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RESEARCH PAPER

Proximate Composition, Microbial, and Sensory Assessment of Smoked *Clarias gariepinus* Packaged in Retort Pouch

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Abstract

This study analyzed the effect of retort processing on smoke-dried fish. Fresh *Clarias gariepinus* were smoked and divided into two groups – retort prosessed samples (RPS) and unretorted samples (URS). Samples were kept in normal room conditions. Significant differences were observed in the proximate compositions and microbial loads over time. The moisture content was higher in RPS (8.53% to 8.84%) compared to URS, with significant differences emerging from day 14. Protein content showed notable changes, with URS recording a high of 70.00±0.00% on day 14 and RPS dropping to the lowest at 65.28±0.40% by day 56. Lipid levels were highest in RPS, peaking at 15.43±0.10, and ash content was lower in RPS (4.39±0.02 on Day 28) compared to URS. Microbial analysis indicated a decrease in total viable count in RPS from the first day, whereas it increased in URS throughout the 56 days. Sensory evaluations showed no significant differences in RPS over time, maintaining high ratings in all categories while URS experienced a decline in sensory qualities, notably with flavour and general acceptability. These findings demonstrate the effectiveness of retort processing in maintaining quality under extended storage

Introduction

Even when eaten in small quantities, fish contributes high amounts of amino acids, fatty acids, minerals, and vitamins to the dietary nutrient requirement of the consumer; this is why it is a vital source of food and livelihood, particularly in developing countries like Nigeria (Okomoda et al., 2020a; Olaniyi et al., 2017; Ricketts & Oyero, 2021a; WorldFish Center, 2011). To meet the demand for fish, Nigeria currently imports about 2.5 metric tons of fish, which exceeds its local fish production of 1.5 tons (FAO, 2018). While local production dwarfs fish importation in Nigeria, the fisheries industry is prone to significant post-harvest losses due to existential deficits in processing/preservation infrastructure and technology required to promote the extended shelf life of fresh or processed fish (Akande & Diei-Ouadi, 2010; Ansen & Davide, 2017; FAO, 2011; Sarr et al., 2016; Tesfay & Teferi, 2017). Faced with these challenges, local fish processors in Nigeria have adopted various processing and preservation methods, individually or in combination, to address their needs. Techniques like salting, sun drying, frying, and smoking have been employed, providing substantial extensions to the shelf life of fish. Notably, among these methods, smoking occupies a prominent position in Nigeria's fish processing industry.(Akinwumi & Adegbehingbe, 2015; Emere & Dibal, 2013; Olagbemide, 2015). Apart from imparting a distinct flavour to the fish, smoking is preferred as a preservation method due to its simplicity, affordability, and ability to produce a stable product. Smoking effectively preserves the fish by reducing moisture content and lowering water activity (Abowei &

Tawari, 2011; Ghaly et al., 2010; Hasan et al., 2016).

Smoking can preserve fish to some extent, but smoked fish products can still be contaminated by microbes and lose nutrients if not protected from their environment (Babic Milijasevic et al., 2019; Nwachukwu et al., 2008). Unfortunately, traders neglect this potential hazard to consumers and the loss of freshness associated with smoked fish by displaying or selling their products without proper protection (Ikutegbe & Sikoki, 2014; Price & Tom, 2001). To address this problem, packaging has been identified as a viable solution that can improve the product's shelf life, preserve its quality and freshness, and facilitate easy handling during distribution.

Various materials have been found effective in packaging smoked fish, such as aluminium foil, paper and cardboard, polyethene, and retort pouches. Retort pouches are flexible laminates that can withstand thermal sterilization. They offer the advantages of metal cans and plastic packages, including shorter processing time, reduced nutrient loss, easy opening, the option to consume the product directly from the pouch, compact storage, and simplified disposal.

Packaging smoked fish in retort pouches involves sealing the food in the pouch and sterilizing it at temperatures ranging from 116°C to 121°C. Compared to traditional containers, retort pouches offer several benefits, including increased shelf stability, reduced weight, efficient storage utilization, easy opening, and minimized heat exposure, leading to better product quality (Dhanapal et al., 2010a; Majumdar et al., 2015; Tribuzi et al., 2015a). This study aims to assess the effectiveness of retort pouch technology in prolonging the shelf life of smoked *Clarias gariepinus* by analyzing its proximate composition and microbial and sensory properties over a certain period.

Material and Methods

Sample Collection

A total of 6 kg of fresh fish was purchased from Wadata Market, Benue State, and taken fresh to the Department of Fisheries and Aquaculture, University of Agriculture, Makurdi.

Experimental Setup

The live fish, *Clarias gariepinus,* was taken to the Department of Fisheries and Aquaculture at the University of Agriculture Makurdi, where they were percussively stunned and euthanized, weighed, degutted, and thoroughly rinsed in preparation for smoking. Smoking was done using a wood-fed smoking kiln. After smoking, the fish was allowed to cool. The sample was hand-picked with sterilized gloves and taken to the laboratory in sterilized polythene bags to avoid contamination from handling. Twenty portions of smoked *C. gariepinus* weighing 15g each were separated into two groups. The first group was subjected to retort processing using retort pouches and autoclaved at 121°C for 15 minutes (Retort Processed Samples (RPS)). The second group was not retorted (Unretorted Samples (URS)) and packaged using paper bags imitating the traditional packaging method. Both groups were stored under ambient room conditions (Temperature: 23°C-35°C, Humidity: 40%-50%). The fish samples were assessed bi-weekly for eight weeks under ambient conditions.

Biochemical Analysis

The initial and biweekly proximate compositions of both treatments were taken using the methods for protein, lipid, ash, and moisture content analyses prescribed by the Association of Official Analytical Chemists (AOAC) (2000).

Microbial Analysis

To assess the total bacterial load and potential faecal contamination, 1 gram of homogenized fish sample was aseptically plated onto Nutrient Agar (NA) and MacConkey Agar (MAC), respectively. Plates were incubated aerobically at 30°C for 48 hours. Colony-forming units per gram of sample were enumerated on NA plates to determine the total viable count (TVC). Lactose-fermenting colonies (pink/red) on MacConkey agar were presumptive for coliforms and were enumerated to determine total Coliform count (TCC). For the detection of fungi and yeasts, 1 gram of the homogenized sample was plated onto Sabouraud Dextrose Agar (SDA) supplemented with antibiotics (mention specific antibiotics if used) to inhibit bacterial growth. SDA plates were incubated aerobically at 25°C for 5-7 days and enumerated to determine the total fungi count (TFC). All equipment and culture media (including Petri dishes, beakers, test tubes, etc.) utilized in this investigation underwent sterilization through autoclaving at a temperature of 121°C for 15 minutes in an electrically powered autoclave.

Sensory Analysis

Using the 7-point hedonic scale (Okomoda et al., 2020b), a panel of ten (10) previously trained assessors composed of staff and students at the Federal University of Agriculture assessed the sensory properties of RPS and URS samples.

Statistical Analysis

The data obtained from the experiments underwent thorough statistical analysis. Analysis of variance (ANOVA) at a 5% significance level was used to assess overall treatment variability, while the T-test facilitated detailed comparisons of means between specific treatments.

Results

The effect of retort processing on the biochemical, microbial, and sensory stability of smoke-dried *Clarias gariepinus* is presented as follows:

Proximate Composition

Table 1 displays the proximate analysis results conducted on the fish samples. The proximate composition of the fish samples, both retort processed and unretorted samples, exhibited significant variations (P<0.05) as the storage period increased. Moisture content ranged from 8.53% to 8.84% and remained consistently higher in the retort processed samples (RPS). Conversely, the moisture content of the un-retorted fish samples showed variations on different storage days (Table 1). A significant difference was observed between the moisture content of the retorted and unretorted fish samples starting from day 14 until the end of the study.

Significant variations were observed in the protein content of both treatments across different days of the experiment. Additionally, notable differences were found between fish packaged with the retort pouch and those without it (P<0.05). On the 14th day of the study, the URS exhibited a higher protein value (70.00±0.00%). However, on the 56th day of the experiment, the RPS had the lowest protein value (65.28±0.40%).

The different treatments also influenced the lipid content of the fish over time. The samples packaged with the retort pouch showed the highest lipid content (15.43±0.10), followed by 15.40±0.60 (on days 28 and 27, respectively) recorded in the same retort pouch packaging. These values were significantly higher than the lipid content obtained from the fish samples without the retort pouch packaging.

The ash content in the fish samples varied depending on the packaging method. The fish packaged without the retort pouch had a higher ash content (6.47±0.14), followed by 6.15±0.05 recorded on the 14th and 56th days of the study, respectively. In contrast, the ash content was lower in the retort pouch packaged fish, with values of 4.39±0.02 and 4.37±0.04 obtained on Day 28 and Day 42 of the experiment. These values were significantly lower than the ash content observed in the samples without the retort pouch packaging.

Microbial Evaluation

Table 2 presents the microbial load on the fish samples during the study. The total viable count (TVC) of the RPS samples declined significantly from the first day to the 28th day of the study, while the TVC on URS samples increased significantly from the 1st to the 56th day. The TVC on the RPS samples was significantly lower than that on the URS samples.

The results of total coliform count (TCC) are presented in Table 2. The TCC on RPS samples was observed to decline from the 1st to the 14th day of the experiment and was absent throughout the study. In contrast, TCC on URS samples increased from the first day with significantly different fluctuations on the research's 14th, 42nd, and 56th day. The lowest and highest TCC was recorded on the 1st and 42nd days.

Table 1: Changes in proximate composition retort processed and unretorted smoke-dried *Clarias gariepinus*

		Treatment		tTest		
Parameter	Days	RPS	URS	P-value	MD	Remark
Moisture	1	8.54±0.22	8.33±0.60 ^{a}	0.68	0.22	Not Significant
	14	8.57±0.04	4.22±0.13 ^{c}	0.00	4.35	Significant
	28	8.53±0.13	6.39±0.22 ^{b}	0.01	2.14	Significant
	42	8.84±0.37	7.67±0.06 ^{a}	0.05	1.17	Significant
	56	8.72±0.48	6.34±0.24^{b}	0.02	2.38	Significant
	P value	0.35				
Protein	1	65.63±0.00^{b}	67.63±1.59 ^{a}	0.22	2.00	Not Significant
	14	67.16±0.93 ^{ab}	70.00±0.00 ^{a}	0.05	2.85	Significant
	28	66.07±0.62 ^{ab}	68.47±0.31^{a}	0.04	2.41	Significant
	42	65.63±0.62^{ab}	67.97±1.02 ^{a}	0.11	2.35	Not Significant
	56	65.28±0.40 ^{a}	60.75±0.53 ^{b}	0.02	4.41	Significant
Lipid	1	15.38±0.68	15.34±0.07 ^{a}	0.94	0.04	Not Significant
	14	15.40±0.60	14.60±0.41 ^{ab}	0.26	0.80	Not Significant
	28	15.43±0.10	12.96±1.53 ^{bc}	0.15	2.48	Not Significant
	42	15.27±0.06	11.91±0.33 ^{cd}	0.00	3.36	Significant
	56	15.39±0.11	10.19±0.56 ^{d}	0.01	5.20	Significant
	P value	0.71				
Ash	1	4.13±0.04	4.04±1.00 ^{b}	0.92	0.09	Not Significant
	14	4.29±0.64	6.15±0.05 ^{a}	0.05	-1.86	Significant
	28	4.39±0.02	4.39±0.06 ^{b}	0.88	-0.01	Not Significant
	42	4.37±0.04	5.51±0.85 ^{ab}	0.20	-1.15	Not Significant
	56	4.21±0.67	6.47±0.14 ^{a}	0.04	-2.26	Significant
	P value	0.56				

**Means with different superscript differ significantly* (P<0.05), *Retort processed Samples =RPS, Unretorted Samples=URS, Mean Difference=MD*

The results of Total fungi count (TFC) on RPS samples were observed only on the first day of the study; on the other hand, the TFC on URS samples increased progressively from day 1 to day 56 with a significant difference between the first day of sampling and the rest. The lowest and highest TFC were recorded on the 1st and 42nd days, respectively.

Sensory Evaluation

Based on the perception of the organoleptic panellist, the sensory evaluation of the RPS samples showed no statistical difference (Table 3). This implies that the appearance, flavour, taste, odour, and general acceptability were consistent and ranked very good through the 56 days of storage. However, the preference of the organoleptic panel showed that the sensory evaluation of URS samples declined with a significant difference.

The appearance of RPS *C. gariepinus* fillets had an excellent rating by the assessment of the organoleptic panellist; the average appearance score throughout the study was higher than 6.50, and changes in the mean score were not significantly different. Whereas the mean score for the appearance of the URS samples was rated excellent within the first 28 days of the study, it declined from excellent (6.64±0.50 by day 1) to fair (4.71±0.73 by day 56). When compared, the means of RPS samples were not significantly different from URS samples within the first 28 days of storage.

The mean flavour score and trend of RPS samples are similar to those of appearance. The average score for flavour throughout the study was also higher than 6.50 with no significant difference in biweekly means; this study recorded a decline from excellent (6.86±0.36 by day 1) to fair (4.00±0.00 by day 56) in the mean score for the flavour of the URS samples. These samples were rated excellent within the first 28 days before being rated fair for the remaining time in storage. When compared, the means of RPS samples were not significantly different from URS samples within the first 28 days of storage.

The mean taste values for URS samples declined significantly from excellent (6.86±0.36, day 1) to poor (3.43±0.51, day 56). In contrast, taste values for samples packaged using RPS ranged from 6.36±0.50 to 6.85±0.38 and remained excellent with no significant difference throughout the study. When compared, the taste values for both treatments were significantly different from day 42 to the end of the study.

According to the ranking of the hedonic scale used in this study, RPS samples had excellent smell, ranging from 6.64±0.51 to 6.86±0.36. However, the unretorted samples declined significantly from excellent (6.86±0.36, day 1) to very poor (2.29±0.47, day 56). Both treatments were significantly different from day 14 to the end of the study.

Mean General Acceptability ranged from 6.71±0.47 to 6.85±0.38 for samples packaged using RPS, while URS samples declined from excellent (6.86±0.36, Day 1) to poor (3.14±0.36, Day 56). The mean general acceptability for unretorted samples was significantly different throughout the study. When the taste values for both treatments were compared, a significant change was recorded from day 42 to the end of the study.

Discussion

Proximate Composition

The proximate composition of smoked fish products is pivotal in determining their shelf life, quality, and nutritional value. This study evaluated the changes in moisture, protein, lipid, and ash contents in smoked fish stored in retort pouches (RPS) compared to those in unretorted samples (URS). The results shed light on how retort pouches can effectively maintain the proximate composition of fish during storage, influenced by factors discussed in previous research.

Moisture content is a critical parameter for the shelf stability and quality of smoked fish. The findings of this study reveal that moisture content in RPS samples remained relatively stable (ranging from 8.53% to 8.84%) throughout the storage period. This stability contrasts sharply with the significant fluctuations observed in URS samples (Ricketts & Oyero, 2021b). This stability in RPS can be attributed to the barrier properties of the retort pouches, which prevent moisture exchange with the surrounding environment. Previous research by Daramola et al., (2007) and Salaudeen & Osibona (2018) support these observations, highlighting how packaging and storage conditions influence moisture dynamics in smoked fish products.

Protein content is essential for assessing the nutritional quality of fish products. In this study, the protein content in URS was generally higher than in RPS, particularly towards the end of the storage period. This trend may result from the more significant moisture loss in URS samples, concentrating proteins in a reduced mass. However, significant decreases in moisture in URS could lead to protein denaturation and loss of nutritional value, as suggested by Abraha et al. (2018). Conversely, the retort pouch mitigates these changes, maintaining a more consistent protein content, which is vital for retaining the nutritional integrity of smoked fish.

Lipid oxidation is a major concern during the storage of smoked fish, affecting flavour, aroma, and nutritional quality. The study results indicate that lipid stability was better maintained in RPS, with less pronounced degradation over time compared to URS. This observation aligns with findings from Guizani et al. (2011) and Bienkiewicz et al. (2019), who noted that processing and storage conditions, including the use of specific packaging technologies like retort pouches, could significantly impact lipid oxidation. The ability of

Table 2: Effect of retort processing on the microbial load of smoke-dried *Clarias gariepinus*

Day	Treatment		t-Test		
	RPS	URS	P-value	MD	Remark
1	$2.20 \times 10^3 \pm 0.12^a$	$2.09 \times 10^4 \pm 0.06^c$	0.01	0.98	Significant
14	$4.90 \times 10^2 \pm 0.12^b$	$4.16 \times 10^4 \pm 0.09^b$	0.00	1.93	Significant
28	$4.90 \times 10^2 \pm 0.30^b$	$5.88 \times 10^4 \pm 0.12^b$	0.01	2.08	Significant
42	NA	$1.14 \times 10^5 \pm 0.07^a$	NA	NA	NA
56	NA	$1.71 \times 10^5 \pm 0.03^a$	NA	NA	NA
1	$5.29 \times 10^2 \pm 0.17$	$1.22 \times 10^3 \pm 0.86^b$	0.62	0.36	Not Significant
14	$2.00 \times 10^2 \pm 0.00$	$3.09 \times 10^4 \pm 0.06^a$	0.00	2.19	Significant
28	NA	$1.36 \times 10^4 \pm 0.61^{ab}$	NA	NA	NA
42	NA	$8.65 \times 10^4 \pm 0.06^a$	NA	NA	NA
56	NA	$7.71 \times 10^4 \pm 0.20^a$	NA	NA	NA
1	1.30×10^3	$1.06 \times 10^3 \pm 0.25^b$	0.62	-0.09	Not Significant
14	NA	$2.09 \times 10^4 \pm 0.06^a$	NA	NA	NA
28	NA	$3.79 \times 10^4 \pm 0.05^a$	NA	NA	NA
42	NA	$5.19 \times 10^4 \pm 0.05^a$	NA	NA	NA
56	NA	$5.31 \times 10^4 \pm 0.31^a$	NA	NA	NA

**Means with different superscript differ significantly* (P<0.05), *Retort processed Samples =RPS, Unretorted Samples=URS, Mean Difference=MD*

Table 3: Comparative Sensory Indices of retort processed and Unretorted smoke-dried *Clarias gariepinus*

Parameters	Days	Treatment		tTest		
		RPS	URS	P value	MD	Remark
Appearance	1	6.64±0.50	6.64 ± 0.50^a	1.00	0.00	Not Significant
	14	6.64±0.51	6.50 ± 0.52^a	0.52	0.14	Not Significant
	28	6.64±0.51	6.50 ± 0.67^a	0.59	0.14	Not Significant
	42	6.62±0.51	4.86 ± 0.95^b	0.00	1.76	Significant
	56	6.58±0.52	4.71 ± 0.73^b	0.00	1.87	Significant
	P value	0.801				
Flavor	1	6.58±0.52	6.86 ± 0.36^a	0.13	-0.27	Not Significant
	14	6.55±0.52	6.33 ± 0.78^{ab}	0.46	0.21	Not Significant
	28	6.50±0.53	6.08 ± 0.79^b	0.17	0.42	Not Significant
	42	6.54±0.78	4.36 ± 1.08^c	0.00	2.18	Significant
	56	6.57±0.51	4.00 ± 0.00^c	0.00	2.57	Significant
	P value	0.762				
Taste	1	6.85±0.38	6.86 ± 0.36^a	0.94	-0.01	Not Significant
	14	6.50±0.53	6.33 ± 0.65^b	0.52	0.17	Not Significant
	28	6.40±0.52	6.25 ± 0.62^b	0.55	0.15	Not Significant
	42	6.43±0.76	4.07 ± 0.83^c	0.00	2.36	Significant
	56	6.36±0.50	3.43 ± 0.51^d	0.00	2.93	Significant
	P value	0.058				
Odor	1	6.86±0.36	6.86 ± 0.36^a	1.00	0.00	Not Significant
	14	6.70±0.48	6.18 ± 0.60^b	0.04	0.52	Significant
	28	6.64±0.51	5.75 ± 0.62^b	0.00	0.89	Significant
	42	6.79±0.58	4.86 ± 0.66^c	0.00	1.93	Significant
	56	6.79±0.43	2.29 ± 0.47^d	0.00	4.50	Significant
	P value	0.312				
General Acceptability	1	6.85±0.38	6.86 ± 0.36^a	0.94	-0.01	Not Significant
	14	6.82±0.41	6.42 ± 0.67^b	0.10	0.40	Not Significant
	28	6.73±0.47	6.33 ± 0.49^b	0.06	0.39	Not Significant
	42	6.71±0.61	5.00 ± 0.78^c	0.00	1.71	Significant
	56	6.71±0.47	3.14 ± 0.36^d	0.00	3.57	Significant
	P value	0.548				

**Means with different superscript differ significantly* (P<0.05), *Retort processed Samples =RPS, Unretorted Samples=URS, Mean Difference=MD*

RPS to limit exposure to oxygen and light, both catalysts for lipid oxidation, likely contributes to these results. This study found minor changes in ash content across both treatments, with occasional significant differences. The less variable ash content in RPS could suggest better preservation of mineral integrity due to reduced exposure to environmental factors that might leach minerals. The use of retort pouches for storing smoked fish effectively maintains the moisture and lipid content while minimizing protein degradation and preserving ash content.

Microbial Evaluation

This study demonstrates clear differences in microbial load between Retort Pouch Samples (RPS) and Unretorted Samples (URS) throughout the experiment. The data on Total Viable Count (TVC), Total Coliform Count (TCC), and Total Fungi Count (TFC) provide compelling evidence of the efficacy of retort packaging in preserving the microbial quality of stored food products.

The results show a significant reduction in TVC in RPS from the first day to the 28th day, whereas URS showed a substantial increase over the same period. This differential can be primarily attributed to the barrier properties of retort pouches, which inhibit the ingress of microorganisms and reduce oxygen availability, thus significantly delaying microbial growth. Studies like those by Kaushik et al. (2017) reinforce our findings, where AL-based retort pouches extended the microbial acceptability of food products. The sharp contrast in microbial loads between RPS and URS underscores the critical role of packaging in food safety, a conclusion supported by Kumar et al. (2015) and Afoakwa (2014), who documented similar declines in microbial counts in retort-processed foods.

TCC results highlighted an initial presence in both RPS and URS, with a subsequent decline in RPS and fluctuating yet generally increasing counts in URS. This suggests that retort pouches not only reduce viable microbial populations but also effectively control coliform bacteria, which are often indicators of sanitary quality and potential faecal contamination. The absence of coliforms in RPS after the 14th day could be a result of both the thermal process during retort packaging and the barrier effect of the pouch itself, aligning with findings from Adeyeye et al. (2015) and Tribuzi et al. (2015), who found similar effects in smoked fish and processed mussel meats, respectively.

The analysis of TFC provided further evidence of the protective properties of retort pouches. The presence of fungi was significantly controlled in RPS, with no growth after the first day, contrasting with the progressive increase observed in URS. This resistance to fungal growth in RPS could be due to the modified atmosphere inside the pouches, as well as the impact of high-temperature processing on fungal spores, which are generally more resistant than bacteria. This finding is in line with the work of Özpolat et al. (2014), who demonstrated the effectiveness of vacuum-packing and storage conditions in inhibiting fungal activity in food products.

The significant reductions in TVC, TCC, and TFC in RPS compared to URS over the storage period underscore the importance of retort pouch packaging in maintaining the microbial integrity of stored food products. These findings highlight the dual function of retort packaging in extending shelf life and enhancing food safety.

Sensory Evaluation

The sensory evaluation of the RPS samples showed consistent appearance, flavour, taste, odour, and general acceptability throughout the 56 days of storage, with no statistical difference observed(Dhanapal et al., 2010). In contrast, sensory evaluation (appearance, flavour, taste, smell, and general acceptability) of URS samples declined significantly over time (Francesco et al., 2004). This decline in sensory attributes of URS samples aligns with findings related to the sensory characteristics of fish fillets (Tribuzi et al., 2015). The comparison of RPS and URS treatments within the first 28 days of storage revealed no significant difference in sensory attributes, indicating initial similarity in sensory quality. However, over time, the sensory qualities of URS samples deteriorated, while RPS maintained their sensory attributes, highlighting the potential of RPS treatment in preserving the sensory quality of fish fillets during storage.

The findings suggest that RPS treatment can effectively maintain the sensory attributes of fish fillets over an extended storage period, offering valuable insights into preserving the sensory quality of fish products.

Conclusions

The study reveals that retort processing is more effective in reducing microbial load and maintaining the quality and safety of smoked *Clarias gariepinus* than unretorted samples. Retort pouch packaging (RPS) effectively maintains the moisture content of fish samples during storage, demonstrating a decline in total viable count (TVC), total coliform count (TCC), and total fungi count over time. This is consistent with previous research on retort pouch packaging and highlights its benefits for preserving fish quality and safety. The consistent moisture levels observed in RPS samples highlight the protective nature of the packaging material, shielding the fish from adverse conditions and minimizing moisture fluctuations. Proper moisture control is essential for preserving the quality, texture, and safety of processed fish, and retort processing is a promising packaging method

Ethical Statement

The fish used in this study were sourced responsibly from sustainable stocks. Prior to processing, all fish were handled humanely to minimize stress and discomfort, following the best practices for animal welfare. The methods employed for smoking and packaging, including retort processing, were designed to adhere to established food safety and quality standards.

Proximate analysis, sensory evaluation, and microbial assessment were conducted in compliance with the highest standards of scientific integrity and transparency. All data were anonymized and processed in a manner that ensures confidentiality and privacy.

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Author Contribution

First Author: Conceptualization, Supervision, Methodology, Analysis, Writing -review and editing; Sophia Onoja: Data Collection, Investigation, Writing-first draft (Proximate Composition); Blessing Uke: Sophia Onoja: Data Collection, Investigation, Writing-first draft (Sensory Assessment); and David Idoko: Sophia Onoja: Data Collection, Investigation, Writing-first draft (Microbial Assessment).

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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