Journal of Food Quality and Hazards Control 11 (2024) 157-165

Effects of Processing and Preservation Technologies on Keeping Quality of *Labeo rohita*: Attributes of Nutritional, Microbial and Sensory

M.S. Arefin [1], S. Akther [2], N. Rahman [2*], M. Begum [1], N. Sarwar [2]

1. Department of Applied Food Science and Nutrition, Chattogram Veterinary and Animal Sciences University (CVASU), Chattogram-4225, Bangladesh
2. Department of Food Processing and Engineering, Chattogram Veterinary and Animal Sciences University (CVASU), Chattogram-4225, Bangladesh

HIGHLIGHTS

- Freezing retained wholesomeness while drying manifested efficient proteins and fats.
- Freezing, sun drying as well as marinating preserved maximum mineral contents.
- Microwave technology demonstrated greater microbial reduction in processed fish.

Article type
Original article

Keywords
Nutritional Value
Fishes
Food Handling
Food Quality
Colony Count, Microbial

Article history
Received: 09 Mar 2024
Revised: 05 Jul 2024
Accept: 20 Sep 2024

Acronyms and abbreviations
CFU=Colony Forming Unit
TBC=Total Bacterial Count
TC=Total Coliforms

ABSTRACT

Background: Fishes being major sources of protein are susceptible to post-harvest losses. Appropriate processing and preservation makes food healthier, safer, tastier, and more shelf-stable. Therefore, an attempt was made to evaluate the effectiveness of different processing and preservation technologies on keeping quality of *Labeo rohita* (rohu fish), a widely found ray-finned species in South Asia that is important for aquaculture.
Methods: Raw fish fillets were subjected to different processing and preservation technologies including freezing, sun drying, mechanical drying, salting, microwave processing, and marinating to determine their effects on keeping quality. Consequently, sensorial attributes, proximate composition, mineral (calcium (Ca), iron (Fe), and zinc (Zn)) contents and microbiological analyses were carried out. Obtained data were analyzed statistically and compared using one-way analysis of variance (ANOVA) followed by Fisher's LSD test at 5% level of significance.
Results: The moisture, protein, fat, ash, and carbohydrate contents were 13.01-77.29, 8.62-52.57, 0.86-18.69, 1.34-12.72, and 1.13-27.22%, respectively in different processing and preservation technologies. Drying manifested to be the efficient method in terms of preserving proteins and fats while retention of sensory attributes was obtained in freezing. The contents of Ca, Fe, and Zn were 120.05-227.97, 0.54-1.14, and 0.72-2.04 mg/100 g, respectively. In addition, maximum retention of Zn, Fe, and Ca contents were observed in freezing, sun drying, and marinating, respectively. Furthermore, total bacterial count was in the range of 0-2.6×10^4 Colony Forming Unit (CFU)/g and no coliforms were detected in any of the raw and processed fish fillets. Results of microbiological study revealed that microwave processing is highly efficient to reduce microbial loads in processed fish.
Conclusion: Combination of different processing and preservation technologies might be useful to the efficient management of fishery resources. Therefore, further research into these combinations is essential to ensure that the nutritional value of fish is preserved.

* Corresponding author (N. Rahman)
E-mail: nahid@cvasu.ac.bd
ORCID ID: https://orcid.org/0000-0003-4797-2803

To cite: Arefin M.S., Akther S., Rahman N., Begum M., Sarwar N. (2024). Effects of processing and preservation technologies on keeping quality of *Labeo rohita*: attributes of nutritional, microbial and sensory. *Journal of Food Quality and Hazards Control*. 11: 157-165.

DOI: 10.18502/jfqhc.11.3.16587 Journal website: http://jfqhc.ssu.ac.ir

Introduction

Fish are well-known nutritious aquatic animals that belong to one of the most diverse animal groups known to humans. Fish and fishery products are valuable sources of essential nutrients and bioactive compounds such as long-chain omega-3 fatty acids, Docosahexaenoic Acid (DHA), Eicosapentaenoic Acid (EPA), fat-soluble vitamins (D and E), minerals (calcium (Ca), iodine (I), zinc (Zn), iron (Fe), and selenium (Se)), low-molecular-mass metabolites (anserine and taurine), and easily digestible proteins (Aubourg, 2018; Gormley et al., 2007; Rokicki et al., 2015; Venugopal, 2008). In addition, health benefits conveyed by regular consumption of fish and fishery products includes decreasing the risk of cardiovascular disease, facilitating infant's neurodevelopment, human fertility, strong bone, and teeth formation (Abraha et al., 2018).

Bangladesh is one of the major fish producing countries, producing a total of 43.84 t in 2018-2019 fiscal year, with inland open waters (capture) accounting for 28.19% (12.35 lakh t) and inland closed waters (culture) accounting for 56.76% (24.88 lakh t) of total production. Major carps are the most important species that supports freshwater fisheries in Bangladesh (DOF, 2020). However, among the major Bangladeshi carps *Labeo rohita* is mostly preferred rather than any other cultured fishes (Belton et al., 2011). Scientifically it belongs to the family *Cyprinidae* within the order of Cypriniformes and is commonly abundant in rivers and fresh water lakes or ponds. Moreover, faster growing rate along with the higher market price and greater feed utilization has made this species a potential candidate for the aquaculture in Bangladesh (FRSS, 2002). Apart from protein supplementation this sector has created diverse livelihood opportunities for millions of people as well as valuable earnings and revenue sources in Bangladesh (DOF, 2012).

However, fish is extremely perishable, resulting in severe post-harvest losses in each and every stages of the supply chain from harvesting to retail distribution. Spoilage proceeds as a series of complex enzymatic, bacterial, and chemical breakdown of protein, and fat contents (agent of rancidity and off-flavor) during prolong storage (EO et al., 2013). Thus, fish becomes unfit for human consumption within about 12 h of fishing at tropical temperatures, unless it is subjected to some form of processing or preservation technologies (Santos et al., 2013). In addition, the spoilage causes a net reduction in the amounts of nutrients potentially available for the consumers; which are creating a great concern for nutritional security and public health promotion (Daramola et al., 2007). Thus, food processors and fishermen are adopting several processing and preservation technologies such as freezing, salting, marinating, drying, etc. to preserve the storage quality as well as extending the shelf-life of the products. Improved processing, handling, transportation, and preservation strategies contribute to an increase in the shelf-life of fish products and also to avoid wastes and losses. However, comparative studies on quality parameters of inland fish species under various storage condition including icing, freezing, drying, etc. are limited in numbers (Dawson et al., 2018; Hematyar et al., 2018). Therefore, the study aimed to evaluate the effectiveness of different processing and preservation technologies on keeping quality of *L. rohita* to identify the efficient preservation methods.

Materials and methods

Fish samples

The sample size for this study was 35 samples of *L. rohita*, collected during the month of April to May, 2022. *L. rohita* (average weight: 1-1.2 kg) were obtained from a particular fish market in Chattogram, Bangladesh. They were kept in iced boxes and immediately transported to the laboratory where the experiment was carried out. Fish samples were eviscerated first to remove the visceral contents, washed with tap water, filleted, and cut into pieces. Fish fillets were then divided into seven groups for treatments, transferred to polyethylene bags, labeled, and then stored at -18 °C.

Processing and preservation technologies of fish fillets

-Freezing

L. rohita fish fillets were packed in polyethylene bags and frozen at -18±2 °C in a quick freezer (Singer BD-215-GL, USA). Frozen products were placed in a freezer chamber at -20 °C until evaluation. Frozen fillets were thawed in running water (25-26 °C) prior to analysis (Akinwumi, 2014).

-Sun drying

Fillets were exposed to direct sunlight for three consecutive days using a wire mesh dryer, tightly covered with mosquito nets to prevent flies, and other pests. During night time the drying rack was covered with plastic sheets to prevent the condensation of water. However, air temperature was maintained at 35-40 °C during sun drying (Msusa et al., 2017).

-Mechanical drying

For mechanical drying, *L. rohita* fillets were placed in a cabinet dryer (DC1000, Genlab, Cheshire, UK), maintained at 60 °C and dried to constant weight for 2-3 days. The products were removed from drying chamber and allowed to cool for 20 min. After that, dried fillets were packed in polyethylene zip-lock bags until further evaluation (Nyangena et al., 2020).

[DOI: 10.18502/jfqhc.11.3.16587]

-*Salting*

The fillets were salted with thin granular salt. The salt ratio used in this process was 25% of total mussel weight (Salt:Fish; 1:4). The fish fillets were then placed in a plastic jar and more salt were sprinkled over the top and bottom surface (Turan et al., 2007). Salted fish fillets were then stored at room temperature (25±5 °C) for further analysis.

-*Microwave processing*

Microwave processing of *L. rohita* fish fillets were carried out in a microwave oven (ME21K7010DS/AA, Samsung, South Korea) at 2450 MHz for 15 min (Ulusoy et al., 2019). Microwave processed fish samples were then stored at room temperature prior to further analysis.

-*Marinating*

L. rohita fish fillets were rubbed well with preservatives such as common salt (NaCl) (Salt:Fish; 1:3), vinegar (25 ml/kg fish), citric acid (Sunson, China) and Na-benzoate (Hawkins Inc., USA) (0.5 g/kg fish) and additives such as sugar (75 g/kg fish), turmeric powder (10 g/kg fish), and pepper (5 g/kg fish). The processed fish were then frozen at -18±2 °C (Sarwar et al., 2019).

Sensory analysis

Sensory analysis of the processed *L. rohita* were carried out by a group of experienced panelists consisting of equal men and women according to the method described by Islam et al. (2022). Processed and untreated cooked samples were presented to each of the panelists and asked to assess the basis of quality attributes such as color, firmness, taste, and overall acceptability using nine-point hedonic scales (9=like extremely; 8=like very much; 7=like moderately; 6=like slightly; 5=neither like nor dislike; 4=dislike slightly; 3=dislike moderately; 2=dislike very much; 1=dislike extremely).

Proximate analysis top of form bottom of form

The analysis of raw and processed *L. rohita* fillets were performed using the Association of Official Analytical Chemists (AOAC) procedure (AOAC, 2006). Moisture content was measured after drying in a vacuum oven (Nabertherm, Germany) at 100 °C and drying up to constant weight. Protein content was determined by Kjeldahl method which converts proteins and organic nitrogen to ammonia during decomposition to sulfuric acid (H_2SO_4; BASF, Germany) in the presence of a mercury-catalyzed mixture. Acid digestion became alkaline and ammonia was distilled off and titrated with standard acid. The percentage of nitrogen was determined and converted to protein using a factor (6.25). Fat analysis was performed by hydrolysis of the sample in a Soxhlet apparatus using hexane (Linde, Germany) as the extracting solvent. The extract was evaporated, dried, and weighed. Ash content was determined by igniting the samples in muffled furnace (Nabertherm, Germany) at 550 ºC until dull red converts to grayish white. Carbohydrate was calculated from the standard equation stated by Musaiger and D'Souza (2008).

$$\text{Carbohydrate } (\%) = 100 - ((\text{moisture} + \text{ash} + \text{protein} + \text{fat})\%)$$

Analysis of minerals

The determination of Ca, Fe, and Zn contents were carried out by using Atomic Absorption Spectrophotometry (AAS; AA-7000, Shimadzu, Japan). Digestion of the samples was done according to the method described by Bassey et al. (2014). Moreover, 0.5 g of the homogenized sample was placed in a digestion tube and pre-digested with 10 ml of concentrated nitric acid (HNO_3; Sigma-Aldrich, USA) at 135 °C until the liquid became clear. Next, 10 ml of HNO_3, 2 ml of hydrogen peroxide (H_2O_2; Sigma-Aldrich, USA) and perchloric acid ($HClO_4$; Sigma-Aldrich, USA) were added and the temperature was maintained at 135 °C for 1 h until the liquid became colorless. The digested liquors were skimmed off through Whatman no. 1 filter paper and diluted up to 25 ml with water. Concentrations of Fe, Zn, and Ca were determined by flame techniques in AAS with the help of calibration curve plotted from the standard solution of Ca, Fe, and Zn (Rubio et al., 2011).

Microbiological analysis

One g representative sample was obtained aseptically from all *L. rohita* fish fillets. The samples were grounded, and four-fold serial dilutions (10^{-1}-10^{-4}) of the homogenized samples were made using sterile Buffer Peptone Water (BPW; Sigma-Aldrich, USA). Fish samples were analyzed for Total Bacterial Count (TBC) and Total Coliforms (TCs). All microbial analyses were performed according to AOAC methods (AOAC, 2000). Aliquots of suitable dilutions were transferred separately to corresponding agar plates for TBC and incubated at 37 ºC for 48 h in incubator (GSP-9080 MBE, Shanghai, China). The results were calculated and expressed as Colony Forming Units (CFU)/g.

TC was also estimated by Most Probable Number (MPN) method described by Feng et al. (2002). Lauryl Tryptose Broth (LSB; Sigma-Aldrich, USA) was used as the selective growth medium for coliforms. Diluted aliquots were transferred to the test tubes containing LSB broth with Durham's tube and grouped into 3 divisions based on (10^{-1}-10^{-3}) inoculums and further incubated at 37 ºC for 48 h in incubator. Gas-producing tubes were marked and recorded and thus TC were calculated by using the MPN chart from bacteriological analytical manual (FDA, 1992).

[DOI: 10.18502/jfqhc.11.3.16587]

Statistical analysis

Each analysis was carried out in triplicates. Obtained data were stored in Microsoft Excel, 2010 and the significant differences were determined by one-way analysis of variance (ANOVA) followed by Fisher's LSD test using Minitab Statistical Software (Version: 19.1.1 0; Minitab, Ltd. United Kingdom). In addition, Kruskal-Wallis test was applied to evaluate differences in sensory attributes (color, firmness, taste, and overall acceptability) among different samples of food, such as raw and processed fish. The level of significance was measured at the level of $p<0.05$.

Results

Sensory attributes

The results of sensory attributes are illustrated in Figure 1. The degree of acceptance of the sensory attributes such as color, firmness, taste, and overall acceptability varied from 5.40 to 8.93, 6.73 to 8.88, 5.73 to 8.71, and 5.60 to 8.72, respectively. Significant differences ($p<0.05$) were observed in all the sensory attributes as fillets of *L. rohita* were subjected to different processing and preservation technologies.

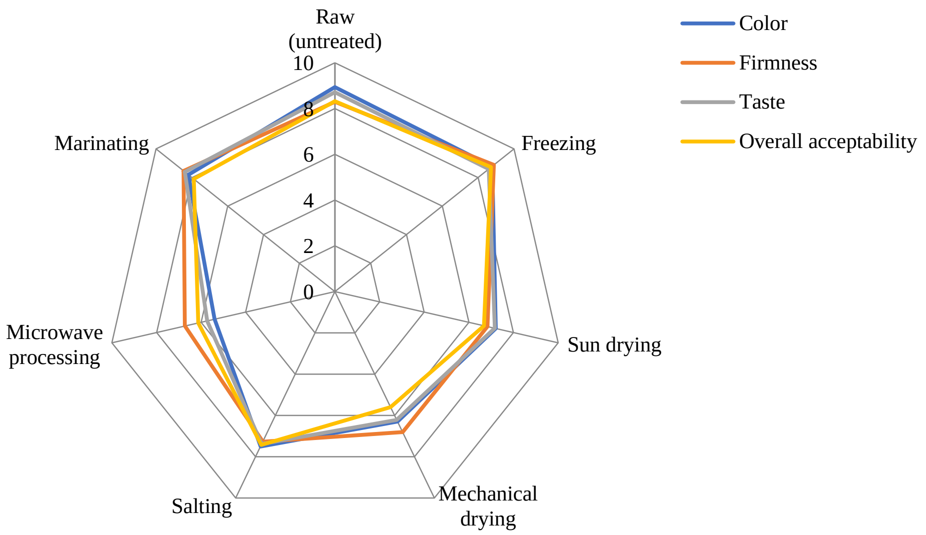

Figure 1: Effect of processing technologies on the sensory attributes in *Labeo rohita*

Proximate composition

Proximate composition of raw (untreated) and processed *L. rohita* fillets are presented in Table 1. Moisture, protein, fat, ash, and carbohydrate contents were in the range of 13.01-77.29, 8.62-52.57, 0.86-18.69, 1.34-12.72, and 1.13-27.22%, respectively in different processing and preservation methods.

Table 1: Proximate composition of *Labeo rohita* in processing and preservation technologies

Treatments	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
Raw (Untreated)	73.72±0.76 ^{b}	17.14±0.59 ^{e}	5.69±0.46 ^{e}	2.31±0.18 ^{d}	1.13±0.73 ^{e}
Freezing	77.29±0.42 ^{a}	18.54±0.43 ^{d}	0.86±0.05 ^{f}	1.34±0.11 ^{e}	1.96±0.07 ^{e}
Sun drying	15.76±0.68 ^{f}	34.12±0.59 ^{c}	18.69±0.49 ^{a}	4.21±0.06 ^{b}	27.22±0.85 ^{a}
Mechanical drying	13.01±0.41 ^{g}	52.57±0.45 ^{a}	14.28±0.36 ^{b}	4.06±0.13 ^{b}	16.08±1.07 ^{b}
Salting	55.18±0.31 ^{d}	17.47±0.37 ^{e}	8.83±0.23 ^{d}	12.72±0.36 ^{a}	5.79±0.79 ^{d}
Microwave	17.46±0.40 ^{e}	48.57±0.76 ^{b}	14.15±0.22 ^{b}	2.99±0.14 ^{c}	16.78±1.19 ^{b}
Marinating	66.61±0.33 ^{c}	8.62±0.34 ^{f}	12.98±0.25 ^{c}	2.34±0.13 ^{d}	10.36±0.36 ^{c}

*****Values are presented as mean±Standard Deviation (SD). Different superscripted lower-case letters in the samecolumn indicate significant difference ($p<0.05$).

Mineral contents

The mineral contents of raw and processed *L. rohita* fillets are depicted in Table 2. The contents of Ca, Fe, and Zn varied from 120.05 to 227.97, 0.54 to 1.14, and 0.72 to 2.04 mg/100 g, respectively. The results showed that mineral contents of fish fillets were significantly affected by different processing and preservation methods. All the processed samples exhibited significantly decreased levels of the mineral contents compared to control ($p<0.05$).

[DOI: 10.18502/jfqhc.11.3.16587]

Microbial analysis

The result of TBC and TC of raw and processed *L. rohita* fillets are presented in Figure 2. The TBC of raw *L. rohita* was reported 2.6×10^4 CFU/g while it ranged from 0 to 1.3×10^4 CFU/g in different processing and preservation technologies. Furthermore, no coliforms were detected in any of raw and processed fish fillets.

Table 2: Mineral contents of *labeo rohita* with different processing and preservation technologies

Treatments	Calcium (Ca) (mg/100 g)	Iron (Fe) (mg/100 g)	Zinc (Zn) (mg/100 g)
Raw, untreated	227.97±2.49 ^{a}	1.14±0.05 ^{a}	2.04±0.04 ^{a}
Freezing	137.61±2.43 ^{d}	0.94±0.01 ^{bc}	1.83±0.06 ^{b}
Sun drying	150.39±1.21 ^{c}	1.01±0.02 ^{b}	1.13±0.02 ^{c}
Mechanical drying	120.05±1.66 ^{f}	0.84±0.03 ^{d}	1.02±0.03 ^{d}
Salting	139.54±0.73 ^{d}	1.00±0.09 ^{bc}	1.13±0.02 ^{c}
Microwave	134.25±0.56 ^{e}	0.54±0.04 ^{e}	0.72±0.04 ^{e}
Marinating	199.78±0.61 ^{b}	0.93±0.03 ^{c}	1.07±0.07 ^{cd}

*****Values are presented as mean±Standard Deviation (SD). Different superscripted lower-case letters in the same column indicate significant difference (p<0.05).

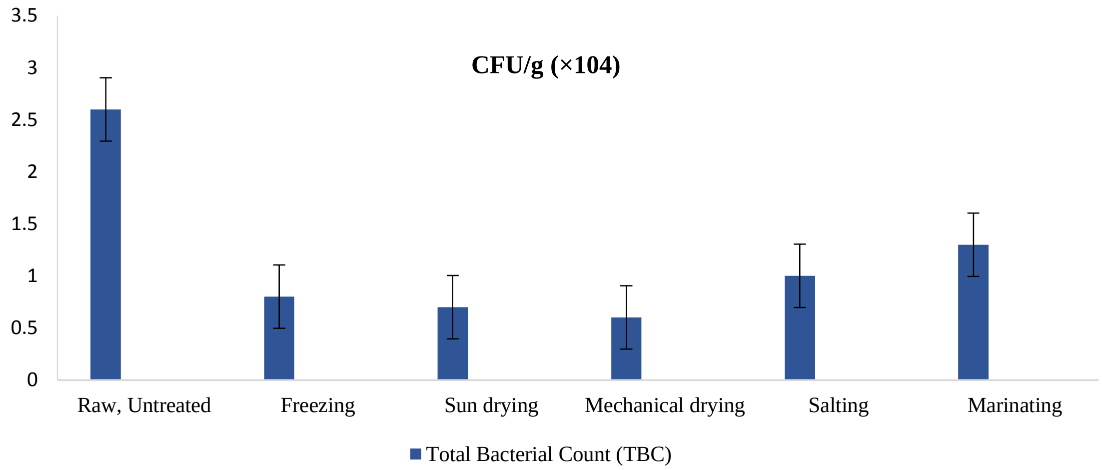

Figure 2: Microbiological quality of raw and processed *Labeo rohita* in different processing and preservation technologies

Discussion

Sensory aspects are essential for determining the quality of any food product. Several factors including raw materials, technological food processes can exert both positive and negative sensorial impacts. However, results showed that freezing followed by marinating as well as salting preserved excellent sensory properties of *L. rohita* irrespective of other processing technologies. Freezing induces reduced water-holding capacity in fish muscle and results in firm texture, uncompromised color, and taste. However, the result is in line with Aidani et al. (2014) where they have concluded that domestic freezing significantly improves the texture, juiciness, color, and aroma of meat product. In addition, overall acceptability of *L. rohita* fillets was more pronounced in freezing, due to the reduced enzymatic reactions held in between the storage period. The sensory score of fishery product at the freezing temperature (-18 °C) obtained by Ali et al. (2019) also showed good sensory characteristics as well as overall acceptability.

In contrast, microwave processed *L. rohita* had the lowest degree of color, firmness, and produce heavy burnt taste compared to raw fish. This could be due to the lack of uniform heating, thus the product loses its natural color and becomes very brittle. Previous studies regarding the impact of microwave processing on the sensory attributes also showed similar drawbacks (Contreras et al., 2017). Furthermore, mechanical drying also imparts least sensory ratings in firmness and overall acceptability of *L. rohita* fillets. The lowest level of firmness was also reported in sun-dried fish. Thermal processes including drying may cause profound physical and chemical alterations which influenced to the reduction in the firmness and overall acceptability of the processed fish. However, similar results were also reported by Ajifolokun et al. (2018). They revealed that drying methods significantly impacted the

[DOI: 10.18502/jfqhc.11.3.16587]

consumer's preferences for aroma, appearance, color, taste, and overall acceptability of shrimps. Therefore, freezing manifested effective technology for preserving excellent sensory properties of *L. rohita* with regard to the retention of wholesomeness.

The highest moisture content of *L. rohita* was recorded in freezing (77.29±0.42%) while the least was reported in mechanical drying (13.01±0.41%). The reduction was attributed to the application of heat declining water activity within fish muscles. Fish with higher moisture content are very prone to microbial spoilage and oxidative degradation which consequently decreases the storage quality (Akintola et al., 2013). However, determined moisture contents were below 20% in both sun-dried and mechanical-dried fish fillets as recommended by Lilabati and Vishwanath (1996) to inhibit both bacterial and fungal growth. Thus, the lowest moisture content recorded in mechanical dried fish samples entailed a longer shelf-life than others.

The mechanical-dried fish fillet had the highest (52.57±0.45%) protein, while the lowest (8.62±0.34%) protein was reported in marinated fillets. The significant increase in protein levels is in agreement with the findings of Ullah et al. (2016) and Wu and Mao (2008). However, the increase was attributed to the dehydration of water molecules present within the protein matrices, which might have aggregated or concentrated proteins (Salán et al., 2006). On the contrary, interactions between the components of additives/preservatives and protein molecules could be associated with the reduced protein in fish fillets, which is also supported by Ali et al. (2022).

The highest fat content of the processed *L. rohita* fillet was recorded in sun drying (18.69±0.49%), while the lowest was in freezing (0.86±0.05%). Similar results were also observed by Akintola et al. (2013) in sun dried giant tiger shrimp (*Penaeus monodon*). Reduction in moisture content owing to drying and heat processing increased the concentration of fat in fish fillets (Akintola et al., 2013; Chukwu, 2009; Chukwu and Shaba, 2009). However, reduced fat content in processed fish can occur due to the evaporation of moisture, which may also carry some volatile lipids along with it as reported by Akintola et al. (2013) and Immaculate et al. (2012). Furthermore, reducing water activity can affect the stability of lipids, potentially leading to oxidative changes over time. The formation of ice crystals during freezing, which disrupt cell structures and thereby some fat may be lost during thawing.

The ash content is an indicator of the total minerals present in fish. The highest ash content of *L. rohita* fillet was recorded in salting (12.72±0.36%) followed by the lowest in freezing (1.34±0.11%). Salting enhances ash content due to the increased concentration of minerals that occurs during salting process. Salt not only acts as a preservative but also interacts with natural minerals of fish, thereby concentrating them. However, although freezing is effective for preserving the freshness of fish, it does not alter the mineral content significantly. The lower ash content in frozen fillets suggests that freezing does not enhance mineral concentration like salting does. This observation is in agreement with Akintola et al. (2013) and Kumar et al. (2017) who reported that increase in ash content is predominant when fish are salted and mechanically dried.

Carbohydrates in fish, though typically low, can vary significantly depending on processing methods. In this context, the notably high carbohydrate content in sun-dried fish fillets (27.22±0.85%) compared to raw fish (1.13±0.73%) suggests that drying not only preserves the fish but also alters its nutrient profile. Obtained results are in agreement with the result published by Abeni et al. (2015). Higher carbohydrate levels in sun-drying might be attributed to the concentration of nutrients as water content decreases. Additionally, during drying, certain biochemical changes may enhance the availability of carbohydrates, possibly from glycogen stored in the fish. The findings also indicate that mechanically dried and microwave-processed fish fillets showed similar carbohydrate levels, suggesting that these methods do not significantly affect carbohydrate retention compared to sun-drying. However, low carbohydrate content in raw fish and non-significant differences observed in frozen and untreated fish suggest that natural carbohydrate levels in fish are minimal. This underlines the importance of processing techniques in enhancing or preserving specific nutrient profiles.

The highest Ca content of *L. rohita* was recorded in untreated raw samples (227.97±2.49 mg/100 g), while the lowest was reported in mechanical drying (120.05±1.66 mg/100 g). Obtained Ca content in raw *L. rohita* was lower than that of 291.02 mg/100 g reported by Zaman et al. (2014). However, all processing and preservation technologies have reduced the Ca content and the negative effect is attributed to the loss of water soluble nutrients owing to drying and salting. Drying can disrupt the cellular structure of fish, making it easier for nutrients to leach out during processing and preservation. Moreover, when fish is salted, especially during brining, the solutes (like salt) draw out moisture, taking some nutrients with them. Besides, findings of the present study are in accordance with the results published by Mphande and Chama (2015).

The untreated raw (1.14±0.05 mg/100 g) fish fillet had the highest Fe content followed the lowest in microwave processing (0.54±0.04 mg/100 g). Obtained Fe content of untreated *L. rohita* was higher than 0.88 mg/100 g reported by Zaman et al. (2014). In addition, thermal destruction followed by oxidation of water soluble nutrients might have reduced Fe content in all the processed fish fillets.

[DOI: 10.18502/jfqhc.11.3.16587]

Thermal processing can lead to changes in food matrix and nutrient interactions that reduce the bioavailability of Fe. Oxidation processes further complicate this by creating less accessible forms of Fe and potentially interacting negatively with other nutrients that aid in Fe absorption. However, the results are in agreement with the results published by Bassey et al. (2014). Similarly, the highest Zn content of *L. rohita* fish fillet was also recorded in untreated raw samples (2.04±0.04 mg/100 g) followed by the lowest in microwave processing (0.72±0.04 mg/100 g). The concentrations of Zn in raw and all the processed fish samples were within the permissible limit (<10 mg/100 g) as recommended by Karayakar et al. (2022). However, the reduction of mineral content might be attributed to exudation or discharge. Furthermore, they might be oxidized or reduced to different forms under heating. Similar trends were also observed by Bassey et al. (2014), where they have opined that heat processing caused 5.1% decrease in the Zn concentration of *Cynoglossus senegalensis* species.

The study also indicates that processing and preservation technologies significantly reduce TBC. The highest TBC observed was in untreated raw samples (2.6×10^4 CFU/g), followed by samples treated with marinating (1.3×10^4 CFU/g), salting (1.0×10^4 CFU/g), freezing (0.8×10^4 CFU/g), sun drying (0.7×10^4 CFU/g), mechanical drying (0.6×10^4 CFU/g), and microwave processing, which showed no detectable TBC. The reduction of microbial contamination during microwave heating is attributed to the polarization effect of electromagnetic radiation. Additionally, high temperatures during drying effectively kill more microorganisms, preventing their growth. These findings align with the results reported by Sarwar et al. (2019).

Consequently, absence of TC in raw and processed *L. rohita* fish fillets indicates that no pre and post-processing contamination has occurred. However, the findings are within the acceptable limit ($\leq5.0\times10^5$ CFU/g) of total bacterial counts as recommended by International Commission on Microbiological Specification for Food (ICMSF, 1986). Similar results were also obtained by Salaudeen and Osibona (2018), where reduced bacterial count was reported in smoked catfish. Therefore, processing resulted in microbiologically accepted final products in this study.

Conclusion

Comparison of raw and processed *L. rohita* showed that there were significant effects of the processing technologies on fillets in relation to their sensorial attributes, proximate composition, mineral contents and microbiological properties. Among the methods, sun drying and mechanical drying could provide a relative nutritional stability for fillets and also enabled the fish to provide higher percentage of protein, fats, carbohydrates, minerals (Fe), and reduced moisture. Freezing preserved excellent sensory properties and higher percentage of minerals (Zn). In regards to microbiological quality, microwave processing yielded least bacterial count along with no coliforms. However, salting increased ash content in the processed fillets while addition of additives and preservatives yielded maximum mineral (Ca) contents. Therefore, use of appropriate and affordable processing technologies could result in the production of superior quality products, beyond satisfying the consumers. Future studies should focus more onto the potential hazards associated with the fish in different processing and preservation technologies.

Author contributions

S.A. and N.S. designed the study; M.S.A. conducted the experimental work; M.B. analyzed the data; N.R. wrote the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

There is no conflict of interest in the study

Funding

The authors are highly thankful to Ministry of Science and Technology (MOST), Government of the People's Republic of Bangladesh for financing this research work.

Ethical consideration

There were no human subject experiments in the study

References

Abeni A.A., Ibiyinka O., Funmilayo C.F. (2015). Effect of processing on the nutritive value of *Clarias gariepinus* from Isinla fish pond, Ado Ekiti, Nigeria. *American Journal of BioScience*. 3: 262-266. [DOI: 10.11648/j.ajbio.20150306.19]

Abraha B., Admassu H., Mahmud A., Tsighe N., Shui X.W., Fang Y. (2018). Effect of processing methods on nutritional and physico-chemical composition of fish: a review. *Food Processing and Technology*. 6: 376-382. [DOI: 10.15406/mojfpt.2018.06.00191]

Aidani E., Aghamohammadi B., Akbarian M., Morshedi A., Hadidi M., Ghasemkhani N., Akbarian A. (2014). Effect of chilling, freezing and thawing on meat quality: a review. *International Journal of Biosciences*. 5: 159-169. [DOI: 10.12692/ijb/5.4.159-169]

Ajifolokun O.M., Basson A.K., Osunsanmi F.O., Zharare G.E. (2018). Effects of drying methods on quality attributes of shrimps. *Journal of Food Processing and Technology*. 10: 772. [DOI: 10.4172/2157-7110.1000772]

Akintola S.L., Brown A., Bakare A., Osowo O.D., Bello B.O. (2013). Effects of hot smoking and sun drying processes on nutritional composition of giant tiger shrimp (*Penaeus monodon*, fabricius, 1798). *Polish Journal of Food and Nutrition Sciences*. 63: 227-237. [DOI: 10.2478/v10222-012-0093-1]

Akinwumi F.O. (2014). Effects of smoking and freezing on the nutritive value of African mud catfish, *Clarias gariepinus* Burchell, 1822. *Journal of Agricultural Science*. 6: 143-149. [DOI: 10.5539/jas.v6n11p143]

Ali A., Wei S., Ali A., Khan I., Sun Q., Xia Q., Wang Z., Han Z., Liu Y., Liu S. (2022). Research progress on nutritional value, preservation and processing of fish—a review. *Foods*. 11: 3669. [DOI: 10.3390/foods11223669]

Ali M., Imran M., Nadeem M., Khan M.K., Sohaib M., Suleria H.A.R., Bashir R. (2019). Oxidative stability and sensoric acceptability of functional fish meat product supplemented with plant− based polyphenolic optimal extracts. *Lipids in Health and Disease*. 18: 1-16. [DOI: 10.1186/s12944-019-0982-y]

Association of Official Analytical Chemists (AOAC). (2006). Official methods of analysis. 18th edition. AOAC International, Gaithersburg, USA. URL: https://www.researchgate.net/publication/292783651_AOAC_2005/link/56b1246508ae5ec4ed4878ab/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19. Accessed 1 August 2023.

Association of Official Analytical Chemists (AOAC). (2000). Official methods of analysis. 17th edition. Gaithersburg, USA. URL: http://kb.psu.ac.th:8080/psukb/bitstream/2553/1564/ 2/279542_app.pdf. Accessed 25 July 2023.

Aubourg S.P. (2018). Impact of high-pressure processing on chemical constituents and nutritional properties in aquatic foods: a review. *International Journal of Food Science and Technology*. 53: 873-891. [DOI: 10.1111/ijfs.13693]

Bassey F.I., Oguntunde F.C., Iwegbue C.M.A, Osabor V.N., Edem C.A. (2014). Effects of processing on the proximate and metal contents in three fish species from Nigerian coastal waters. *Food Science and Nutrition*. 2: 272-281. [DOI: 10.1002/fsn3.102]

Belton B., Karim M., Thilsted S., Murshed-E-Jahan K., Collis W., Phillips M. (2011). Review of aquaculture and fish consumption in Bangladesh. *The World Fish Center*. URL: http://hdl.handle.net/1834/24444.

Chukwu O. (2009). Influences of drying methods on nutritional properties of tilapia fish (*Oreochromis nilotieus*). *World Journal of Agricultural Sciences*. 5: 256-258.

Chukwu O., Shaba I.M. (2009). Effects of drying methods on proximate compositions of catfish (*Clarias gariepinus*). *World Journal of Agricultural Sciences*. 5: 114-116.

Contreras C., Benlloch-Tinoco M., Rodrigo D., Martínez-Navarrete N. (2017). Impact of microwave processing on nutritional, sensory, and other quality attributes. In: Regier M., Knoerzer K., Schubert H. (Editors). The microwave processing of foods. 2nd edition. Woodhead Publishing, Sawston, United Kingdom. pp: 65-99. [DOI: 10.1016/B978-0-08-100528-6.00004-8]

Daramola J.A., Fasakin E.A., Adeparusi E.O. (2007). Changes in physicochemical and sensory characteristics of smoke-dried fish species stored at ambient temperature. *African Journal of Food, Agriculture, Nutrition and Development*. 7. [DOI: 10.18697/ajfand.17.1980]

Dawson P., Al-Jeddawi, W., Remington N. (2018). Effect of freezing on the shelf life of salmon. *International Journal of Food Science*. 2018. [DOI: 10.1155/2018/1686121]

Department of Fisheries (DOF). (2012). Fish fortnight compendium. Department of Fisheries, Ministry of Fisheries and Livestock, Government of Peoples Republic of Bangladesh.

Department of Fisheries (DOF). (2020). Yearbook of fisheries statistics of Bangladesh 2018-19. Fisheries Resources Survey System (FRSS), Department of Fisheries, Bangladesh, Ministry of Fisheries and Livestock. 36. URL: https://file-rangpur.portal.gov.bd/uploads/e9c5f421-3765-4473-91fc-a9ab3974cbd8//64e/2e7/458/64e2e7458f60d053864113.pdf. Accessed 25 July 2023

EO E.O.D., Ugwueze A.U., Igbegu H.E. (2013). Microbiological quality and some heavy metals analysis of smoked fish sold in Benin City, Edo State, Nigeria. *World Journal of Fish and Marine Sciences*. 5: 239-243. [DOI: 10.5829/idosi.wjfms.2013.05.03.7149]

Feng P., Weagant S.D., Grant M.A., Burkhardt W., Shellfish M., Water B. (2002). Enumeration of *Escherichia coli* and the coliform bacteria. *Bacteriological Analytical Manual (BAM)*. 13: 1-19.

Fisheries Resources Survey System (FRSS). (2002). Fishery statistical yearbook of Bangladesh 2001-2002. 19th edition. Fisheries Resources Survey System, Department of Fisheries, Bangladesh. URL:https://fisheries.portal.gov.bd/sites/default/files/files/fisheries.portal.gov.bd/page/4cfbb3cc_c0c4_4f25_be21_b91f84bdc45c/Statistical%20Year%20Book_2001-02.pdf. Accessed 25 July 2023.

Food and Drug Administration (FDA). (1992). Bacteriological analytical manual. 7th edition. AOAC International, Arlington, VA. URL: file:///C:/Users/admin/Downloads/FDA-1995-N-0063-0134_attachment_1.pdf. Accessed 25 July 2023.

Gormley T.R., Neumann T., Fagan J.D., Brunton N.P. (2007). Taurine content of raw and processed fish fillets/portions. *European Food Research and Technology*. 225: 837-842. [DOI: 10.1007/s00217-006-0489-4]

Hematyar N., Masilko J., Mraz J., Sampels S. (2018). Nutritional quality, oxidation, and sensory parameters in fillets of common carp (*Cyprinus carpio* L.) influenced by frozen storage (–20 °C). *Journal of Food Processing and Preservation*. 42: e13589. [DOI: 10.1111/jfpp.13589]

Immaculate J., Sinduja P., Jamila P. (2012). Biochemical and microbial qualities of *Sardinella fimbriata* sun dried in different methods. *International Food Research Journal*. 19: 1699-1703.

International Commission on Microbiological Specifications for Foods (ICMSF). (1986). Microorganisms in Foods 2. Sampling for microbiological analysis: principles and specific applications. 2nd edition. Blackwell Scientific Publications, London. URL: https://seafood.oregonstate.edu/sites/agscid7/ files/snic/ sampling-for-microbiological-analysis-principles-and-specific-applications-icmsf.pdf.

Accessed 25 July 2023.

Islam M.R., Baten M.A., Newaz A.W. (2022). Sensory and physico-chemical quality evaluation of traditional, improved and commercially dried *Puntius sophore*. *International Journal of Animal Resources*. 2: 52-61.

Karayakar F., Işık U., Cicik B., Canli M. (2022). Heavy metal levels in economically important fish species sold by fishermen in Karatas (Adana/TURKEY). *Journal of Food Composition and Analysis*. 106: 104348. [DOI: 10.1016/j.jfca.2021.104348]

Kumar G.P., Xavier K.A.M., Nayak B.B., Kumar H.S., Venkateshwarlu G., Balange A.K. (2017). Effect of different drying methods on the quality characteristics of *Pangasius hypophthalmus*. *International Journal of Current Microbiology and Applied Sciences*. 6: 184-195. [DOI: 10.20546/ijcmas.2017.610.024]

Lilabati H., Vishwanath W. (1996). Biochemical, nutritional and microbiological quality of three smoked fishes (*Wallago attu*, *Tor putitora*, *Puntius jayarami*) sold in the Imphal market, Manipur. *Journal of Fresh Water Biology*. 8: 217-223.

Mphande J., Chama L. (2015). Preservation methods and storage period affect the mineral and moisture composition of freshwater fish species. *International Journal of Food Science and Nutrition Engineering*. 5: 147-153. [DOI: 10.5923/ j.food.20150503.06]

Msusa N., Likongwe J., Kapute F., Mtethiwa A., Sikawa D. (2017). Effect of processing method on proximate composition of gutted fresh Mcheni (*Rhamphochromis species*) (Pisces: Cichlidae) from Lake Malawi. *International Food Research Journal*. 24: 1513-1518.

Musaiger A.O., D'Souza R. (2008). The effects of different methods of cooking on proximate, mineral and heavy metal composition of fish and shrimps consumed in the Arabian Gulf. *Archivos latinoamericanos de Nutrición*. 58: 103-110.

Nyangena D.N., Mutungi C., Imathiu S., Kinyuru J., Affognon H., Ekesi S., Nakimbugwe D., Fiaboe K.K.M. (2020). Effects of traditional processing techniques on the nutritional and microbiological quality of four edible insect species used for food and feed in East Africa. *Foods*. 9: 574. [DOI: 10.3390/foods9050574]

Rokicki J., Li L., Imabayashi E., Kaneko J., Hisatsune T., Matsuda H. (2015). Daily carnosine and anserine supplementation alters verbal episodic memory and resting state network connectivity in healthy elderly adults. *Frontiers in Aging Neuroscience*. 7: 219. [DOI: 10.3389/fnagi.2015. 00219]

Rubio C., Jalilli A., Gutiérrez A.J., González-Weller D., Hernández F., Melón E., Burgos A., Revert C. Hardisson A. (2011). Trace elements and metals in farmed sea bass and gilthead bream from Tenerife Island, Spain. *Journal of food protection*. 74: 1938-1943. [DOI: 10.4315/0362-028X.JFP-11-118]

Salán E.O., Galvão J.A., Oetterer M. (2006). Use of smoking to add value to the salmoned trout. *Brazilian Archives of Biology and Technology*. 49: 57-62. [DOI: 10.1590/S1516-89132006000100007]

Salaudeen M.M., Osibona A.O. (2018). Impact of smoking techniques and storage conditions on microbial safety and stability of catfish (*Clarias gariepinus*). *Ife Journal of Science*. 20: 345-353. [DOI: 10.4314/ijs.v20i2.15]

Santos J., Lisboa F., Pestana N., Casal S., Alves M.R., Oliveira M.B.P.P. (2013). Shelf life assessment of modified atmosphere packaged turbot (*Psetta maxima*) fillets: evaluation of microbial, physical and chemical quality parameters. *Food and Bioprocess Technology*. 6: 2630-2639. [DOI: 10.1007/s11947-012-0900-z]

Sarwar N., Ahmed T., Akther S. (2019). Effect of different processing and preservation methods on the quality of *Tenualosa ilisha* (Hilsa Shad) fish. *Journal of Advances in Food Science and Technology*. 6: 75-87.

Turan H., Sönmez G., Çelik M.Y., Yalçin M., Kaya Y. (2007). Effects of different salting process on the storage quality of Mediterranean mussel (*Mytilus galloprovincialis* L. 1819). *Journal of Muscle Foods*. 18: 380-390. [DOI: 10.1111/j.1745-4573.2007.00093.x]

Ulusoy Ş., Üçok Alakavuk D., Mol S., Coşansu S. (2019). Effect of microwave cooking on foodborne pathogens in fish. *Journal of Food Processing and Preservation*. 43: e14045. [DOI: 10.1111/jfpp.14045]

Ullah N., Hazarika P., Handique P.J. (2016). Biochemical quality assessment of ten selected dried fish species of North east India. *International Advanced Research Journal in Science, Engineering and Technology*. 3: 30-33. [DOI: 10.17148/ IARJSET.2016.3107]

Venugopal V. (2008). Marine products for healthcare: functional and bioactive nutraceutical compounds from the ocean. 1st edition. CRC press, Boca Raton. [DOI: 10.1201/ 9781420052640]

Wu T., Mao L. (2008). Influences of hot air drying and microwave drying on nutritional and odorous properties of grass carp (*Ctenopharyngodon idellus*) fillets. *Food Chemistry*. 110: 647-653. [DOI: 10.1016/j.foodchem.2008. 02.058]

Zaman M., Naser M.N., Abdullah A.T.M., Khan N. (2014). Nutrient contents of some popular freshwater and marine fish species of Bangladesh. *Bangladesh Journal of Zoology*. 42: 251-259. [DOI: 10.3329/bjz.v42i2.23367]

[DOI: 10.18502/jfqhc.11.3.16587]