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Assessment of Quality and Safety of Some Imported and Locally Sourced Fish in the Egyptian Markets

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Abstract

AS FISH is a crucial and diverse protein source in many diets, its high susceptibility to spoilage necessitates close attention to quality and safety. This study assessed the quality and safety of both imported and locally sourced fish found in Egyptian markets through physico-chemical, microbiological, and sensory analyses. While acceptable pH levels were observed across all samples, an alarming increase in ash content (except for frozen fish) was noted. Additionally, frozen, salted, canned, and smoked fish exceeded specific quality standards, particularly concerning smoked fish exceeding recommended limits. Although sensory evaluations deemed the organoleptic properties of most fish satisfactory, canned fish ranked highest, while salted fish fell short. Notably, the microbiological quality of some samples was concerning, suggesting potential lapses in sanitation and unsafe handling practices during processing and distribution.

Keywords: Fish quality, Fish microbiology, Fish composition, Spoilage.

Introduction

Global fish production reached a record high of 171 million tons in 2016, according to the 2018 FAO report. Aquaculture contributed almost half, or 47%, of this production, and when excluding non-food uses, it exceeded half (53%) [1]. Despite the advancements in fish farming, the highly perishable nature of fish and the increasing global food trade has created a vulnerable system. Poor quality, often originating from low-grade raw materials, can lead to product rejections [2, 3].

From a nutritional point of view, incorporating fish and shellfish into your diet offers numerous health benefits, particularly for children. Research suggests that the positive impact on heart health, promoting normal growth and development. Beyond being excellent sources of protein, vitamins, minerals, and essential omega-3 fatty acids, which make fish as a diet crucial for healthy brain development [4, 5]. Additionally, it is rich in essential amino acids like histidine, arginine, and proline, providing valuable building blocks for our bodies [6].

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Many countries› fisheries, processors, and traders operate under immense constraints – limited access to hi tech equipment, basic infrastructure, knowledge, and financial resources, especially in rural areas. This vulnerability, often compounded by information gaps and limited skills, increases the risk of unsanitary handling and processing practices. inconsequence, spoilage of fishery products, contamination with harmful bacteria, and economic losses due to reduced fish quality and lower prices [7]. Investing in capacity building, knowledge sharing, and access to suitable technologies can aid in these issues mitigation to ensure food safety and security and improve human life.

Recent foodborne disease outbreaks associated with fish eating have put pressure and regulations on food quality and safety [8]. Fish are recognized carriers of various health risks, harboring pathogenic microbes like *Salmonella* spp and *Vibrio* spp, along with fungi, parasites, mycotoxins, natural toxins, metals, and other contaminants [9]. Enteropathogenic *E. coli* is particularly concerning, causing severe diarrhea in children and food poisoning in adults [10]. *Salmonella*, for example, poses a serious public health risk by contaminating fish and causing food poisoning [11, 12]. Biochemical changes driven by enzymes and microbial activity significantly impact fresh fish stored on ice, while frozen fish experience quality loss through physical, chemical, and biochemical reactions.

Maintaining high-quality fish throughout the supply chain remains a principal concern for global industry [13]. Consumers prioritize aspects like safety, nutritional value, and convenience, which depend heavily on factors like origin, catching methods, and processing techniques [14, 15]. Beyond the obvious elements like species and size, the concept of "quality" encompasses a multifaceted range of considerations, including freshness, handling methods, and packaging. Addressing these diverse aspects across all stages of the fish industry is crucial in ensuring consumer satisfaction and market success [16].

The essence of quality lies in exceeding mere compliance and striking a balance between legal requirements, product consistency, and the dynamic expectations of consumers across different markets. Achieving this necessitates a flexible system that can adapt to the ever-changing landscape of consumer wants and needs [17, 18].

Evaluating fish quality effectively hinges on employing a range of tools, including sensory, chemical, physical, and microbiological assessments. In addition to techniques like volatile compound analysis, lipid oxidation measurement, and biogenic amine production monitoring offer valuable data [19], sensory evaluation retains its crucial role in determining freshness and overall quality. It serves as a complementary and crucial component of the fish quality assessment toolkit [20].

The Quality Index Method (QIM) offers a simple, fast, and reliable way to assess the length of storage period and help in predicting the shelf life of the product. This information is crucial for meeting consumer demands regarding freshness and quality, especially in the increasing demand on online seafood sales. Implementing QIM throughout the fish production chain can empower manufacturers to provide safe, high-quality, and nutritious fish products at competitive prices [21, 22].

This study investigated the quality and safety of imported and locally sourced fish and fish products found in Egyptian markets.

Material and Methods

Sample Collection

To assess the quality and safety of fish available in Egypt, 100 random samples were acquired from multiple markets across various governorates. The samples comprised smoked (24), salted (36), and canned fish (18), along with 22 frozen mackerel specimens. To ensure sample integrity, collection from dedicated retailers occurred with cooled transportation to the laboratory. The detailed analysis involved aseptically weighing 25g of each fish type, followed by sterile mincing in a mortar with 225mL buffered peptone water and brief blending, adhering to established procedures [23-25].

Preparation of serial dilution

For subsequent microbiological analysis, fish samples were serially diluted tenfold, starting with a 1:10 dilution and reaching a final dilution of 1:100,000. Each dilution step utilized 9 mL of buffered peptone water (Himedia®, India).

Culture media and reagents

This study employed selective medium culture media for bacterial detection. The aim is to evaluate the quality and safety of fish products in the markets. Coliforms are a group of enterobacteriacea, MacConkey broth selectively enriched *Escherichia coli* (*E. coli*), while Rappaport Vassiliadis R10 Medium targeted *Salmonella* spp. Buffered peptone water served as a general enrichment broth. For isolation, Xylose-Lysine Deoxycholate Agar (XLD) identified *Salmonella* spp, while Eosin Methylene Blue (EMB) and Levine agar differentiated and purified *E. coli*. Plate count agar determined the total viable bacterial count (TBC). All media were sterilized via autoclaving at 121°C for 15 minutes. (Hemedia® supplied all media.)

Analysis methods

Sensory evaluation

Sensory evaluation and instrumental techniques are indispensable in determining fish and fishery product safety. Nonetheless, when assessing spoilage and freshness, sensory evaluation proves predominantly reliable compared to alternative approaches [26]. Such judgment relies heavily on comprehensive physical inspection of diverse visual and tactile properties, which includes analyzing skin tone and integrity, observing eye radiance, and examining gills' texture and color [27, 28]. Collectively, applying these rigorous sensory tests enables experts to accurately gauge seafood quality, identify early signs of deterioration, and distinguish premium commodities from inferior ones.

Microbiological analysis

Psychrotrophic count

One milliliter of each previously prepared serial dilution was aseptically transferred using a sterile pipette into two separate sterile Petri dishes. Each dish received approximately 15 ml of sterile, melted, and tempered plate count agar (45°C), which was then gently swirled to mix with the sample. To ensure even solidification, the inoculated plates were rotated and left undisturbed at 7°C for 10 days. Following incubation in an inverted position, plates containing between 30 and 300 colonies were used to calculate the total psychrotrophic count/g as described in reference [29].

Total bacterial count (TBC)

The study employed the standard pour plate technique to quantify the total bacterial count (TBC). Diluted samples (10-3 and 10-4) were prepared, and 1 mL aliquots were poured onto solidified plate count agar (Himedia®, India) in Petri dishes. Thorough mixing ensured even distribution before incubation at 37°C for 48 hours. Following incubation, only plates containing 30-300 colonies were selected, enumerated, and recorded according to reference [30].

Total coliform count (TCC)

To estimate the overall coliform count in the samples, this study employed the MPN method. Serial dilutions (10^{-2}, 10^{-3}, and 10^{-4}) were prepared, and 1 mL from each dilution was inoculated into separate tubes containing MacConkey broth and inverted Durham's tubes [31, 32]. All tubes were incubated at 37°C for 48 hours. Only tubes showing acid and gas production within Durham's tubes were considered positive. The MPN formula was then used to calculate the most probable number of coliforms per milliliter of the original sample.

Isolation and identification of Bacteria from Sample fish

Escherichia coli

Over 24 hours, fecal *E. coli* presence was confirmed on MacConkey broth tubes (Himedia®, India) incubated at 44°C. Acidification and gas production within the tubes served as confirmation, followed by inoculation of the most probable number (MPN) into fresh broth as described by [33]. Characteristic colony morphology on EMB agar (Himedia®, India) solidified the *E. coli* identification. Strains exhibiting a distinctive greenish metallic sheen on semisolid agar were further preserved for characterization.

Salmonella spp.

Building upon reference [34], the study employed specific microbiological and analytical techniques to assess samples. A 1 mL culture aliquot was enriched in a selective R10 medium (HiMedia®, India) at 37°C for 24 hours. Subsequently, a loopful of the enriched culture was plated on XLD agar (HiMedia®, India) and incubated at 37°C for 24 hours for bacterial growth evaluation.

Determination of salt

For precise salt content determination, one gram of each sample was meticulously weighed and homogenized with 50 milliliters of distilled water. Standardized titration proceeded using 0.1N silver nitrate solution. The endpoint, marked by a subtle orange shift against the indicator's yellow, was achieved with 0.5-1 milliliter of 5% potassium chromate. Applying the conversion factor of 1 ml of 0.1N silver nitrate equaling 0.005845 grams of sodium chloride, the percentage of NaCl in each sample was calculated. Salt content determination followed established practices outlined [24].

Measurement of moisture, ash, fat, TDS, EC, and pH

Duplicate analyses were performed to determine the proximate composition (moisture, ash, and fat content) of all samples as outlined in reference [35]. TDS and EC are measured according to [24]. Following established protocols [36], five grams of each fish sample were homogenized in a ratio of 0.1% weight/volume (w/v) with fifty milliliters of distilled water using a laboratory blending apparatus. To determine the pH, a calibrated digital pH meterwas employed, with its electrodes carefully inserted into the homogenized mixtures. The calibration of the meter involved standard pH 4 and 7 buffer solutions, ensuring accurate measurements.

Statistical Analysis

To analyze the collected data, statistical methods were employed. Firstly, the average (mean) and standard deviation were calculated for all results. Subsequently, a one-way analysis of variance (ANOVA) was performed, followed by a General Linear Model (GLM) test at a significance level of $p \leq 0.05$ to assess variations between different sample values. The Duncan post hoc test was then utilized to identify specific differences between mean values. Data analysis was carried out using the Statistical Package for Social Science (SPSS) version 21.00 software. Notably, all experiments were conducted in triplicate to ensure data reliability.

Results

Physiochemical properties

Ash Contents

Where the ash content average was 7.15±2.32%. Smoked fish had the highest ash content (8.66%), followed by canned (7.10%), frozen (6.63%), and salted (6.21%). Statistical analysis revealed significant differences ($p \leq 0.05$) in ash content among all fish types, both within and between groups. Notably, smoked and canned fish exhibited the most significant differences compared to other types ($p \leq 0.05$) (Table 1).

Electronic Conductivity (EC (ds/m))

The average EC of all types was 11.83, and significant variations were observed. Notably, salted fish exhibited the highest EC (24.15), followed by smoked fish (9.08). Conversely, canned and frozen fish displayed the lowest readings (2.24 and 1.85, respectively). Statistical analysis confirmed significant differences between and within groups ($p \leq 0.05$). Notably, the EC of salted fish differed significantly from all other types ($p \leq 0.05$). Similarly, smoked fish showed significant differences compared to both canned and frozen varieties, which lacked significant differences themselves. These findings underscore the distinct impact of processing methods on fish EC, with salt leading to significant increases, likely due to elevated salt content (Table 1).

Moisture Content %

At 20.42%, frozen fish had the highest moisture content, followed by canned (14.28%) and smoked (13.07%) fish. Salted fish had the lowest moisture content (10.63%). Statistical analysis revealed significant differences among all fish types except smoked and salted, which showed no significant difference at the $p \leq 0.05$ level (Table 1).

pH value

Frozen fish displayed the highest average pH (6.65), while canned fish were the least acidic (5.67). Salted and smoked fish fell in between. Notably, all fish except frozen types fell within the acceptable pH range defined by EOS:2005 [37] for salted fish (6-6.5) and canned fish (6.7). This highlights the importance of monitoring pH levels to ensure fish quality and safety (**Table 1**).

Total dissolved Solids (TDS)

Table 1 shows among all fish samples, salted fish stood out with the highest TDS content, reaching 12.08 g/l. This value was triple the amount found in smoked fish (4.54 g/l) and even lower in canned fish, measuring only 1.12 g/l, again three times less than smoked fish. Frozen fish emerged with the lowest TDS, recording a mere 0.92 g/l. Statistically, salted fish held significantly higher TDS levels compared to all other types ($p \leq 0.05$), followed by smoked fish. Interestingly, no significant difference in TDS was observed between canned and frozen fish ($P \leq 0.05$).

Microbiological analysis results

Total bacterial count (TBC)

TBC for each fish type, expressed in colony-forming units per gram (CFU/g) multiplied by 10^3. The TBC values varied considerably, ranging from 2.1×10^4 to 4.23×10^5 in frozen fish (mean: 2.00×10^5), 1.1×10^4 to 4.02×10^5 in salted fish (mean: 9.03×10^4), 1.6×10^4 to 3.62×10^5 in smoked fish (mean: 1.02×10^5), and 2.1×10^4 to 4.7×10^5 in canned fish(mean: 1.85×10^5). Overall, TBC ranged from 1.1×10^5 to 4.7×10^5 CFU/g across all samples. Statistical analysis revealed significant differences ($p \leq 0.05$) in TBC between both frozen and canned fish compared to both salted and smoked fish (**Table 2**).

TABLE 1. The physiochemical properties of the fish types.

Fish Types	N	Ash% M±SD	EC (ds/m) M±SD	MC% M±SD	pH M±SD	TDS(g/L) M±SD
CANNED	6	7.10±1.286[a]	2.24 ±0.55[c]	14.28±3.83[b]	5.67±0.20[c]	1.12±0.27[c]
FROZEN	20	6.63±2.108[b]	1.85±0.23[c]	20.42±3.50[a]	6.65±0.72[a]	0.92±0.11[c]
SALTED	26	6.21±1.937[b]	24.15±4.25[a]	10.63±2.91[c]	6.14±0.28[b]	12.08±2.13[a]
SMOKED	23	8.66±2.430[a]	9.08±2.13[b]	13.07±3.93[b,c]	6.24±0.11[b]	4.54±1.07[b]
Mean total	75	7.15±2.317	11.83±9.88	14.28±5.19	6.27±0.49	5.92 ±4.94

The letters in the column indicate the mean difference is significant at the ≤0.05 level.

TABLE 2. Total Bacterial count TBC (CFU/g) of 'fish-type's samples.

Fish Types	N	Mean	SD	Minimum	Maximum
Frozen	22	$200*10^3$a	$153*10^3$	$21*10^3$	$423*10^3$
Salted	36	$903*10^2$b	$127*10^3$	$11*10^3$	$402*10^3$
Smoked	24	$102*10^3$b	$124*10^3$	$16*10^3$	$362*10^3$
Canned	18	$185*10^3$a	$166*10^3$	$21*10^3$	$470*10^3$
Total	100	$134*10^3$	$146*10^3$	$11*10^3$	$470*10^3$

The different letters in the column indicate the significant differences at the p≤0.05 level.

Total Coliform Count (TCC)

TCC for different fish types highlights significant variations. Frozen fish had the highest average TCC (5.18 x 10^2 CFU /g), while smoked fish held the lowest (2.22 x 10^1 CFU /g). Notably, statistically significant differences (p≤0.05) were evident between frozen fish and all other types, indicating a marked discrepancy in microbial burden. Conversely, no statistically significant differences were observed among salted, smoked, and canned fish, suggesting comparable TCC levels amongst these groups. (**Table 3**).

The different letters in the column indicate the significant differences at p ≤0.05 level.

The percentage of acceptable fish samples based on TCC. All frozen tilapia samples were found acceptable, while only 45% of frozen mackerel were within safe limits. Similarly, 33.3% of both salted small Sardine and Feseekh samples exceeded acceptable TCC levels. Notably, all salted Big Sardine and the lowest rate of unacceptable samples (16.7%) were observed in smoked Ringa. Among canned fish, 16.7% of Tuna samples fell short of the standard. Overall, 22.25% of all tested fish samples were deemed unacceptable based on TCC, as reported by [37] (**Figure 1**).

Psychotropic count

Table 4 presents the average psychrotrophic bacterial counts (CFU /g) in various fish samples. Frozen fish exhibited the highest average count (5.39x10^5), followed by salted (5.37x10^5), canned (1.94x10^5), and smoked (1.09x10^5) fish. The overall average across all types was 1.76x10^5 CFU/g. Statistical analysis revealed a significant difference (p ≤ 0.05) between the frozen fish count and the counts of all other types, highlighting a potentially higher level of contamination. However, no significant differences were found among salted, smoked, and canned fish, indicating similar bacterial levels in these categories.

Pathogenic bacteria

Among the fish samples analyzed, only two types of pathogenic bacteria were identified: Salmonella and *E. coli*. Notably, *Salmonella spp* was detected in a substantial number of samples (50, representing 50%), while *E. coli* was found in 45 samples (45%). This data reveals the concerning presence of these potential health risks in a large portion of the tested fish (**Table 5**).

TABLE 3. The Total coliform count TCC (CFU /g) of fish type's samples.

Fish Types	N	Mean	SD	Minimum	Maximum
Frozen	22	$5.18*10^{2a}$	$5.60*10^{2}$	0.00	$1.22*10^{3}$
Salted	36	$1.74*10^{2b}$	$3.55*10^{2}$	0.00	$1.15*10^{3}$
Smoked	24	$2.22*10^{1b}$	$9.38*10^{1}$	0.00	$4.60*10^{2}$
Canned	18	$1.91*10^{2b}$	$4.38*10^{2}$	0.00	$1.16*10^{3}$
Total	100	$5.18*10^{2}$	$5.60*10^{2}$	0.00	$1.22*10^{3}$

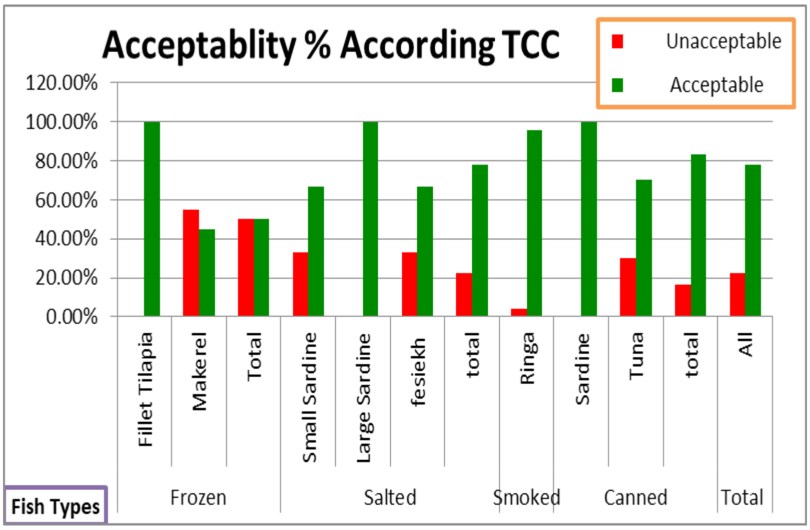

Fig.1. The rates of acceptability of fish types according to their TCC (CFU/g) based on the Egyptian Standards.

TABLE 4. The Psychotropic count (CFU/g) of fish type's samples

Fish Types	N	Mean	SD	Minimum	Maximum
Frozen	22	$5.39*10^{5}$a	$1.13*10^{6}$	0.00	$3.40*10^{6}$
Salted	36	$5.37*10^{4}$b	$1.14*10^{5}$	0.00	$3.52*10^{5}$
Smoked	24	$1.09*10^{4}$b	$3.59*10^{4}$	0.00	$1.75*10^{5}$
Canned	18	$1.94*10^{5}$b	$1.60*10^{5}$	$1.80*10^{4}$	$3.98*10^{5}$
Total	100	$1.76*10^{5}$	$5.67*10^{5}$	0.00	$3.40*10^{6}$

The different letters in the column indicate the significant differences at the $p\leq0.05$ level.

TABLE 5. The number and percentage of pathogenic bacteria in fish samples.

	Salmonella spp.	*E. coli*
Number of sample detection	50	45
Percentage	50%	45%

The Sensory analysis results

Sensory evaluation of various fish types revealed a range of scores. Color scores varied from 3.37 (salted fish) to 4.44 (canned fish), with an average of 3.77. Texture scores ranged from 3.11 (salted) to 4.39 (canned), averaging 3.74. Freshness scores generally surpassed other scores, except for salted fish (2.92, lowest) and canned fish (4.39, highest). Taste scores followed a similar pattern, ranging from 3.07 (salted) to 4.36 (canned), with an average of 3.71. Overall, canned fish scored highest in all sensory properties (mean: 4.40), followed by frozen and smoked (means: 3.95 and 3.94, respectively). Salted fish consistently scored lowest (mean: 3.12). Statistical analysis confirmed significant differences within and between groups at $p \leq 0.05$. Notably, canned fish significantly outperformed all other types in all sensory aspects, while salted fish scored significantly lower on all aspects (**Table 6**).

Regarding the overall sensory acceptability of different fish types, 82% of frozen fish and 83% of salted small sardines received "good" ratings, while the remaining samples in these categories were considered "medium". Both large sardines and Fesiekh (salted pickled fermented and dried gray mullet of the genus Mugil) exclusively received "medium" ratings. Smoked Ringa (the type of genus of the herring family Clupeidae) fish followed the pattern of frozen and small sardines, with 83% categorized as "good" and 17% as "medium". Canned sardines exhibited the broadest range of scores, with 25% considered "very good", 38% "medium", and 38% "good". Canned tuna fared better, with 44% achieving the highest "very good" rating, followed by 44% receiving "good" and 11% deemed "fair" (**Figure 2**).

While taste testers found all frozen, salted, smoked, and canned fish samples generally acceptable, statistical analysis revealed significant differences ($p<0.05$) in sensory evaluations across the various fish types examined in this study. This suggests subtle variations in sensory characteristics despite overall palatability.

TABLE 6. The sensory analysis results of fish types.

Fish Type		Color	Texture	Freshness	Taste	Mean all
Frozen	N	22	22	22	22	22
	Mean	3.82^{b}	3.97^{b}	4.03^{b}	3.95^{b}	3.94^{b}
	SD	0.39	0.34	0.39	0.15	0.31
Salted	N	36	36	36	36	36
	Mean	3.37^{c}	3.11^{c}	2.92^{c}	3.07^{c}	3.12^{c}
	SD	0.19	0.31	0.35	0.24	0.27
Smoked	N	24	24	24	24	24
	Mean	3.83^{b}	3.98^{b}	4.04^{b}	3.95^{b}	3.95^{b}
	SD	0.38	0.33	0.38	0.14	0.30
Canned	N	18	18	18	18	18
	Mean	4.44^{a}	4.39^{a}	4.39^{a}	4.36^{a}	4.40^{a}
	SD	0.64	0.75	0.76	0.90	0.76
Total	N	100	100	100	100	100
	Mean	3.77	3.74	3.70	3.71	3.73
	SD	0.54	0.66	0.76	0.65	0.64

Where: 1-1.9 = Unacceptable. 2-2.9= Fair, 3-3.9= Medium, 4-4.9 = Good and 5-6.0 =Very good. The different letters in the column indicate the significant differences between means at $P \leq 0.05$.

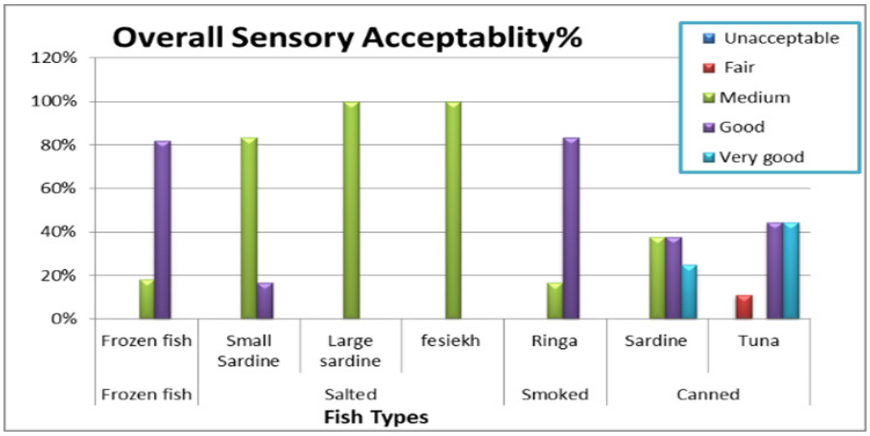

Fig. 2. The overall sensory acceptablity% of fish types.

Discussion

Physiochemical properties

A recent study compared the ash content of commercially prepared salted hilsa to this study's findings [38]. The commercially available samples from Lab, Boro bazar, Mechoya Bazar, and Kewatkhali bazar showed considerably higher ash content (10.21%, 14.23%, 14.91%, and 15.32%, respectively), exceeding this study's values by 2-2.5 times. This difference suggests that commercially prepared salted hilsa may undergo different processing techniques or incorporate additional ingredients, potentially affecting their compositional profile.

Smoked tuna (*Auxis thazard*) from Tuticorin, India, exhibited a remarkably high ash content of 6.6%, significantly exceeding the 4.13-5.56% observed in canned tuna, 4.71-5.19% in canned sardine, and 1.91-1.91% in canned mackerel [39, 40]. This variation across fish types and preparation methods suggests contributing factors like species differences, raw material sources, and processing methods, particularly the use of salt water.

The variations in electrical conductivity (EC) observed across different fish types are likely due to a combination of factors: varying salt concentrations, water content and hardness, specific fish species, and processing methods. These factors influence the charges and concentrations of ions within the fish, as seen in the fermentation process of salted fish and the addition of preservatives in canned fish, both of which impact conductivity.

The electrical conductivity (EC) of fish meat offers valuable insights into its microbial state, decomposition processes, and overall quality. Higher EC values correlate with increased microbial growth and diversity, as well as enzymatic activities responsible for breaking down proteins into amino acids, fats into fatty acids and glycerol, and carbohydrates into organic acids. Additionally, EC reflects the oxidation of fats and proteins, leading to the formation of compounds like ketones, aldehydes, alcohols, organic acids, and free radicals. Therefore, measuring EC provides a crucial tool for assessing fish quality and potential spoilage, ensuring the safety and integrity of seafood for consumers.

This study observed significantly higher moisture and ash content in commercially sourced salted hilsa compared to lab-prepared samples. Hilsa from Boro Bazar, Rajshahi (45.38% moisture, 14.23% ash), Mechoya Bazar, Mymensingh (45.73% moisture, 14.91% ash), and Kewatkhali Bazar, Mymensingh (47.82% moisture, 15.32% ash) all displayed noticeably higher values compared to the lab-treated hilsa (42.92% moisture, 10.21% ash) [38]. Similar disparities were found when comparing commercially smoked mackerel moisture content (58.1% - 59%) to our study's results (unpublished) [41]. This suggests potential variations in processing methods or ingredients used by commercial producers [42]. Previous research [39] reported a higher moisture content (16.20%) in smoked tuna compared to the present study's 13.07%. This potentially reflects water loss during heating during smoking [43].

Similarly, another study [44] observed significant moisture reduction in dry-salted, wet-salted, and sun-dried fish (71.80% to 37.06%, 44.90%, and 25.95%, respectively). The observed pH increase in our frozen samples likely stems from bacterial spoilage, leading to the formation of basic compounds like trimethylamine, ammonia, and other biogenic amines [45]. Additionally, microbial contamination and enzymatic activity releasing oxygen and hydrogen could have increased hydroxyl ion concentration, raising the pH [46]. A prior study assessed the microbiological quality of marine food from a Dammam, Saudi Arabia, fish market. Prawn TPC values above the acceptable margins, while total coliform counts exceed the limits in all examined samples.

The acidity (pH) of seafood significantly impacts microbial growth, with higher pH indicating a greater likelihood of spoilage and reduced shelf life [47]. While the current study observed generally higher pH values, previous research documented frozen shrimp in Egypt with a wider range of 7.48 to 7.92 [48]. Notably, smoked fish showed lower pH compared to our findings, with Smoked Tuna Fish in India reported at 6.16 [39]. This aligns with other studies where fresh and frozen fish fillets had pH values between 6.5 and 6.6, and fresh and frozen shrimp ranged from 6.6 to 7.5, respectively [49]. Furthermore, canned fish pH varied from 5.6 in tuna to 6.45 in mackerel [40]. These diverse findings warrant further investigation into optimal pH ranges for different seafood types and their impact on preservation and safety.

This study revealed a higher salt content of 2.04g in the tuna smoked fish sample compared to previous research [39] citing 1.80g as the permissible limit for smoked salmon [50]. Our findings align with those studies, suggesting that extended salting times can lead to exceeding allowed salt levels.

Microbiological analysis

The detection of *E. coli* bacteria in these fish samples points to potentially inadequate post-catch handling practices, including storage, transportation, and processing [51, 52]. Such lapses in hygiene likely led to the contamination of the fish meat with this pathogenic bacterium, posing a potential health risk to consumers. These findings underscore the critical need for stricter hygienic measures and quality control throughout the fish supply chain to ensure food safety.

Microbiological analysis plays a crucial role in understanding the microbial landscape of fish and fishery products. This involves identifying and characterizing predominant microbes, exploring factors influencing their growth and survival, and pinpointing their likely locations within processing facilities [53]. Notably, inadequate personal hygiene during production and management can potentially introduce various pathogens to fish meat, contrary to natural shrimp populations exhibiting minimal presence of such bacteria [54]. This finding underscores the importance of stringent hygiene practices throughout the fish processing chain to minimize contamination risks.

High bacterial counts in salted fish likely originate from various sources, such as cross-contamination from fresh fish, the type of salt used, human or animal waste, inadequately cleaned equipment, and exposure to unsanitary environments [55]. Microbiological analysis measures bacterial levels to assess fish freshness, sanitation, and potential presence of harmful organisms [56]. According to the International Commission on Microbiological Specifications for Foods (ICMSF), the Aerobic Plate Count (APC) plays a crucial role in evaluating food quality by indicating the overall level of microbial contamination [57]. The estimated bacterial count helps determine food safety, shelf life, and overall quality [58]. Using representative samples, counts below 5×10^5 CFU/g are considered good quality, 5×10^5 to 10^7 are marginally acceptable, and above 10^7 are unacceptable [59]. Notably, various organizations, including ICMSF, Carret, FDA, and EOSQC, recommend a maximum acceptable limit of 10^6 CFU/g for Total Viable Count (TVC) at 30°C in frozen shrimp [55, 60, 61, 62]. Additionally, a TVC limit of 5×10^5 CFU/g is suggested to distinguish between “excellent” and “bad” quality products [63].

Following Egyptian and international standards for seafood safety, this study assessed the bacterial content of various fish products. The total bacterial count (TBC) in both frozen fish species remained within permissible limits defined by ES 889-1/2005 for frozen finfish and ES889-2/2005 for fish chips. Similarly, the TBC of salted and canned fish samples complied with relevant Egyptian standards (ES 804/2005, ES 1521/2005, ES 1725-1/2005) and international guidelines established by ICMSF and FDA [37, 55, 61, 63]. These findings suggest good microbiological quality across all studied fish samples. Additionally, the total viable aerobic count (TVAC) ranged from 2.8×10^5 to 4.9×10^5 CFU/g in all samples, which adheres to the ICMSF's maximum limit for high-quality frozen fish, further supporting the safety and quality of these products [64]. Notably, previous research indicates significantly higher TVC levels in frozen shrimp, with values exceeding 10^6 CFU/g, highlighting the comparatively favorable bacterial profile observed in this study's frozen fish.

Several studies have demonstrated the increased risk of spoilage in frozen fish, particularly during the summer months. In one study, a staggering 66.6% of frozen fish samples were declared unfit for consumption during the summer [66]. Similarly to [67] that observed significant deterioration in frozen tilapia over time, with protein and lipid content decreasing by 27.9% and 25.92%, respectively. Notably, the total coliform bacteria count also skyrocketed, climbing from 3x103 to a concerning 7.5x106 CFU/g. Comparing this study to prior research [68], the total bacterial count (TBC) appears lower. However, that study reported significantly higher counts in other fish types, ranging from 5.3×10^4 to 8.9×10^7 CFU/g. These findings underscore the importance of proper handling and storage, especially during warmer months, to ensure the safety and quality of frozen fish.

Previous studies have reported higher TBC in fish products compared to this study. For example, one study found an average TBC of 51 million in Feseikh samples and 15.75 million in salted sardines [69]. However, another study reported a much lower maximum TBC of 13 thousand for Feseikh [70]. Microbial contamination was also concerning in other studies. One study found that over half of tested Feseikh, Sardine, and Melloha samples exceeded acceptable Staphylococcus aureus levels, with *E. coli* and *Vibrio* parahaemolyticus also detected in varying proportions across different fish types [68]. Additionally, a separate study reported unacceptably high microbial counts in a significant portion of Feseikh, sardine, and Melloha samples based on various regulations [71]. These findings raise concerns about potential safety risks associated with these fish products and highlight the need for stricter quality control measures.

Microbial studies of salted-fermented fish revealed a total bacterial count ranging from 2.81 to 4.72 CFU/g, total *Staphylococci spp* count 2.71–3.85 CFU/g, halophile bacteria count 3.26–5.14 CFU/g, and coliforms count CFU/g [72].

Our findings raise concerns about potential bacterial contamination in smoked fish, mirroring results observed in our salted fish samples. Previous research on various fish products also indicates diverse bacterial loads [73, 74]. Notably, salted sun-dried Nile perch showcased higher counts during the rainy season [74]. Importantly, in our study, 33.33% of smoked fish samples violated the Egyptian standard (ES 288/2005) for TBC and TCC, highlighting potential safety risks [37]. While these counts fell below the reported value for smoked tuna and the general recommended limit [39, 63], further research and stricter adherence to standards are imperative to ensure consumer safety. These efforts could involve investigating seasonal variations, improving handling practices, and implementing stricter quality control measures throughout the production chain.

Canned tuna and sardines exhibited the lowest total viable bacterial counts within a previous study [40], ranging from $2.5 \pm 0.01 \times 10^2$ to $4.6 \pm 0.21 \times 10^3$ CFU/g for mackerel. Notably, these values are lower than those observed in the present study, implying potentially higher bacterial contamination, particularly in canned mackerel. Further investigation is needed to elucidate the possible reasons for this discrepancy.

Previous research on canned sardines stored under refrigeration found even higher TVC than those observed in this study's canned fish, ranging from 0.1 to 2.8 million CFU/g [75]. At room temperature, these values soared to between 0.1 and 4.4 million CFU/g. Fortunately, the coliform levels detected in the fish samples here remained below the established guidelines of 400 CFU/g [60, 61]. However, they exceeded the stricter limit of 102 CFU/g mandated by Egyptian standards for smoked fish, despite this study's smoked fish exhibiting a lower mean TVC than the recommended limit [37]. The presence of coliform bacteria, including *E. coli*, in shrimp indicates unsanitary conditions during various stages, from harvesting/capturing to processing. Notably, total coliform counts were found to range from 5 to 28MPN/g, while fecal coliforms ranged from 3 to 8.3MPN/g, exceeding acceptable standards [64]. Similarly, studies reported high levels of coliform contamination in smoked fish from Nigeria, particularly at the production source [76]. This alarming finding suggests potential lapses in hygienic practices during pre- and post-handling, as well as the smoking process itself.

A previous study revealed alarmingly high levels of Staphylococcus aureus in sardine Fesiekh, with counts reaching 4.25 x 10^3/gm and 15 x 10^3/gm in different samples [69]. This is particularly concerning as Egyptian standards deem the presence of either Enteropathogenic *E. coli* (n=30) or *Salmonella spp* unacceptable in salted fish samples [37]. Notably, in this study, 50% and 45% of samples contained *Salmonella spp* and *E. coli*, respectively, exceeding these safety limits. These findings underscore the significant variation in fish meat quality based on factors like origin, processing methods, water source (culture or capture), storage temperature, and moisture content. This variability highlights the need for robust quality control measures throughout the fish production and distribution chain to safeguard consumer health.

The Sensory analysis results

Sixty percent (18 out of 30) of frozen samples and 50% (15 out of 30) of frozen shrimp were considered acceptable in sensory evaluation. However, 40% (12 out of 30) of frozen fillets and 50% (15 out of 30) of frozen shrimp were rejected by panelists, as reported in [49]. While canned fish was generally considered safe in previous studies, canned tuna consistently outperformed canned sardines and mackerel in sensory ratings. Notably, canned mackerel acceptance varied from 6.40 to 8.66 [40].

Conclusion

The presence of contaminants in some fish samples underscores the urgent need for a multi-pronged approach to safeguard consumer health. Regular inspections at markets and food entry points, alongside strict enforcement of food safety regulations, can act as crucial barriers against contamination by heavy metals, microorganisms, and other harmful substances. Additionally, public education campaigns are essential to raise awareness about the dangers of these contaminants and empower consumers to make informed choices. Collaborative efforts at various levels, from regulatory bodies to consumers, are critical to ensure a safe and healthy food supply chain.

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Conflicts of interest

There are no conflicts to declare. The authors declared no competing interests.

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تقييم جودة وسلامة بعض الأسماك المستوردة والمحلية الموجودة بالأسواق المصري

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نظرًا لأن الأسماك تعمل كمصدر حاسم ومتنوع للبروتين في العديد من الأنظمة الغذائية، فإن قابليتها العالية للتلف تتطلب اهتمامًا وثيقًا بالجودة والسلامة. قيمت هذه الدراسة جودة وسلامة كل من الأسماك المستوردة والمحلية الموجودة في الأسواق المصرية من خلال التحليلات الفيزيائية الكيميائية والميكروبيولوجية والحسية. وفي حين لوحظت مستويات مقبولة للأس الهيدروجيني في جميع العينات، لوحظت زيادة مقلقة في محتوى الرماد (باستثناء الأسماك المجمدة). بالإضافة إلى ذلك، تجاوزت الأسماك المجمدة والمملحة والمعلبة والمدخنة (TCC) معايير الجودة المحددة، لا سيما فيما يتعلق بالأسماك المدخنة التي تتجاوز الحدود الموصي بها. على الرغم من أن التقييمات الحسية اعتبرت الخصائص العضوية لمعظم الأسماك مرضية، إلا أن الأسماك المعلبة احتلت المرتبة الأعلى، بينما كانت الأسماك المملحة قصيرة. والجدير بالذكر أن الجودة المكروبيولوجية لبعض العينات كانت مثيرة للقلق، مما يشير إلى وجود ثغرات محتملة في الصرف الصحي وممارسات المناولة غير الآمنة أثناء التجهيز والتوزيع.

الكلمات الدالة: جودة الأسماك، ميكروبيولوجيا الأسماك، تركيب الأسماك، التلف.