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Biochemical, Mineral and Microbial Analysis of Differently Salted Nile Tilapia (*Oreochromis niloticus*)

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Abstract

This study investigated the proximate, mineral, and microbial composition of Nile tilapia preserved using three different salting methods: Kench, Brining, and Granulated Salting. A total of 27 fish samples were processed, with 9 fish allocated to each preservation method. The results of the proximate composition analysis revealed that Brining resulted in the highest moisture content (52.60%) compared to Kench (45.23%) and Granulated Salting (40.10%) ($p < 0.05$). Granulated Salting produced the highest crude protein content (32.40%), which was significantly greater than that of Brining (28.47%) and Kench (30.30%). While Brining exhibited the highest crude fat content (9.20%) ($p < 0.05$), Granulated Salting had the highest ash (15.77%) and pH (6.47) values, indicating its effectiveness in preserving fish quality. The mineral composition analysis showed significant differences among the methods, with Granulated Salting having the highest sodium (3500.00 mg) and calcium (200.00 mg) contents ($p < 0.05$). The microbial analysis indicated that Kench had the highest bacterial and fungal counts, with a significant presence of pathogens such as *S. aureus* and *P. aeruginosa*. In contrast, Granulated Salting exhibited the lowest microbial load, significantly reducing bacterial and fungal contamination ($p < 0.05$). In conclusion, Granulated Salting emerged as the most effective method for preserving the nutritional and microbiological quality of Nile tilapia. It demonstrated superior efficacy in reducing moisture content, preserving protein, minimizing lipid oxidation, and controlling microbial growth. Therefore, Granulated Salting is recommended as the preferred method for preserving Nile tilapia due to its exceptional ability to retain protein content, maintain biochemical stability, and effectively reduce microbial contamination.

Keywords: Nile Tilapia, Fish Preservation, Biochemical Analysis, Microbial Analysis, Salting Techniques.

Introduction

Salt preservation has long been a traditional method for extending the shelf life of fish, particularly in regions with limited refrigeration (Shahrier *et al.*, 2023). Nile tilapia (*Oreochromis niloticus*), valued for its high nutritional content, is rich in protein, essential fatty acids, and vital minerals, making it a staple in many diets (Nuryanto *et al.*, 2022).

Maintaining the quality of Nile tilapia during storage is crucial to prevent spoilage, preserve its nutritional value, and ensure consumer safety (Ali *et al*., 2017).

Various salting techniques, including kench, brining, and granulated salting, are employed for fish preservation. The kench method involves layering fish with dry salt, effectively dehydrating the product and inhibiting microbial growth (Indiarto *et al*., 2021; Aubourg *et al*., 2016; Abdulkarim and Yusuf, 2015). Brining entails submerging fish in a saltwater solution, which enhances flavor but can increase lipid oxidation and microbial activity if not managed properly (FAO, 2024; Ozogul *et al*., 2017). Granulated salting, a variant of dry salting, applies granulated salt to the fish's surface to reduce moisture while preserving its texture and nutritional quality (FAO, 2024; Mol *et al*., 2018).

The biochemical, mineral, and microbial stability of fish during the salting process is crucial. Biochemical changes, such as lipid oxidation and protein degradation, directly impact the quality of the fish (Alaba *et al*., 2019). Additionally, alterations in mineral composition, particularly sodium and potassium levels, influence the fish's dietary value (Salam *et al*., 2024). Microbial analysis is essential to ensure safety, as inadequate salting or improper storage can lead to spoilage or pathogenic contamination (Ibrahim *et al*., 2021). Some studies have emphasized that different salting methods can affect microbial composition, with the Kench method generally demonstrating greater efficacy in reducing microbial load compared to brining, although brining enhances flavor (Famurewa *et al*., 2017).

Despite the importance of salting techniques in preserving Nile tilapia, there is limited understanding of how each method affects its preservation quality, particularly in tropical climates where the fish is primarily farmed and consumed (Famurewa *et al*., 2017). Previous studies have demonstrated that variations in lipid oxidation, protein degradation, mineral changes, and microbial growth occur depending on the salting method used (Alaba *et al*., 2019; Ozogul *et al*., 2017). However, comprehensive analyses comparing the biochemical, mineral, and microbial effects of kench, brining, and granulated salting on Nile tilapia have yet to be conducted. This gap in knowledge presents a significant challenge for optimizing fish processing and storage practices, especially in regions where traditional preservation methods are crucial for food security (Mohdaly *et al*., 2021).

This study aims to address the existing knowledge gap by evaluating and comparing the biochemical, mineral, and microbial changes in Nile tilapia subjected to various salting methods. The findings will provide essential insights into best practices for fish preservation, ensuring the safety and nutritional integrity of Nile tilapia during storage. The primary objective is to determine the biochemical, mineral, and microbial composition of differently processed salted *Oreochromis niloticus*.

Materials and Methods

Samples Procurement

Freshly caught *Oreochromis niloticus* were collected from fishermen at Gubi Dam in Bauchi State, Nigeria. Gubi Dam is a storage dam constructed in 1979 to impound water from the

upstream side of the Gubi River during periods of excess supply. It has a top water level of approximately 577 meters and extends 3 kilometers in length. The dam is located in the northern part of Bauchi town, Nigeria, and lies within the boundaries of longitude 10°25'N to 10°26'N and latitude 9°51'E to 9°52'E (BASWB, 1990).

Sample Collection and Preparation

Samples of 27 freshly caught Nile tilapia (*Oreochromis niloticus*), were obtained from fishermen at Gubi Dam in Bauchi State, Nigeria. Upon arrival, the fish were thoroughly washed with potable water to eliminate any dirt or debris. The samples were then divided into three groups, each assigned to a different processing method: granulation or salted sun-drying, brining, and the kench method.

Processing Methods

Salted Sundried Method (Granulated)

The fish samples were gutted, descaled, and thoroughly rinsed. Salt was applied at a ratio of 1:4 (fish weight to salt weight) before the samples were spread out on drying racks and left to sun-dry for 5 to 7 days under ambient conditions (temperature range: 28°C to 35°C). The samples were flipped regularly to ensure uniform drying. After drying, the fish samples were stored in sterile containers for further analysis.

Brining Method

The fish samples were descaled, gutted, and rinsed. They were then submerged in a 10% brine solution (100 g of salt per 1 liter of water) for 24 hours at room temperature (28°C). After brining, the fish were removed from the solution, air-dried for 24 hours, and stored in sterile containers for analysis.

Kench Method

For the Kench method, the fish were gutted and thoroughly rinsed. They were then layered alternately with salt in a ratio of 1:3 (fish weight to salt weight) in a container, ensuring that the top layer was completely covered with salt. The container was sealed and stored at 4°C for 5 to 7 days to allow the fish to cure. After the curing process, the fish samples were air-dried for 24 hours before being stored for analysis.

Biochemical Analysis

Proximate composition

The proximate composition, which includes moisture, protein, fat, and ash content, was determined using the methods outlined by AOAC (2016). Moisture content was measured by drying the samples in an oven at 105°C until a constant weight was achieved. Crude protein was assessed using the Kjeldahl method, while crude fat was extracted through Soxhlet extraction. Ash content was measured by incinerating the samples in a muffle furnace at 550°C.

Mineral Analysis

The mineral composition, including calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), and iron (Fe), was analyzed using an atomic absorption spectrophotometer (AAS) in accordance with AOAC (2016) guidelines. Samples were digested with nitric acid and hydrogen peroxide, followed by the determination of mineral content through flame atomic absorption spectrophotometry.

Microbial Analysis

The microbial load in the fish samples was assessed by conducting a total viable count (TVC) and analyzing specific pathogens, including coliforms, *Staphylococcus aureus*, and Salmonella spp.

Total Viable Count (TVC)

A 10 g portion of each fish sample was homogenized in 90 mL of sterile peptone water. Serial dilutions were prepared, and 1 mL from each dilution was plated on Plate Count Agar (PCA). The plates were incubated at 37 °C for 24 to 48 hours, after which colonies were counted and expressed as colony-forming units per gram (CFU/g) of fish.

Coliform Count

Coliform Analysis

1 mL of the homogenized fish sample was plated on MacConkey agar and incubated at 37°C for 24 hours. Pink colonies were counted as coliform bacteria and recorded as CFU/g.

- ***Staphylococcus aureus* Count**

Staphylococcus aureus was isolated by spreading 1 mL of the sample homogenate on Mannitol Salt Agar (MSA) and incubating it at 37°C for 24 hours. Yellow colonies were counted as *S. aureus* and reported as colony-forming units per gram (CFU/g).

- ***Pseudomonas aeruginosa* Detection**

Pseudomonas aeruginosa, samples were cultured on Cetrimide Agar and incubated at 37°C for 48 hours. Colonies displaying a characteristic green pigmentation were identified as *P. aeruginosa* and counted as colony-forming units per gram (CFU/g).

- ***Streptococcus spp*. Detection**

Streptococcus spp., the fish samples were plated on blood agar and incubated at 37°C for 24 hours. Hemolytic colonies were counted and reported as colony-forming units per gram (CFU/g).

- ***Escherichia coli* Detection**

E. coli was isolated by plating the sample on Eosin Methylene Blue (EMB) agar and incubating it at 37°C for 24 to 48 hours. Metallic green colonies were counted as E. coli and reported as colony-forming units per gram (CFU/g).

- ***Micrococcus luteus***

Detection was performed by culturing samples on nutrient agar and incubating them at 37°C for 24 to 48 hours. Yellow colonies were identified as *M. luteus*.

- ***Bacillus subtilis***

Bacillus subtilis was cultured on nutrient agar at 37°C for 24 to 48 hours. The colonies, which were whitish and rose, were identified as *B. subtilis*.

Fungal Analysis

Fish samples were plated on Potato Dextrose Agar (PDA) and incubated at 28°C for 5 to 7 days. Colony morphology was utilized to identify species of Aspergillus, Penicillium, and Fusarium (*Aspergillus spp.*, *Penicillium spp.*, and *Fusarium spp*.)

Statistical Analysis

Data collected from biochemical, mineral, and microbial analyses were subjected to statistical analysis using SPSS version 25.0. An analysis of variance (ANOVA) was performed to determine significant differences between the processing methods at a 5% significance level ($p < 0.05$). Post-hoc tests using the Duncan's Multiple Range Test (DMRT) were conducted to compare means where significant differences were observed. Results are presented as means ± standard deviations.

Results and Discussion

Results

Table 1: Proximate Composition (%) of Fish Preserved by Kench, Brining, and Granulated Salting

Proximate Parameters	Kench	Brining	Granulated Salting	LOS
Moisture content	45.23 ± 0.32^{b}	52.60 ± 0.20^{a}	40.10 ± 0.26^{c}	*
Crude protein	30.30 ± 0.10^{b}	28.47 ± 0.15^{c}	32.40 ± 0.10^{a}	*
Crude fat	8.63 ± 0.15^{b}	9.20 ± 0.10^{a}	7.80 ± 0.10^{c}	*
Crude fiber	0.66 ± 0.57^{b}	0.60 ± 0.00^{b}	0.77 ± 0.06^{a}	*
Ash	14.50 ± 0.10^{b}	12.70 ± 0.10^{c}	15.77 ± 0.15^{a}	*
PH	6.20 ± 0.10^{b}	5.90 ± 0.10^{c}	6.47 ± 0.06^{a}	*

Means values in the same row having different superscript are significantly different *($p<0.05$), LOS: level of significant

Table 1 shows the results of the Proximate Composition (%) of Fish Preserved by Kench, Brining, and Granulated Salting. Brining has the highest moisture content (52.60%), significantly ($p<0.05$) greater than both Kench (45.23%) and Granulated Salting (40.10%). Granulated salting show the highest crude protein content (32.40%), significantly ($p<0.05$) higher than Brining (28.47%), while Kench (30.30%) falls in between. Brining exhibits the highest crude fat content (9.20%), which is significantly higher than that of both Kench (8.63%) and Granulated Salting (7.80%). Granulated Salting has the highest ash content (15.77%), followed by Kench (14.50%), while Brining shows the lowest (12.70%). There is no significant difference in crude fiber content between Kench (0.66%) and Brining (0.60%), both of which are lower than Granulated Salting (0.77%). Granulated Salting has the highest pH (6.47), followed by Kench (6.20%), with Brining having the lowest pH (5.90).

Table 2: Mineral Composition (mg/kg) of Fish Preserved by Kench, Brining, and Granulated Salting

Mineral Parameter	Kench	Brining	Granulated Salting	LOS
Sodium (Na)	2400.00 ± 10.00^{c}	2800.00 ± 10.00^{b}	3500.00 ± 10.00^{a}	*
Potassium (k)	420.00 ± 5.00^{a}	390.00 ± 5.00^{c}	410.00 ± 5.00^{b}	*
Calcium (Ca)	180.00 ± 5.00^{b}	160.00 ± 5.00^{c}	200.00 ± 5.00^{a}	*
Iron	$14.97\pm.15^{b}$	12.13 ± 0.21^{c}	16.00 ± 0.20^{a}	*
Zinc	10.00 ± 0.10^{b}	8.87 ± 0.15^{c}	11.00 ± 0.20^{a}	*

Means values in the same row having different superscript are significantly different *($p<0.05$), LOS: level of significant

Table 2 presents the results of mineral composition (mg/kg) of fish preserved by kench, brining, and granulated salting. A statistically significant difference was observed among the preservation methods. Granulated salting (3500.00 mg) exhibited the highest sodium content ($p < 0.05$), followed by brining (2800.00 mg) and kench (2400.00 mg). The potassium content was significantly ($p<0.05$) higher in kench (420.00 mg) compared to brining (390.00 mg) and granulated salting (410.00 mg) ($p < 0.05$). Calcium levels were significantly higher in granulated salting (200.00 mg) compared to brining (160.00 mg) and kench (180.00 mg) ($p < 0.05$). Granulated salting (94.67 mg) demonstrated significantly higher magnesium content compared to brining (80.00 mg), while kench (90.00 mg) was intermediate ($p < 0.05$). Iron content was significantly higher in granulated salting (16.00 mg) than in brining (12.13 mg) and kench (14.97 mg) ($p < 0.05$). Similarly, zinc levels were significantly higher in granulated salting (11.00 mg) compared to brining (8.87 mg) and kench (10.00 mg) ($p < 0.05$).

Table 3: Microbial Isolate and Count in Fish Preserved by Kench, Brining, and Granulated Salting

Microorganism	Kench	Brining	Granulated Salting
Staphylococcus aureus	+++	++	+
Pseudomonas aeruginosa	+++	++	+
S. epidermis	++	+	+
Streptococcus spp.	+	–	––
Escherichia coli	++	–	–
Micrococcus luteus	+++	+	–
Bacillus subtilis	++	+	–
Aspergillus spp.	++	+	–
Penicillium spp.	++	+	–
Fusarium spp.	+	–	–

Legend Key: +++: High prevalence, **++**: Moderate prevalence, **+**: Low prevalence, –: Not detected, **––**: Absent

Table 3 presented the Microbial Isolate and Count in Fish Preserved by Kench, Brining, and Granulated Salting. Kench exhibited the highest overall microbial load with significant counts of *S. aureus, P. aeruginosa,* and *Micrococcus luteus* (indicated by +++). Brining demonstrated a moderate microbial load. While it still retained a number of pathogenic bacteria, including *S. aureus* and *P. aeruginosa* (both ++), the counts were lower compared to Kench. Granulated Salting displayed the lowest microbial load across all examined microorganisms, demonstrating that this method effectively minimized microbial survival. Notably, many bacterial and fungal isolates showed low to no presence (indicated by + or –).

The Bacteria isolate are *S. aureus* and *P. aeruginosa*: Both were present in high counts in Kench (+++) and moderate counts in Brining (++), indicating that these methods were less effective at controlling these pathogens. In contrast, Granulated Salting showed only trace amounts (+), suggesting it significantly reduced the risk of foodborne illnesses associated with these bacteria. *S. epidermis* and *B. subtilis*: Present in Kench and Brining, but their counts diminished in Granulated Salting. This decrease reinforced the effectiveness of Granulated Salting in reducing not only harmful pathogens but also other bacterial populations. *E. coli* was detected in Kench (++) but absent in both Brining and Granulated Salting. This result indicated a critical improvement in sanitation and safety of the preserved fish when employing brining or granulated methods.

The Fungal Isolates were *Aspergillus spp.*, *Penicillium spp.*, and *Fusarium spp*. These were present in both Kench and Brining, indicating that these preservation methods did not sufficiently prevent fungal growth. In Granulated Salting, fungal presence was not detected, which indicated superior antifungal efficacy.

Table 4: Microbial Analysis of Fish Preserved by Kench, Brining, and Granulated Salting

Microbial Parameter	Kench	Brining	Granulated Salting	LOS
Total Plate Count (cfu/g) 10^3	2.3 ± 0.10^b	4.80 ± 0.10^a	1.60 ± 0.10^c	*
Yeast and Mold Count (cfu/g) 10^2	1.10 ± 0.10^b	2.00 ± 0.10^a	0.80 ± 0.10^c	*
Total Viable Bacterial Count (CFU/g)	$5.80\pm0.10^a\times10^5$	$1.26\pm0.11^c\times10^5$	$4.80\pm0.10^b\times10^3$	*
Total Viable Fungal Count (CFU/g)	$2.10\pm0.10^b\times10^4$	$6.3\pm0.10^a\times10^3$	Not Detected	*

Means values in the same row having different superscript are significantly different *($p<0.05$), LOS: level of significant

Microbial Analysis of Fish Preserved by Kench, Brining, and Granulated Salting are presented in table 4. Kench exhibited a significantly higher bacterial count compared to both Brining and Granulated Salting ($p < 0.05$). Brining also demonstrated a significantly higher bacterial count than Granulated Salting ($p < 0.05$). Granulated Salting displayed the lowest bacterial count, significantly different from both Kench and Brining. Kench exhibited a significantly higher fungal count than Brining ($p < 0.05$). Brining demonstrated a detectable fungal count while Granulated Salting had no detectable fungi, indicating a significant difference between Granulated Salting and both other methods ($p < 0.05$). Brining exhibited the highest total plate count, significantly different from both Kench and Granulated Salting ($p < 0.05$). Kench demonstrated a higher total plate count than Granulated Salting, which was significantly lower ($p < 0.05$). Brining exhibited the highest yeast count, significantly different from both Kench and Granulated Salting ($p < 0.05$). Kench demonstrated a higher yeast count than Granulated Salting, which exhibited the lowest count ($p < 0.05$).

Discussion of Results

Proximate Composition of Fish Preserved by Salting Methods

The study revealed that moisture content was highest in brined fish (52.60%), followed by kench salted fish (45.23%) and granulated salted fish (40.10%). These findings corroborate the research of Obiero *et al*. (2018), who reported a moisture content of 19.44% in normally packaged fish, and Oyekanmi *et al*. (2024), who observed a moisture content as low as 3.82% in smoked *Clarias gariepinus,* compared to 74.83% in fresh fish. The elevated moisture in brined fish is attributed to its milder salting process, while granulated salting induces greater water loss, thereby extending shelf life and altering the fish's texture.

Crude protein levels exhibited an inverse relationship with moisture content. Granulated salted fish demonstrated the highest protein content (32.40%), followed by kench salted (30.30%) and brined fish (28.47%). This observation aligns with Oyekanmi *et al*. (2024), who reported increased protein levels (57.05%) after smoking *Clarias gariepinus,* compared to

20.00% in fresh samples. Similarly, Oku and Amakoromo (2023) noted an increase from 18.4% in fresh fish to 52.5% in unsalted smoked fish. The increase in protein concentration is a consequence of moisture loss during salting, which reduces water content and increases the relative proportion of proteins.

Crude fat content varied among the samples: brined fish contained 9.20%, kench salted 8.63%, and granulated salted 7.80%. Sarwar *et al*. (2019) reported fat levels of 28.14% in sun-dried Hilsa shad, with salted samples exhibiting lower fat levels (13.67%). Obiero *et al*. (2018) observed 19.12% fat in salted fish. These variations are likely attributable to differences in fish species and drying methods. The reduction in fat content during salting may be due to the removal of surface oils during brining and dehydration in kench and granulated salting processes.

Ash content, an indicator of mineral concentration, was highest in granulated salted fish (15.77%), followed by kench salted (14.50%) and brined (12.70%). Oyekanmi *et al*. (2024) reported ash content ranging from 3.43% to 14.25% for smoked *Clarias gariepinus,* and Ayuba *et al*. (2019) observed significant increases in ash content using traditional processing methods. The higher ash content correlates with the dehydrating effect of salting, which reduces water content and increases the proportion of minerals in the fish.

Mineral Composition of Fish Preserved by Salting Methods

Sodium levels in fish varied significantly, ranging from 2,400 mg/kg in brined fish to 3,500 mg/kg in granulated salted fish. In contrast, Basak *et al*. (2023) reported much lower sodium levels, ranging from 51.85 mg to 58.10 mg in sun-dried tilapia. The elevated sodium content in granulated salted fish suggests that this method facilitates greater salt absorption and retention compared to sun-drying or lighter salting techniques.

Calcium levels ranged from 160 mg to 200 mg, with the highest concentration found in granulated salted fish. This finding contrasts with the results of Famurewa *et al*. (2017), who reported calcium levels of only 0.03 mg/kg to 0.15 mg/kg in fresh frozen fish. Sarwar *et al*. (2019) recorded a higher calcium content of 219.44 mg/100 g in raw Hilsa Shad, while Basak *et al*. (2023) reported extremely elevated calcium levels of 957.60 mg to 961.60 mg in sundried tilapia. These results suggest that drying methods, such as sun-drying, may better preserve calcium, likely because the bones remain intact.

Zinc levels ranged from 8.87 mg to 11.00 mg, with granulated salted fish exhibiting the highest concentrations. These values are significantly higher than those reported by Famurewa *et al*. (2017), which ranged from 0.19 mg/kg to 0.57 mg/kg in fresh frozen fish. Sarwar *et al*. (2019) observed zinc levels of 0.90 mg/100 g to 1.21 mg/100 g in Hilsa Shad, while Basak *et al*. (2023) documented zinc levels in sundried tilapia ranging from 12.30 mg to 12.80 mg. This indicates that while salted fish retains a substantial amount of zinc, sun-drying may preserve even higher levels.

Microbial Isolate and Count in Fish Preserved by Kench, Brining, and Granulated Salting

The study found that the Total Viable Bacterial Count (TVC) was 5.8×10^5 CFU/g for Kench, 1.2×10^5 CFU/g for Brining, and 4.8×10^3 CFU/g for Granulated Salting. These results align with the findings of Dinrifo (2024), who reported TVC levels ranging from 4.50×10^5 to 3.08×10^7 CFU/g, depending on salt concentration and temperature. The lower TVC observed in Granulated Salting suggests more effective microbial control compared to the higher counts in Kench and Brining. Buba *et al*. (2021) also reported elevated TVC levels in B. nurse fish, further demonstrating the effectiveness of Granulated Salting. Staphylococcus aureus was most prevalent in Kench (+++), while Granulated Salting exhibited the lowest prevalence (+). This supports the findings of Yassan *et al*. (2022) and Ali *et al*. (2021), who also detected S. aureus in processed fish. Pseudomonas aeruginosa was present in all treatments, consistent with Yassan *et al*. (2022), highlighting its resilience. Escherichia coli was found only in Kench (++), and its absence in Brining and Granulated Salting indicates that higher salt concentrations are more effective at inhibiting coliform bacteria.

Fungal species, such as Aspergillus spp. and Penicillium spp., were identified in Kench and Brining but not in Granulated Salting. This finding is consistent with Salaudeen and Osibona (2018), who reported lower fungal contamination in high-salt fish preservation. Yeast and mold counts were recorded at 1.10 for Kench, 2.00 for Brining, and 0.80 for Granulated Salting, with Granulated Salting demonstrating superior microbial control. Kench exhibited high microbial loads, particularly for Staphylococcus aureus and Pseudomonas aeruginosa, which aligns with the observations of Fuentes *et al*. (2011), who found that traditional dry salting methods resulted in elevated microbial counts. This may be attributed to the slower salt penetration observed in Kench. Brining displayed moderate microbial control, as noted by Leroi *et al*. (2017), but still permitted the growth of certain pathogens, such as S. aureus and P. aeruginosa, highlighting the necessity for additional safety measures (Møretrø *et al*., 2016).

Granulated salting demonstrated the best performance, exhibiting low bacterial and fungal counts. This supports the findings of Karami *et al*. (2021), which indicate that fine salt granules provide superior surface coverage and microbial control. Similarly, Abdulla *et al*. (2020) reported a reduction in microbial populations using this method. Overall, granulated salting proved to be the most effective technique for reducing microbial loads, consistent with the research of Köse (2020), who found dry salting methods to be more effective than wet ones, and Patir *et al*. (2018), who observed enhanced fungal inhibition. These results align with the conclusions of Ozogul *et al*. (2017), which stated that dry salting techniques better control microbial growth by lowering water activity and creating an environment that is unsuitable for microorganisms.

Conclusion

The results of this study demonstrate the varying effectiveness of Kench, Brining, and Granulated Salting in preserving fish, with significant differences observed across several key parameters. Granulated Salting consistently emerged as the superior preservation method, exhibiting the highest levels of crude protein, ash, and most minerals, along with lower microbial counts. These findings indicate better preservation of fish quality, reduced lipid oxidation, and a lower microbial load. Brining, while effective in moisture retention and maintaining crude fat content, resulted in higher levels of protein degradation, lipid oxidation, and microbial counts, suggesting it may be less suitable for long-term preservation. Kench, while performing at an intermediate level, exhibited higher microbial loads and lower mineral retention compared to Granulated Salting.

Recommendations

Based on the findings, the following recommendations are made:

i. Granulated Salting is recommended as the preferred method for preserving Nile tilapia due to its superior ability to retain protein content, maintain biochemical stability, and effectively reduce microbial contamination.
ii. Further measures should be implemented to improve microbial control in Brining and Kench, such as optimizing salt concentrations or incorporating other preservation techniques like refrigeration or drying.
iii. Further Research studies are needed to explore the long-term effects of these salting methods on fish quality during storage and to assess their applicability to other fish species or food products.
iv. Educating consumers and food processors on the benefits of using granulated salting for fish preservation, highlighting its effectiveness in maintaining fish quality and safety.
v. Depending on the desired characteristics of the final product (e.g., moisture content, fat content), processors may choose different preservation methods. However, for the best overall quality and safety, Granulated Salting is recommended.

Limitations

This study was limited by several factors. First, the sample size of 27 Nile tilapia, while adequate for preliminary analysis, may not provide sufficient statistical power to generalize the findings to larger populations. The study focused on fish sourced from a single geographical location (Gubi Dam, Bauchi State, Nigeria), which may limit the applicability of the results to other regions with different environmental or fishing practices. Additionally, the study evaluated only three salting methods, potentially excluding other traditional or modern preservation techniques that may offer different outcomes in terms of biochemical, mineral, and microbial stability. Moreover, the microbial analysis was

limited to a select group of bacteria and fungi, leaving out other potential pathogens that could impact the safety and shelf life of the fish.

Areas for Future Study

Future research should explore a broader range of preservation methods, including modern techniques like vacuum packaging combined with salting or the use of natural preservatives such as herbal extracts, to compare their effects on the biochemical, mineral, and microbial quality of fish. Expanding the sample size and sourcing fish from diverse regions would enhance the generalizability of the findings. Additionally, more detailed microbial studies should be conducted to include a wider spectrum of pathogens, particularly those relevant to foodborne illnesses. Investigating the long-term effects of different salting methods on the sensory qualities of the fish, such as texture and flavor, would also provide valuable insights for optimizing preservation techniques. Finally, the health implications of sodium and other mineral content in salted fish products could be explored to ensure that the final product meets nutritional standards while minimizing health risks, such as hypertension.

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