saturated sodium chloride solution in a 50 mL glass vial screw cap before extraction. The enclosed fish sample receptacle was preincubated for 10 minutes at 60 degrees Celsius. SPME fibers were divulged to the headline of the fish sample for 40 minutes at 150 rpm on a magnetic stirrer after passing through 20 mm vial spectra. After extraction, the fiber was quickly inserted into the GC inlet injection port and desorbed for 5 minutes. Prior to their first usage, all of the new SPME fibers were thermally conditioned in the GC injection port.

2.7.2. Gas Chromatography-Mass Spectrometry (GC-MS). The volatile organic compounds fraction (VOCF) was shredded on an Agilent Technologies DB WAX column (60 m 0.25 mm 0.25 m film thickness) (Beijing, China). The GC settings are as follows: oven temperature was set to a start temperature of 40°C for 3 minutes and then increased to a final temperature of 250°C at a rate of 8°C min^{-1} for 10 minutes; the injector temperature was set to 250°C. The helium flow rate was set at 1 ml·min^{-1}, and the injections were done discreetly. The operation of the 5973-mass selective detector was as follows: ion source temperature at 250°C; transfer line temperature at 250°C; electronic impact at 70 ev; scan model at 1 Scan-1. Data were collected in the 30–550 u.m.a. m/z range.

2.8. Identification of Volatile Compounds. The separated VOCFs were determined by comparison of their GC retention time (RT) and mass spectra fragmentation following the National Institute of Standards and Technology (NIST), Gaithersburg, USA (2005), recommendations. The internal standard (IS) used for quantifying VOCFs was 4-methyl-2-pentanol. The IS was used without considering the calibration or response parameters, and all factors were regarded as 1.0 in the study [20]. The estimated concentration was calculated using equation (1) as follows:

$$\mathrm{VOCs}\left(\frac{\mathrm{ng}}{\mathrm{g}}\right) = \frac{\text{Peak area ratio} \times 10\mu L\,(\mathrm{IS}) \times 0.807\,(\mathrm{ng}/\mu L)\,(IS)}{3\mathrm{g\ sample}}. \quad (1)$$

2.9. Fatty Acid Profile. The qualitative and quantitative determination of fatty acid compositions of salmon fish oil obtained by ultrasound-assisted solvent extraction using dichloromethane/methanol (2 : 1; v/v) was determined by a GC-MS system (Agilent Technologies). For separation, the capillary column was J and W 0.15 DB-23 capillary column (60 m × 0.25). Before injection of the extracted oil, it was converted to fatty acid methyl esters (FAMEs) fish oil (0.5 g), and 2M metabolic potassium hydroxide (KOH) solution (2 ml) was added to a 25 ml test tube and mixed vigorously. Then, hexane (7 ml) was added to the mixture, and the test tube was placed in the water bath at 55°C temperature for 15 min. The mixture was vigorously vortexed three times, and 2 ml of the organic phase was added to 0.2 g $NaSO_4$ for dehydration. Then, 1 μl of FAMEs was injected into the column at a split ratio of 1 : 200. The GC oven temperature was raised as follows: starting at 50°C for 1 min then 25°C/min to 175°C, held at 4°C/min to 230°C, and maintained for 5 min. Finally, it was heated at a rate of 1°C/min to 280°C. Hexane was used three times to extract fatty acid methyl esters, which were then dried under a moderate stream of

nitrogen. All of the solvents utilized in the extraction and FAMEs derivatization methods were of HPLC grade (>99%).

2.10. Electronic Nose (E-Nose) Analysis. An automated electronic nose (E-nose) PEN3 (AIRSENSE Analytics, Germany) was used to examine the sensory properties of Atlantic salmon fish. The system incorporates ten metal oxide sensors semiconductors with various chemical parameters that enable volatile compound selectivity. The device is beneficial for analyzing the headspace of liquid or solid samples. A 3 g of fish sample was placed in a 20 ml tube, sealed up with plastic film, and stirred for 30 minutes at 30°C for optimal headspace propagation before detection. The measurement interval was set at 180 seconds in order to achieve stable sensor detection. After every procedure, clean air was charged into the sensor matrix for 100 seconds through Teflon tubing affixed to a needle. At a rate of 400 mL/min, the sample gas was injected into the sensor chamber. Every second, the acquired data were processed and automated throughout the E-nose determination depending on the sensor matrix.

2.11. Low-Field Nuclear Magnetic Resonance (LF-NMR). For the determination of the transverse relaxation time (T_2), 10 g of sample was put in cylindrical glass tubes (50 mm in diameter) and measured using an NMR analyzer (Newman Analytical Instrument Co. Ltd, NMI20-030v-1, Suzhou, China). The relaxation time T_2 was determined with the use of the Carr-Purcell-Meiboom-Gill (CPMG) array at a temperature of 32°C and a proton resonance frequency of 22.6 MHz. T_2 relaxation data were analyzed by computer software (version 2.5, Oxford Instruments), which revealed that the system required four exponentials to be described, yielding four components. All experiments were performed in triplicate for each sample.

2.12. Statistical Analysis. Data were analyzed using Statistical Product and Service Solutions (SPSS) software (version 25.0, IBM Corporation, Armonk, USA). The significant difference between means was determined by the analysis of variance (ANOVA) at $p < 0.05$. Moreover, principal component analysis (PCA) and hierarchical cluster analysis (HCA) were used to further interpret the variations between the sensory qualities of different treatments by considering the correlations significant at 95% confidence level using OriginPro 2018 software (Version 95. E, OriginLab Corporation, Northampton, USA).

3. Results and Discussion

3.1. Proximate Composition. The nutritional value of fish is obtained from its proximate composition, which varies widely among species and is greatly affected by processing methods [21]. In this study, the proximate composition of the raw and cooked Atlantic salmon ranged from 55.43 ± 1.14 to $62.71 \pm 2.76\%$ moisture, with the raw fish having the highest moisture content. This is similar to the study of Bastías et al. [22], which reported a decrease in the moisture content of cooked (steamed) salmon (64.94%) compared to the raw fish (68.05%). Moreover, the moisture composition of the fish is lower than the recommended value of 66–81% [23]. During culinary treatment, the reduction in moisture content results from fractional water loss via evaporation. It has been described as responsible for the significant protein and fat increase in cooked fish, showing an inverse linkage of moisture content and nutritional components [2, 24]. However, moisture loss in seafood could be minimized by adding water to fish during culinary treatment [25].

The ash content of the raw and cooked salmon ranged from 2.71 ± 0.35 to $4.79 \pm 0.05\%$. This is higher than the values of 2.20 ± 0.30 to $4.30 \pm 0.01\%$ recently reported in Atlantic salmon by-products [26]. Also, there was a significant decrease in the ash content of boiled salmon. Ash content of marine fishes reduces after boiling because of the volatile nature of the mineral elements at high temperatures [27]. The protein content of steamed and oven-cooked salmon was significantly higher than that of the boiled and raw fish ($p < 0.05$) as shown in Table 2.

Nevertheless, the cooked salmon was within the recommended range (16–21%), with oven-cooked and steamed salmon having significantly higher protein values ($20.59 \pm 0.43\%$ and $18.90 \pm 0.56\%$, resp.) than boiled salmon ($16.69 \pm 0.51\%$). Conversely, Bastías et al. [22] reported higher protein content in oven-cooked salmon and Chilean Jack mackerel. Seafood contains a high-quality protein that makes it a complete protein source since protein is the most potent constituent in processed fish besides moisture [28–30]. The raw salmon has the lowest fat content but was not significantly different from the cooked samples during the study. Raw fish's protein and fat contents rarely supply precise knowledge on the nutritional value, while significant changes occur in fish composition after cooking [22].

3.2. Sensory Properties. Sensory analysis was performed using color, odor, texture, appearance, and taste to elucidate the consumer's responses to different cooking methods [31]. A radar chart was used to display the scores graphically (Figure 1(a)), and the attributes ratings ranged from 5 to 6, which could be classified as "moderately liked" and "liked extremely" on a 7-point scale, except for texture and taste with the lowest score. Besides, the correlation coefficients among consumer attributes reveal a high correlation of color versus odor, with boiled salmon having a greater preference than steamed and oven-cooked salmon. Earlier studies have shown that trained panelists' results on sensory qualities are analogous to results from descriptive interpretation [32]. Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were performed to interpret the quality and sensory characterization scores clearly. The PCA projected the different culinary treatments and the sensory properties in a two-dimensional space of PC1 and PC2 differentiated by four main clusters (Figure 1(b)). PC1 was characterized by appearance, odor, and color, accounting for 55.61% of the variance, and PC2 was characterized by texture and taste,

Table 2: Proximate composition of Atlantic salmon after different culinary treatments.

Proximate composition	Moisture (%)	Protein (%)	Ash (%)	Fat (%)
Raw	62.71 ± 2.76^{a}	14.73 ± 0.29^{c}	3.17 ± 0.04^{b}	9.02 ± 1.41^{a}
Boiled	55.61 ± 0.34^{b}	16.69 ± 0.51^{b}	3.31 ± 0.48^{b}	9.52 ± 1.05^{a}
Steamed	58.78 ± 0.18^{ab}	18.90 ± 0.56^{a}	2.71 ± 0.35^{b}	11.19 ± 1.54^{a}
Oven-cooked	55.43 ± 1.14^{b}	20.59 ± 0.43^{a}	4.79 ± 0.05^{a}	11.66 ± 1.9^{a}

Values with different letters within the column are significantly different ($p < 0.05$). values with the same letters are not significantly different ($p > 0.05$). values are shown as the mean, standard error of triplicates.

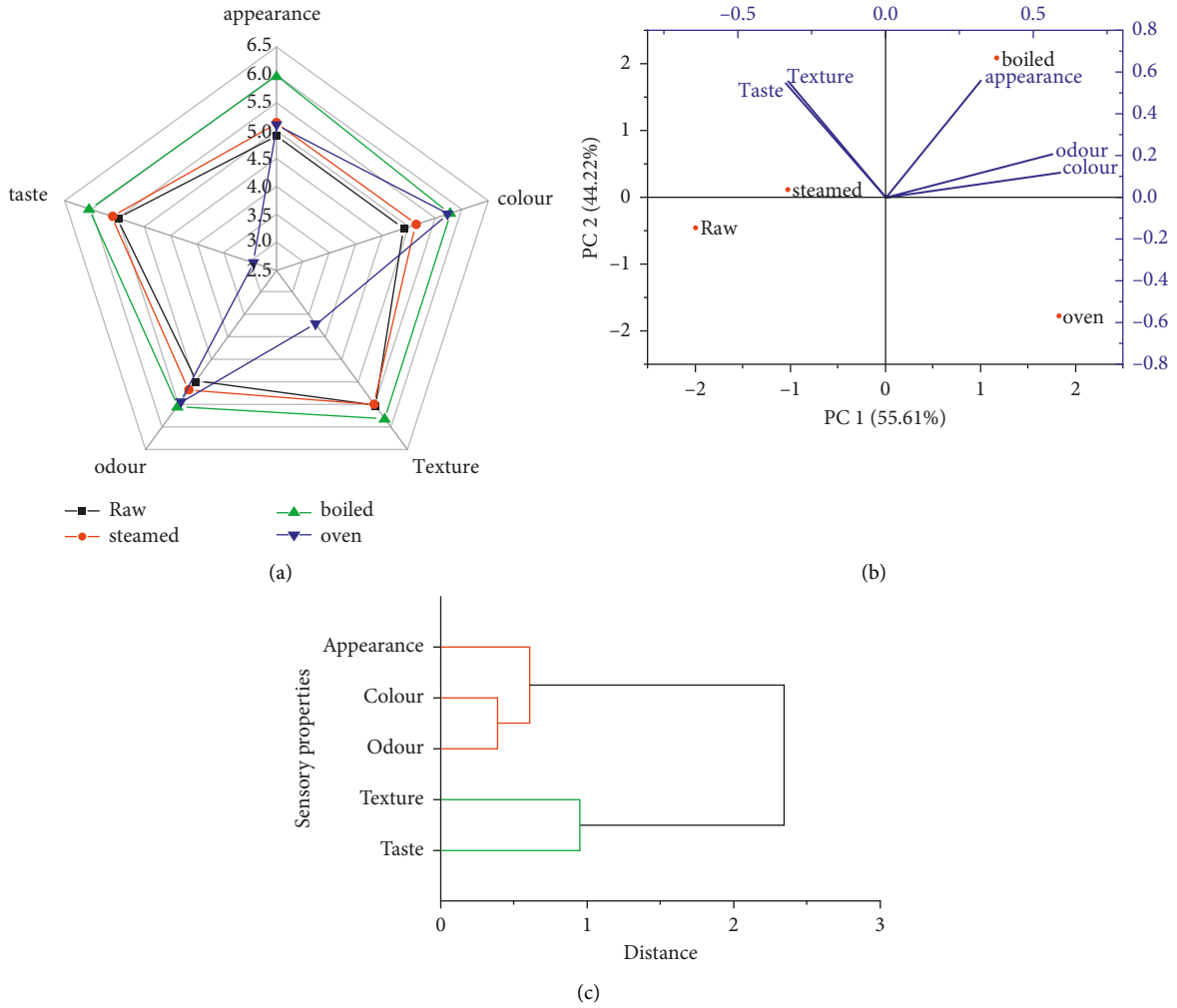

Figure 1: (a) Radar plot showing sensory scores of Atlantic salmon after different culinary treatments, (b) principal component analysis of raw and cooked Atlantic salmon projecting the relationship among sensory properties on a biplot, and (c) hierarchical cluster analysis showing the groupings of sensory properties using Euclidean distance as the scale.

accounting for 44.22% of the total variance, which is sufficient to interpret the relationships between the attributes and the treatments [33].

The biplot shows that boiled and steamed salmon correlated more with sensory properties, whereas raw and oven-cooked salmon negatively correlated with sensory properties. Conversely, Głuchowski et al. [12] reported a significantly ($p < 0.05$) lower intensity of cooked fish odor and flavor despite a positive effect caused by the low temperature of the sous-vide method (57°C) on higher juiciness as compared to traditional methods used in cooking salmon. In addition, the factor loading (FL) value of the PCA shows a significance at > 0.56, representing a strong influence of the sensory properties with color and odor heavily deposited on the plane created by PC1 [34, 35]. Figure 1(c) shows the HCA, which further demonstrates the consumers' attributes to sensory properties. Color, odor, and appearance indicated the slightest differences, forming the first two multivariable clusters at a distance below 1. However, the five sensory properties were fused in stable sequence, based on their grouping into two main clusters (cluster 1: color, odor, and appearance; cluster 2: taste and texture). It is noteworthy that

Table 3: Texture properties of Atlantic salmon after different culinary treatments.

	Hardness	Resilience	Cohesiveness	Springiness	Gumminess	Chewiness
Raw	128.87 ± 8.58^{b}	15.86 ± 1.01^{a}	0.40 ± 0.04^{a}	85.84 ± 9.04^{a}	59.22 ± 4.64^{b}	59.58 ± 5.99^{b}
Boiled	120.77 ± 3.70^{b}	14.45 ± 1.72^{a}	0.42 ± 0.04^{a}	86.89 ± 4.22^{a}	51.02 ± 2.95^{b}	135.96 ± 2.47^{c}
Steamed	75.32 ± 4.73^{c}	12.49 ± 0.48^{a}	0.407 ± 0.01^{a}	90.56 ± 3.94^{b}	30.87 ± 2.03^{c}	127.76 ± 1.13^{c}
Oven-cooked	394.28 ± 26.19^{a}	13.59 ± 1.67^{a}	0.47 ± 0.01^{a}	84.45 ± 4.43^{a}	172.48 ± 20.44^{a}	143.95 ± 13.30^{a}

Different lowercase letters in the same column indicate significant differences ($p < 0.05$).

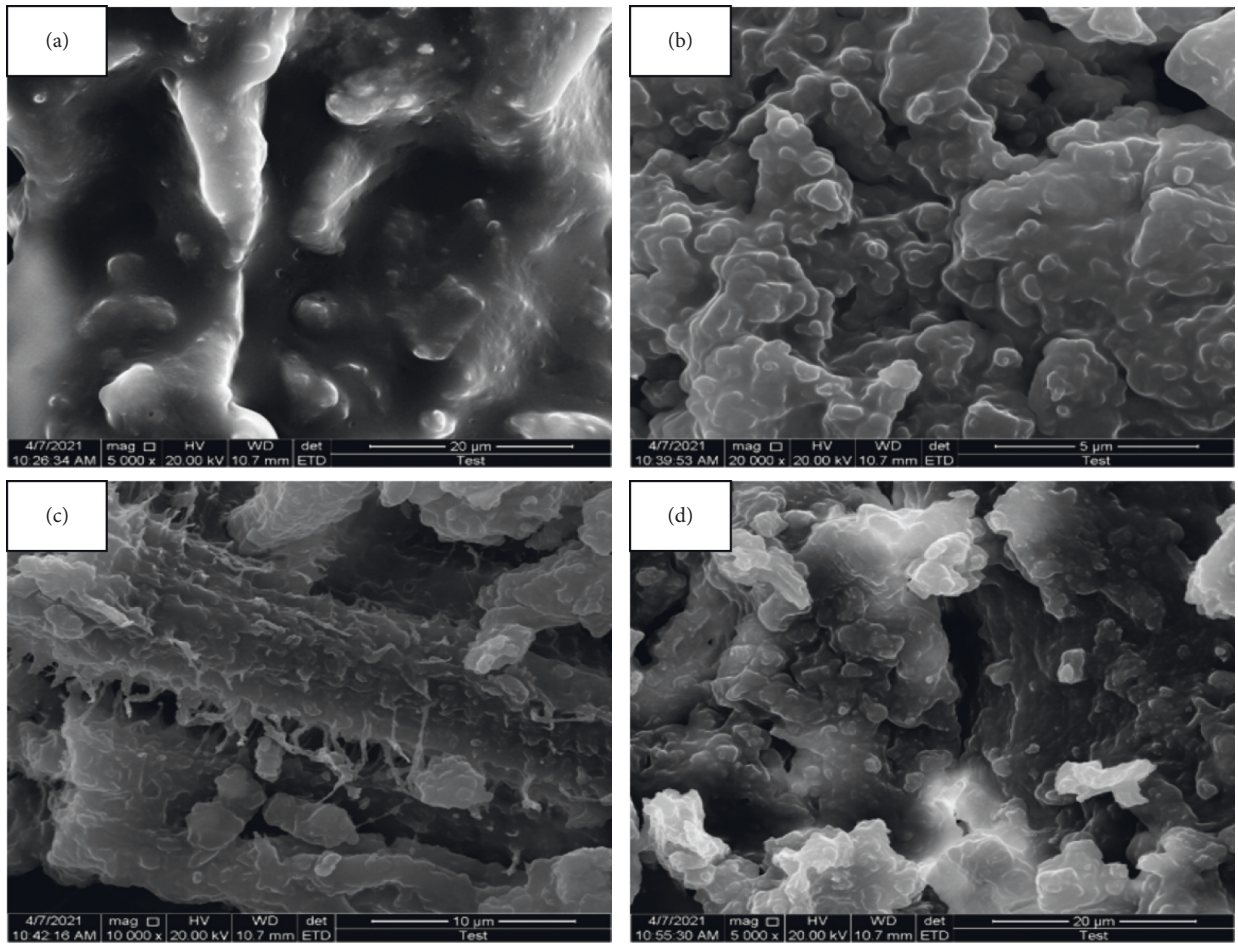

Figure 2: Scanning electron micrographs showing the culinary treatment impacts on the microstructure of Atlantic salmon fish, (a) raw (5,000x), (b) boiled (20,000x), (c) steamed (10,000x), and (d) oven (5,000x).

Atlantic salmon revealed a higher preference for color, odor, and appearance when boiled as well as taste and texture when steamed. This confirms that the sensory properties of Atlantic salmon influenced consumers' acceptability, thus, suggesting that boiling allows for high nutritional quality and high sensory attributes to be preserved [15, 36, 37].

3.3. Texture Profile Analysis. The texture properties of fish are influenced by several factors, including species, age and size, fat content, treatment methods, and storage conditions [38]. In this study, hardness, gumminess, and chewiness were significantly higher ($p < 0.05$) in oven-cooked salmon than in boiled and steamed salmon (Table 3). Hardness is a mechanical textural attribute relating to the force required to compress fish samples, and chewiness is the mouthfeel sensation of mastication due to sustained, elastic resistance from the fish due to gumminess [39]. Similarly, Larsen et al. [40] reported that cooking increased the hardness and chewiness of salmon. However, there was no significant difference ($p > 0.05$) in the raw and cooked salmon's resilience, cohesion, and springiness. Similar studies have reported a significant increase in springiness, cohesiveness, and resilience of cooked salmon, which was attributed to initial heating treatment conditions [40, 41].

3.4. Scanning Electron Microscopy. Scanning electron microscopy (SEM) was used to investigate the morphological structure in raw and cooked salmon (Figure 2). The raw

Table 4: Free amino acid content (mg/100 g) of Atlantic salmon after different culinary treatments.

Free amino acid	Raw	Boiled	Steamed	Oven-cooked
Asp	14.34 ± 0.96^{b}	22.39 ± 1.98^{a}	18.07 ± 4.09^{ab}	13.82 ± 4.09^{b}
Glu	7.36 ± 0.08^{a}	8.42 ± 0.02^{b}	7.62 ± 0.12^{a}	7.62 ± 0.12^{a}
Ser	2.45 ± 0.08^{a}	1.82 ± 0.13^{b}	1.85 ± 0.08^{b}	1.76 ± 0.07^{b}
His	8.92 ± 0.20^{b}	9.50 ± 0.47^{ab}	10.14 ± 0.86^{ab}	10.63 ± 0.14^{a}
Gly	6.81 ± 0.11^{a}	6.26 ± 0.14^{b}	6.42 ± 0.30^{ab}	6.33 ± 0.04^{b}
Thr	10.70 ± 0.26^{ab}	9.96 ± 0.14^{b}	10.93 ± 0.54^{a}	11.48 ± 0.09^{a}
Arg	8.84 ± 0.14^{a}	6.39 ± 0.09^{c}	6.39 ± 0.09^{c}	7.38 ± 0.03^{b}
Ala	17.37 ± 0.27^{bc}	15.91 ± 0.44^{c}	17.76 ± 1.05^{ab}	19.17 ± 0.13^{a}
Tyr	2.93 ± 0.08^{a}	2.23 ± 0.16^{b}	2.74 ± 0.23^{a}	2.74 ± 0.23^{a}
Cys-s	0.030 ± 0.03^{a}	0.026 ± 0.016^{a}	0.026 ± 0.011^{a}	0.023 ± 0.015^{a}
Val	4.06 ± 0.75^{ab}	3.46 ± 0.11^{b}	3.83 ± 0.23^{ab}	4.62 ± 0.15^{a}
Met	1.87 ± 0.02^{a}	1.64 ± 0.05^{a}	1.78 ± 0.13^{a}	1.87 ± 0.12^{a}
Trp	0.74 ± 0.34^{a}	0.48 ± 0.09^{a}	0.84 ± 0.24^{a}	1.19 ± 0.61^{a}
Phe	1.77 ± 0.09^{ab}	1.62 ± 0.06^{b}	1.95 ± 0.09^{a}	1.83 ± 0.13^{ab}
Ile	1.70 ± 0.03^{b}	1.69 ± 0.04^{b}	1.82 ± 0.04^{a}	1.79 ± 0.05^{ab}
Leu	3.07 ± 0.02^{a}	3.05 ± 0.27^{a}	3.25 ± 0.14^{a}	3.22 ± 0.13^{a}
Lys	4.66 ± 0.02^{a}	3.43 ± 0.14^{b}	3.73 ± 0.30^{b}	3.65 ± 0.04^{b}
Pro	1.08 ± 0.01^{a}	1.41 ± 0.24^{a}	1.35 ± 0.15^{a}	1.19 ± 0.05^{a}
TEAA	33.07 ± 6.96^{a}	44.46 ± 11.67^{b}	42.59 ± 2.36^{b}	31.14 ± 6.86^{a}
TNEAA	54.92 ± 8.32^{bc}	82.18 ± 2.20^{a}	68.51 ± 4.91^{ab}	52.90 ± 6.46^{c}
EAA/NEAA	25.54 ± 2.54^{a}	33.83 ± 5.43^{b}	31.25 ± 1.65^{b}	25.20 ± 2.78^{a}
HAA	18.63 ± 3.69^{a}	25.03 ± 6.10^{b}	24.52 ± 1.41^{b}	17.93 ± 3.82^{a}
PCAA	18.97 ± 4.36^{a}	23.57 ± 6.25^{b}	24.03 ± 2.35^{b}	17.12 ± 3.93^{a}
NCAA	22.13 ± 1.68^{b}	30.62 ± 1.31^{a}	25.53 ± 3.38^{ab}	22.20 ± 0.76^{b}
AOAA	23.72 ± 5.71^{a}	31.73 ± 8.59^{a}	30.53 ± 2.33^{a}	21.99 ± 5.63^{a}
TAA	98.70 ± 3.49^{a}	99.69 ± 4.59^{b}	100.50 ± 8.60^{c}	100.31 ± 6.06^{c}

Ala, alanine; Arg, arginine; Asp, aspartic acid; Cys, cysteine; Glu, glutamic acid; Gly, glycine; His, histidine; Iso, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Phe, phenylalanine; Pro, proline; Ser, serine; Thr, threonine; Trp, tryptophan; Tyr, tyrosine; Val, valine; AOAA: antioxidative amino acids; HAA: hydrophobic amino acids; NCAA: negatively charged amino acids; PCAA: positively charged amino acids; TAA: total amino acids; TEAA: total essential amino acids; TNEAA: total nonessential amino acids. The same superscript letters within the same rows represent significant differences ($p < 0.05$) between different cooking methods.

salmon (Figure 2(a)) shows intact cellular walls. However, there were obvious structural changes after subjecting the salmon fish to different cooking methods (boiling at 90°C for 10 min, steaming at 160°C for 8 min, and oven-cooking at 180°C for 8 min) (Figures 2(b)–2(d)). Other studies have reported overt changes in the muscle fibers and structures of fish and meat samples after heating [8, 42]. Among all the cooking methods applied, oven-cooked salmon had the most significant impact on the structure. The differences in structure could be attributed to treatment temperature difference and time since oven treatment hardens the fish [8]. Boiling enhanced the softness of the fish; hence, it could clearly be seen in its structure being more porous than steaming and oven treatment. Notably, fish samples undergo obvious breakage of protein fibers into deep trenches after boiling and steaming treatments [6]. Thus, the apparent difference in raw and cooked salmon is a mixed impact of different treatments ranging from the hardening caused by denaturation and accumulation of the proteins, consequent contraction and desiccation, and a cushioning effect caused by solubilization [43].

3.5. Free Amino Acid Analysis. Amino acids contribute to protein synthesis, immune function, nutrition, and health [44]. They are classified as essential (EAA), nonessential (NEAA), hydrophobic (HAA), positively charged (PCAA), negatively charged (NCAA), and antioxidative (AOAA) [45, 46]. Table 4 depicts variations in the free amino acid composition of Atlantic salmon following various culinary treatments. The primary amino acids in raw and cooked salmon were aspartic acid and alanine. Their concentrations were significantly higher ($p < 0.05$) than the other amino acids recorded in this study. These amino acids are essential for regulating glucose metabolism, secretion of essential hormones, and prevention of fatigue and weakness of the body [47]. In cooked salmon, most essential amino acids, such as histidine, isoleucine, lysine, threonine, and valine, were significantly different ($p < 0.05$) from raw salmon. Also, amino acid contents decreased from cooked to raw samples in this study. Cooking increases the content of essential, nonessential, and other amino acids in fish due to the Maillard reaction, which results in a synergy between the carbonyl group of the reducing sugar and the free amino group of the amino acid or protein [48, 49]. Alanine, threonine, and valine concentrations increased significantly in oven-cooked salmon, similar to other findings, which reported an increase in the amino acid composition of oven-cooked rainbow trout compared to the raw samples [50].

The TEAA, TNEAA, EAA/NAA, HAA, PCAA, and AOAA contents of steamed and oven-cooked salmon were significantly higher than those of the boiled and raw samples.

Table 5: Volatile compounds composition (ng/g) in raw and cooked Atlantic salmon.

Compounds	RT	OD	Raw	Boiled	Steamed	Oven-cooked
Acid						
Acetic acid	19.88	Strong vinegar-like	0.49 ± 0.05	0.50 ± 0.06	1.13 ± 0.24	1.24 ± 0.12
Alcohols						
Ethanol	9.96	Vinous	0.26 ± 0.05	0.39 ± 0.07	0.46 ± 0.13	0.29 ± 0.03
1-Heptadecanol	17.87	NA	—	—	—	0.12 ± 0.04
2-Nonen-1-ol	18.94	Green and waxy	—	0.18 ± 0.07	—	—
Tetradecanol	19.75	Waxy, fruity, and coconut	—	—	—	0.08 ± 0.02
2-(2-Ethoxyethoxy)ethanol	27.95	Mild pleasant	0.22 ± 0.04	0.42 ± 0.04	0.71 ± 0.09	0.46 ± 0.04
Aldehydes						
Propanal	7.67	Slightly fruity	—	0.12 ± 0.04	—	0.09 ± 0.01
Butanal	8.94	Pungent	0.31 ± 0.01	—	—	0.05 ± 0.01
Pentanal	10.89	Strong, acrid, and pungent	—	—	—	0.08 ± 0.01
Butanal-3-methyl	10.91	Peach and fatty	0.09 ± 0.01	—	—	—
Hexanal	12.97	Oily green	0.56 ± 0.06	0.65 ± 0.11	—	0.75 ± 0.11
Heptanal	14.97	Pervasive fruity and oily greasy	0.13 ± 0.04	0.07 ± 0.01	—	0.10 ± 0.01
(E)-2-Octenal	15.48	Distinctive green and leafy	—	—	—	0.07 ± 0.01
Octanal	17.10	Fruit-like	0.13 ± 0.02	0.09 ± 0.01	0.09 ± 0.02	0.23 ± 0.11
trans-2-Heptenal (E)	17.87	Pungent green	0.06 ± 0.02	—	0.17 ± 0.02	—
1-Nonanal	18.95	Rose-orange	0.33 ± 0.04	0.22 ± 0.02	0.47 ± 0.26	0.56 ± 0.32
trans,trans-2,4-Heptadienal (EE)	20.22	Pungent cinnamon-like	0.34 ± 0.03	—	—	0.23 ± 0.08
Undecanal	20.77	Citrus and waxy-floral	0.11 ± 0.03	—	—	0.12 ± 0.06
Benzaldehyde	21.39	Almond-like	0.21 ± 0.08	—	—	—
trans,trans-2,4-Decadienal (EE)	22.95	Orange-like	—	—	—	1.75 ± 0.05
2,4-Decadienal	25.41	Citrus, orange, or grapefruit	0.50 ± 0.04	—	—	0.92 ± 0.04
Alkanes (hydrocarbons)						
Pentane	5.99	Mild gasoline-like	0.37 ± 0.21	—	0.07 ± 0.03	0.12 ± 0.01
Octane	7.88	Gasoline-like	0.24 ± 0.11	—	0.04 ± 0.01	0.16 ± 0.02
Nonane	9.31	Gasoline-like	0.07 ± 0.04	—	—	—
Decane	11.24	Gasoline-like	0.17 ± 0.06	—	—	—
Dodecane	14.98	Irritant	—	—	0.28 ± 0.04	—
Eicosane	16.96	Odorless	—	—	0.16 ± 0.01	—
Cycloheptane	18.91	Petroleum-like	—	—	—	0.28 ± 0.13
Nonadecane	20.46	Fuel-like	0.13 ± 0.03	—	0.71 ± 0.02	—
Pentadecane	20.47	Fruit-like	—	0.21 ± 0.01	1.69 ± 0.92	0.20 ± 0.02
Hexadecane	20.49	Gasoline-like and odorless	—	—	0.35 ± 0.22	—
Heptadecane,8-methyl	20.50	NA	—	—	—	0.23 ± 0.06
4-Cyano-1-cyclohexane	22.29	NA	—	—	0.52 ± 0.06	—
Aromatic hydrocarbon						
Toluene	12.23	Sweet, pungent, and benzene-like	0.59 ± 0.04	0.55 ± 0.02	0.36 ± 0.08	0.43 ± 0.03
Esters						
Ethyl acetate	19.88	Pineapple, fruity, and sweet	—	0.60 ± 0.37	0.18 ± 0.08	0.06 ± 0.03
Ketones						
2-Pentanone	10.75	Acetone-like	—	—	—	1.34 ± 0.16
3-Hydroxy-2-butanone	17.60	Buttery	—	0.84 ± 0.66	1.29 ± 0.48	1.49 ± 0.34
3,5-Pentandien-2-one	21.98	NA	0.08 ± 0.01	—	—	—
Phenol						
2,6-Di-tert-butyl-4-methylphenol	26.60	Phenolic	0.38 ± 0.07	0.36 ± 0.05	0.93 ± 0.06	0.86 ± 0.05
Others						
2-Propanamine	1.48	Ammonia-like	0.20 ± 0.03	0.20 ± 0.03	—	—
Trimethyl amine	6.25	Fish-like	0.31 ± 0.05	0.31 ± 0.05	0.23 ± 0.07	0.56 ± 0.11
1,3-Butanediamine	6.80	NA	0.15 ± 0.03	0.15 ± 0.03	—	—
Acetamide	8.15	Mousy	0.04 ± 0.02	—	—	—
Dimethylamine	13.82	Fish-like	1.32 ± 0.03	—	—	—
5-Amino-1-pentanol	14.92	NA	0.41 ± 0.04	—	0.41 ± 0.04	—
N-Methylallylamine	15.59	NA	0.45 ± 0.02	0.45 ± 0.02	—	0.19 ± 0.03
1,6-Hexylenediamine	18.93	Fish-like	0.43 ± 0.06	—	—	—
Heptanamine	22.17	NA	0.06 ± 0.01	0.06 ± 0.01	—	0.26 ± 0.02

NA: not available; OD: odor description; RT: retention time.

Similar studies have reported higher content of TNEAA in cooked fishes [51]. However, boiled salmon recorded significantly lower TEAA than other types of cooked salmon. The reduced TEAA concentration in boiled salmon could be attributed to the previous reports that boiling causes a decrease in protein content by wrecking essential amino acids, making them absent [49]. PCAA and HAA such as lysine, arginine, methionine, and glycine were significantly higher in raw salmon than in cooked salmon. At the same time, aspartic acid and glutamic acid were significantly lower in raw salmon than in cooked salmon, with boiled salmon having the highest concentration. Similar values have been reported in red salmon [52]. These disparities result from the processing conditions of the fishes, such as heating temperature and time of heating [52]. However, arginine and histidine may be considered provisionally essential amino acids because the body cannot synthesize them in sufficient quantities during specific physiological periods of growth [53]. Some nonessential amino acids such as alanine, glutamic acid, and glycine are accountable for flavor and taste in seafood products [54]. Also, glycine contributes to protein synthesis, metabolic regulation, and antiantioxidant activity [19].

3.6. Volatile Organic Compounds in Raw and Cooked Salmon. The results of the volatile organic compounds are illustrated in Table 5 with RT values, odor description, and relative concentrations. Overall, 48 volatile compounds, including 1 acid, 5 alcohols, 15 aldehydes, 12 alkanes (hydrocarbons), 1 aromatic hydrocarbon, 1 ester, 3 ketones, 1 phenol, and 9 other compounds, were identified in raw, boiled, steamed, and oven-cooked salmon fish samples. Among the salmon samples, the concentrations of aldehydes (12.66 ± 0.73 ng/g) and ketones (2.83 ± 0.50 ng/g) were the highest in oven-cooked fish samples. Enzymatic reactions could have caused the prevalence of aldehydes in oven-cooked fish, mainly due to the Maillard reaction [55]. High concentrations of ketones were also recorded in steamed salmon. Ketones have a unique fragrance and fruity flavor that contributes to the pleasant odor of fish. The higher concentrations of butanal in raw samples follow the observations of Dong et al. [56] while also considering their absence in boiled and steamed salmon. This could be the reason for the decreased fish-like odor in cooked fish samples.

The raw fish samples contain all the volatile organic compounds grouped as others in this study. The odor of these compounds is mostly fish-like except for ethyl acetate with a pleasantly fruity odor. Moreover, the pleasant odor of fish products is primarily from aldehydes, ketones, and alcohol which are mostly abundant in oven-cooked salmon. This is in accordance with the findings of Husein et al. [13] who reported higher VOC content of these volatile compounds in cooked salmon compared to sous-vide-treated salmon fillets. Nonetheless, the fish-like and unpleasant odor of fish increases as it becomes less fresh, usually due to compounds like ammonia, dimethylamine, and trimethylamine [57]. During the culinary treatment, the fish-like odor of the raw fish samples gradually disappeared. The odor of fish samples decreases through several chemical reactions during cooking, including lipid oxidation and Maillard reaction, resulting in many volatile compounds [56]. Five alcohols (ethanol, 1-heptadecanol, 2-nonen-1-ol, tetradecanol, and 2-(2-ethoxyethoxy)ethanol) were detected with the highest concentrations in steamed salmon (1.17 ± 0.22 ng/g). The concentrations of alcohol were lower than those of aldehydes, ketones, and alkanes. Unless present in significant concentrations or unsaturated, alcohols are typically relatively insignificant flavor contributors [58].

3.7. Fatty Acid Contents. In this study, the comparison of the fatty acid contents (mg/100 g) between the raw and cooked (boiled, steamed, and oven-cooked) Atlantic salmon was performed to provide an overview of any compositional changes in the lipids during processing as presented in Table 6. Fatty acids responded differently to heat treatments, and fatty acid profiles of raw and cooked samples were significantly different ($p < 0.05$) throughout the study. A total of 15 fatty acids were recorded, mostly dominated by monounsaturated fatty acids (MUFA, 6186.0–15288.9 mg/100 g), followed by polyunsaturated fatty acids (PUFA, 4127.5–5392.6 mg/100 g), and saturated fatty acids (SFA, 2500.9–3241.7 mg/100 g) with a relatively lower concentration. Similar to the findings of Bastías et al. [22] on salmon (*Salmo salar*) and Chilean Jack mackerel (*Trachurus murphyi*) fillets, the most abundant fatty acids were palmitic acid (C16 : 0), oleic acid (C18 : 1 n−9), linoleic acid (C18 : 2 n−6), and docosahexaenoic acid (DHA) (C22 : 6 n−3).

The lower SFA values recorded in this study were in accordance with similar studies [59, 60] for raw and cooked salmon. Many studies have recommended low concentrations of SFA in foods and food items, including fish products due to the severity of chronic diseases such as atherosclerotic artery lesions and cardiovascular diseases (CVD) linked to its consumption [61, 62].

SFA concentration was significantly higher ($p < 0.05$) in oven-cooked (3241.7 ± 11.97 mg/100 g) and raw (2736.4 ± 38.93 mg/100 g) salmon fish than in other treatments, with steamed fish having a significantly lower concentration (2500.9 ± 16.18 mg/100 g). Conversely, Costa et al. [59] reported a lower level of SFA in boiled farmed fish species meager (*Argyrosomus regius*) compared to the other treatments. However, Bastías et al. [22] reported no significant difference in SFA of boiled, steamed, and oven-cooked salmon. SFAs are generally heat stable at temperatures encountered in standard cooking processes. However, oxidation products form when the temperature exceeds 150°C and oxygen is present [63].

The concentration of MUFA in boiled fish was significantly higher (15288.9 ± 8.77 mg/100 g) followed by steamed salmon (6948.6 ± 10.76 mg/100 g), with oven-cooked salmon having a significantly lower value (6186.0 ± 10.02 mg/100 g). This is contrary to the findings of Bastías et al. [22] who reported a higher concentration of MUFA in oven-cooked salmon (*Salmo salar*). According to Redfern et al. [9], higher temperatures used in cooking the fish appear to cause thermal alteration of the PUFA double bonds, resulting in

Table 6: Fatty acid profile (mg/100 g) of raw and cooked Atlantic salmon fish*.

Fatty acids (FA)	Name of fatty acid	Raw	Boiled	Steamed	Oven-cooked
SFA					
C14 : 0	Myristic acid	610.7 ± 9.02^{c}	562.0 ± 7.01^{a}	583.0 ± 7.81^{b}	746.0 ± 3.60^{d}
C16 : 0	Palmitic acid	1659.0 ± 25.12^{c}	1588.0 ± 18.19^{b}	1485.3 ± 3.21^{a}	1964.7 ± 2.08^{d}
C18 : 0	Stearic acid	435.7 ± 3.79^{b}	416.3 ± 3.21^{a}	406.6 ± 4.16^{a}	486.0 ± 5.29^{c}
C20 : 0	Arachidic acid	31.0 ± 1.00^{b}	37.0 ± 2.65^{c}	26.0 ± 1.00^{a}	45.0 ± 1.00^{d}
Σ SFA		2736.4 ± 38.93^{c}	2603.3 ± 31.06^{b}	2500.9 ± 16.18^{a}	3241.7 ± 11.97^{d}
MUFA					
C16 : 1	Hexadecanoic acid	287.7 ± 2.52^{a}	593.0 ± 2.65^{d}	462.6 ± 0.58^{c}	426.3 ± 3.21^{b}
C18 : 1	Oleic acid	5735.6 ± 3.51^{b}	6956.6 ± 2.08^{d}	5894.3 ± 4.51^{c}	5065.0 ± 2.65^{a}
C20 : 1	Eicosenoic acid	925.3 ± 4.73^{b}	1139.3 ± 4.04^{d}	985.7 ± 2.08^{c}	694.7 ± 4.16^{a}
Σ MUFA		6948.6 ± 10.76^{b}	15288.9 ± 8.77^{d}	7342.6 ± 7.17^{c}	6186.0 ± 10.02^{a}
PUFA					
C18 : 2n−6	Linoleic acid	1745.7 ± 1.53^{c}	1427.6 ± 2.52^{a}	1855.0 ± 4.58^{d}	1565.0 ± 4.58^{b}
C18 : 3n−3	α-Linolenic acid	658.0 ± 1.00^{a}	742.6 ± 2.52^{b}	893.7 ± 3.21^{d}	787.0 ± 2.65^{c}
C18 : 4n−3	Stearidonic acid	157.0 ± 1.73^{c}	126.3 ± 3.21^{a}	195.3 ± 3.51^{d}	139.0 ± 1.00^{b}
C20 : 3n−3	Eicosatrienoic acid	56.0 ± 1.00^{c}	44.0 ± 1.00^{a}	125.3 ± 4.51^{d}	53.6 ± 1.53^{b}
C20 : 4n−6	Arachidonic acid	38.0 ± 1.00^{a}	43.0 ± 1.00^{b}	44.6 ± 1.53^{d}	40.0 ± 1.00^{ab}
C22 : 5n−3	DPA	288.0 ± 1.00^{c}	243.0 ± 1.00^{b}	308.0 ± 2.00^{d}	223.7 ± 1.54^{a}
C20 : 5n−3	EPA	602.0 ± 1.00^{c}	546.0 ± 2.65^{b}	685.7 ± 2.08^{d}	523.3 ± 3.06^{a}
C22 : 6n−3	DHA	1285.0 ± 1.00^{c}	955.0 ± 4.58^{a}	1285.0 ± 1.00^{c}	991.7 ± 2.08^{b}
Σ PUFA		4829.7 ± 9.26^{c}	4127.5 ± 17.48^{a}	5392.6 ± 22.42^{d}	4323.3 ± 17.44^{b}
Σ n−3		3046.0 ± 6.73^{c}	2656.9 ± 14.96^{a}	3492.0 ± 12.80^{d}	2717.7 ± 11.86^{b}
Σ n−6		1783.7 ± 2.53^{c}	1470.6 ± 3.52^{a}	1899.6 ± 6.11^{d}	1605.0 ± 5.58^{b}
Σ n−3/Σ n−6		1.71 ± 2.66^{ab}	1.81 ± 4.25^{ab}	1.84 ± 2.09^{b}	1.69 ± 2.13^{a}
EPA + DHA		1887.0 ± 2.00^{c}	1501.0 ± 7.23^{a}	1970.7 ± 3.08^{d}	1515.0 ± 5.14^{b}

* The most crucial fatty acids are presented. Values with different letters within the row are significantly different ($p < 0.05$) and are presented as average ± standard deviation; SFA, saturated fatty acid; PUFA, polyunsaturated fatty acid; DPA, docosapentaenoic acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.

more saturated forms of the MUFA. MUFA has also been identified as possibly useful for the lowering of CVD risk throughout the last few decades [64].

Moreover, high n-3 PUFA (omega-3) and n-6 PUFA (omega-6) contents were recorded in the raw and cooked salmon, with the steamed salmon having a significantly higher concentration ($p < 0.05$) than other treatments. This is in accordance with the findings of Redfern et al. [9] on the effects of cooking salmon sous-vide on its fatty acid profile. Therefore, this study shows that the omega-3 and omega-6 fatty acids in Atlantic salmon are well preserved during various culinary treatments. Besides, the omega-3 fatty acids in salmon fish are said to be more heat stable than those in other fish [63]. Tsoupras et al. [61] opined that fish's high omega-3 content is associated with anti-inflammatory properties, which play a significant role in the nutritional health benefits of fish and fish oil. Nevertheless, consuming omega-3 and omega-6 is highly advised, but their consumption must be balanced to get the health benefits; an excess of either might disrupt the catabolism of the other, limiting their absorption in tissues and changing their biological effects [22].

In addition, raw and cooked salmon is rich in PUFA with a beneficial low ratio of n-3/n-6, with steamed salmon having a significantly higher concentration ($p < 0.05$) than the other treatments. Similar to the findings of Bastías et al. [22], the omega-3: omega-6 ratio significantly increased in the steamed samples compared to the other treatments and the control. These findings are also consistent with previous studies on raw and cooked salmon samples [9, 65] and highlight the potential cardioprotective properties of salmon, even when cooked, because the lower the ratio, the better the health benefits in cardiovascular diseases and other chronic disorders [61].

Similar to the reports of Biandolino et al. [66] on the effects of cooking processes on *Mytilus galloprovincialis*, EPA and DHA significantly decreased during culinary treatments, except for steamed and raw salmon with the highest EPA and DHA contents. Conversely, Costa et al. [59] reported a significantly lower EPA + DHA in raw samples compared to cooked fish samples. The boiled and oven-cooked salmon showed a significant reduction of DHA compared to the raw and steamed samples. However, this trend was also observed in EPA concentration, although the steamed salmon was significantly different from the raw sample ($p < 0.05$). Hosseini et al. [67] reported no significant difference in EPA, DHA, and EPA + DHA contents during culinary treatments in raw and cooked fish. Even though previous findings have reported that cooking reduces the amount of EPA and DHA in fish species, steamed salmon was significantly enriched with these fatty acids. However, a recent study suggested that the consumption of foods rich in EPA and DHA may have a positive effect on immunological and reproductive system activities [61]. Also, small amounts

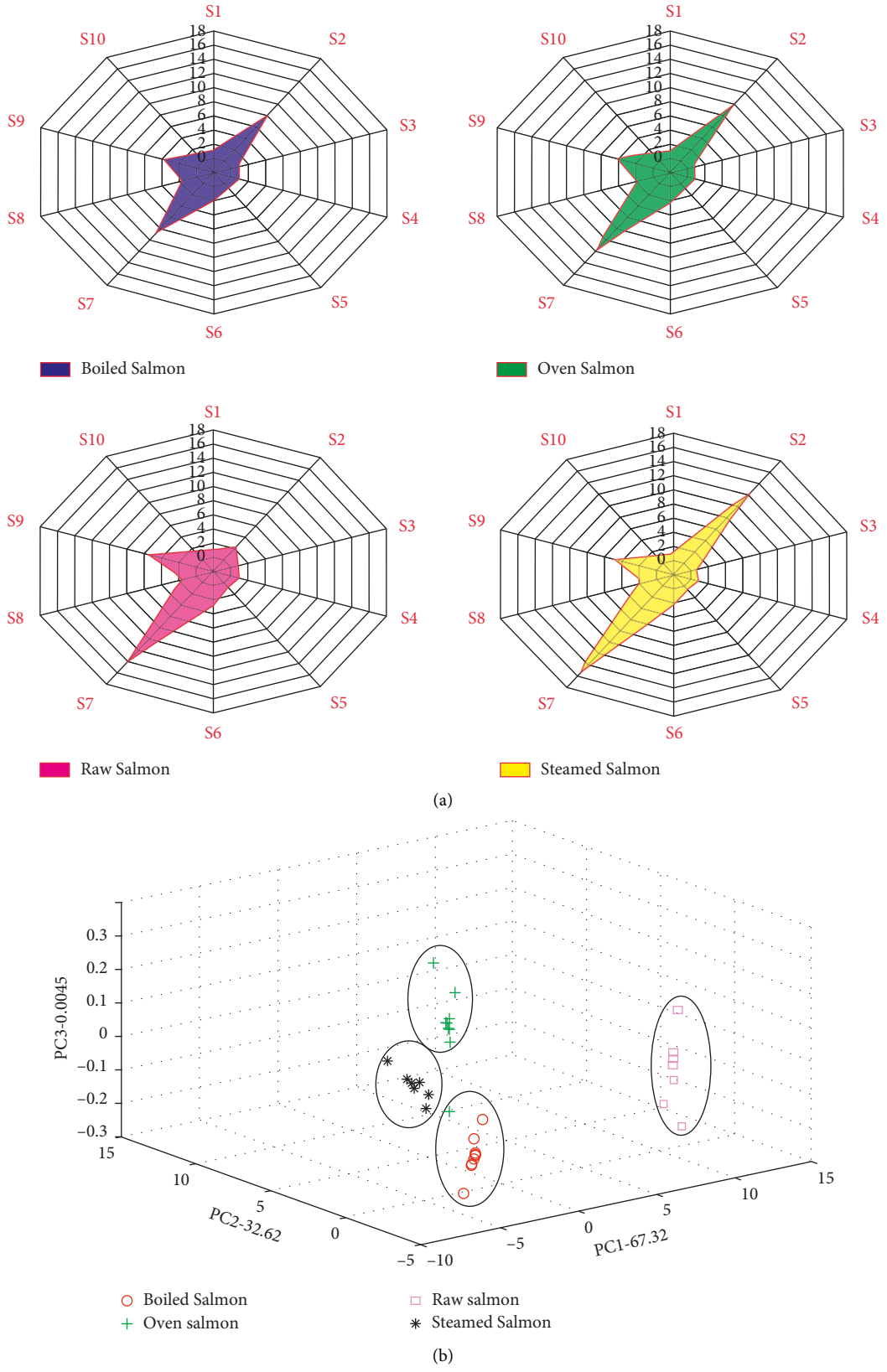

Figure 3: Radar chart (a) and PCA plot (b) of the electronic nose of Atlantic salmon after different culinary treatments.

of fish cover the daily nutritional consumption demands (recommended daily intake, RDI) of these fatty acids as suggested by the FAO/WHO.

3.8. Electronic Nose. The E-nose consists of a pattern-assimilation data processing method intended to imitate natural olfactory senses as accurately as possible [58, 68]. Figure 3(a) shows a graphical description of the flavor profiles for various sensory detection. The primary sensors for distinguishing between the raw sample and the various culinary treatments were the E-nose S2, S7, and S9. The results showed that S2 and S7 were relatively sensitive during the culinary treatments except for the raw sample. However, the S7 and S9 arrays decreased as heating temperatures increased, possibly due to changes in Maillard reactions, with steamed salmon having higher sensory values. Sensors S1, S3, S4, S5, S6, S8, and S10, on the other hand, were resistant to heating.

To determine the correlation patterns with distinct variables between raw and cooked salmon fish, the principal component analysis (PCA) was used (Figure 3(b)). Principal components (PC1 and PC2) accounted for a high percentage of the total variance (67.32 and 32.62%, resp.), accounting for more than 99% variance in the model. The raw and cooked samples were mostly aggregated along PC1 and PC2, respectively, with obvious variation among the two groups. The datasets were found in three nonoverlapping regions, demonstrating that raw and cooked samples could be easily distinguished. This could be due to the dissimilarity concession in S2 and S7 sensors for the raw and cooked samples previously mentioned. Moreover, the categorization precision of the linear discriminative analysis (LDA) training model was 90.1%. These PCs assist in recognizing relations among features by detecting useful predictors for intersecting classes. This facilitated the interactive removal of nonuseful predictors for disjoining classes. After the training set, the built classification models for LDA were conveyed to obtain a prediction precision of 87.2% on test data. There was a distinction in odor among the three culinary treatments, with oven-cooked and steamed salmon showing a distinctive correlation with sensory responses, thus ascertaining the initial sensory evaluation. Dong et al. [56] reported similar observations in steamed turbot (*Scophthalmus maximus*) fish muscle. The characterization of flavor changes and selection of quality indicators that correlate with sensor responses have enhanced the rapid monitoring of spoilage of salmon fish [69]. Therefore, electronic nose analysis could serve as a link between chemical and sensory analysis of Atlantic salmon.

3.9. Low-Field NMR. Low-field NMR has been employed recently to investigate potential variations in moisture movement in fish products during processing and storage [70]. The chemical context of hydrogen protons in the sample is reflected in the transverse relaxation time T_2 measured by LF-NMR [71]. The T_2 inversion Atlas was created using multiplex exponential fitting of NMR signal data from the three culinary treatments since they can lead to

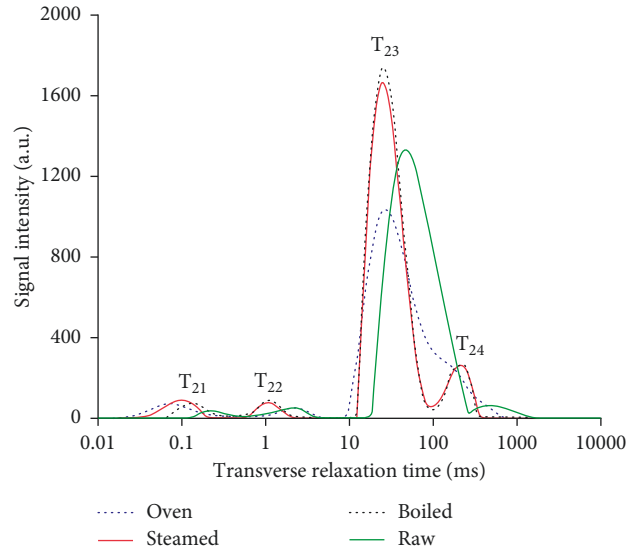

FIGURE 4: Transverse relaxation time (T_2) curves of Atlantic salmon at different culinary treatments.

proton changes by influencing their physicochemical properties during food processing [6]. Different transverse relaxation times T_2 can clearly distinguish the moisture distribution of different states. The T_2 relaxation spectra further show the four peaks of the four treatments, representing the proton change in the fish products in four different states (Figure 4). The first peak ranges from 0.01 to 0.5 ms, accounting for 0.5% moisture content, expressed as T_{21} for weakly bound water. The second peak ranges from 0.9 to 8.5 ms, accounting for about 15% moisture content, expressed as T_{22} with low mobility for strong binding water. The third and fourth peaks range from 10 to 580 ms and 100 to 1200 ms, accounting for 80% and 4.5% of the water content, respectively, expressed as T23 and T24 for immobile and free waters.

Among the various culinary treatments, T_{21} and T_{22} relaxation values of the raw samples fluctuated in the range of 0.01 to 2.23 ms, while $T2_3$ and T_{24} ranged from 16.37 to 579.67 ms. However, the boiled and steamed salmon have the highest relaxation values (Figure 4). This could indicate increased and decreased proton freedom and movement, respectively [6]. Conversely, Xiao et al. [72] reported a dramatic decrease in proton mobility and freedom of protons and the relaxation time T_2 in steamed and boiled salmon compared to sous-vide-treated salmon. Three peaks in the T_2 relaxation curves have been reported in most studies, with the first relaxation time T_{21} (0.1 to 10 ms), the second part T_{22} (10 to 200 ms), and the third portion T_{23} (200 to 1000 ms). They are assigned to protons from biological macromolecules, trapped immobilized water in the myofibrillar network, and extra-myofibrillar free water, respectively [73]. The protons of the first relaxation time, T_{21} (P_{21}), have water molecular flowability in an aqueous phase. They exist in protoplasts, vacuoles, and intercellular spaces in the cell structure [68].

Besides, the peak area relaxation showed an alternating discrepancy, and the result was spontaneous for the analogy

Table 7: The variation in peak area of Atlantic salmon during different culinary treatments.

Culinary treatment	P_{21}	P_{22}	P_{23}	P_{24}
Raw	1.38 ± 0.34^{a}	1.95 ± 0.66^{a}	81.77 ± 0.54^{ab}	1.95 ± 1.26^{a}
Boiled	2.55 ± 0.66^{b}	2.40 ± 0.46^{ab}	90.40 ± 5.67^{a}	4.65 ± 4.57^{a}
Steamed	3.14 ± 0.13^{b}	2.65 ± 0.11^{ab}	94.72 ± 2.16^{a}	12.44 ± 0.46^{ab}
Oven-cooked	4.58 ± 0.90^{c}	2.86 ± 0.10^{b}	84.51 ± 6.74^{b}	6.62 ± 5.99^{b}

The same superscript letters within the same columns represent significant differences ($p < 0.05$) between different culinary treatments.

to a greater extent. The various cooking methods (boiled, steamed, raw, and oven) resulted in T_{22} relaxation water release in descending order. However, instead of reducing peak area ratios, the T_{23} peak area (P_{23}) showed an increasing trend for all the treatments, with steamed salmon having the highest peak. This revealed that cooking media such as water and oil may have percolated the fish samples during cooking, with the raw sample having the lowest P_{23} value. Also, P_{24} decreased significantly ($p < 0.05$) during the early cooking process, owing to free water evaporation; however, P_{21}, P_{22}, and P_{23} did not vary significantly, with steamed salmon having the highest peak (P_{23} and P_{24}) areas of 94.72 ± 2.16 and 12.44 ± 0.46 (Table 7). This is contrary to the findings of Xiao et al. [72], where the peak areas were reported to be higher during sous-vide cooking, suggesting the role of mild temperature in preserving the physicochemical and structural properties of cooked salmon.

Moreover, the total free water T_{23} decreased significantly ($p < 0.05$) compared to bound water T_{21} and semibound water T_{22}. The peak area gradually reduced and deviated to the left, indicating that the free water content decreased frequently, and water and nonaqueous components became increasingly linked [71]. The change in water content was also analogous. Because so much water was lost in the fish during cooking, the residual protons in the cooked samples were confined, leading to reduced mobility. This may be due to the changes in the molecular structure of muscle fiber caused by heating. Therefore, these findings demonstrate the relevance of the structural characteristics within muscle tissue for water mobility.

4. Conclusion

This study assessed the effect of boiling, steaming, and oven-cooking on the fatty acid profile, physicochemical composition, and sensory properties of Atlantic salmon fish. Even though the cooked salmon was within the recommended range, the protein content of steamed and oven-cooked salmon was significantly higher than the boiled and raw fish ($p < 0.05$). Steaming significantly ($p < 0.05$) influenced the fatty acid profiles of Atlantic salmon fish, which exhibited the lowest SFA and the highest omega-3, omega-6, and PUFA contents. The E-nose sensors showed that S2 and S7 were significantly correlated during oven-cooking and steaming. Furthermore, low-field NMR showed that the values of T_{21} and T_{22} relaxation characteristics of raw samples fluctuated, with steamed salmon having the highest peak values indicating reduced proton mobility and increased freedom of the protons compared to other treatments. Therefore, steaming resulted in the best quality salmon, suggesting further studies to ascertain its effectiveness compared to modern treatments.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Zongbao Sun and Nidelle Sausten Fomena Temgoua contributed to conceptualization. Nidelle Sausten Fomena Temgoua contributed to methodology and resources. Charles Obinwanne Okoye contributed to software and review and editing. Nidelle Sausten Fomena Temgoua, Charles Obinwanne Okoye, and Zongbao Sun contributed to validation. Nidelle Sausten Fomena Temgoua and Charles Obinwanne Okoye contributed to formal analysis and data curation. Nidelle Sausten Fomena Temgoua and Haodong Pan contributed to investigation and original draft preparation. Haodong Pan contributed to visualization. Zongbao Sun contributed to supervision, project administration, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Supplementary Materials

Table S1. Pearson correlation for the various attributes for the sensory score. Table S2. Factor values of various principal components for hedonic point score. Figure S1. LDA plot for raw and cooked Atlantic salmon fish based on E-nose data. (*Supplementary Materials*)

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