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Physicochemical and Microbiological Assessment of Fresh and Frozen Fish Marketed in the Coastal Area of Togo

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Abstract

In Togo, seafood consumption is based on local fishing and imports. Local and imported fish pass through various distribution channels and undergo several post-fishing handling processes, which can impact their physicochemical and microbiological qualities. To assess the physicochemical and microbiological qualities of fresh and frozen fish subjected to various handling practices, samples were collected from fishermen, wholesalers, importers and fish shops, and then analyzed. The sampling used a mixed approach, combining a reasoned non-probabilistic selection of collection sites with a random probabilistic selection of actors present at each site during sample collection. Thus, 42 actors were sampled at targeted landing and commercialization sites for fresh and frozen fish, selected based on their importance. Based on defined criteria, 22 composite samples of fresh and

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frozen fish were formed and submitted for analysis. Freshness and Total Volatile Basic Nitrogen (TVBN) were assessed according to European Regulations, pH by the potentiometric method, and microbiological analysis according to AFNOR's analytical methods. The results showed that fish from beach fishermen and importers had the highest freshness index (I=3), followed by seining fishermen (I=2.4), fish shops (I=2.2), and wholesalers (I=1.8). The pH ranged from 5.72 (importers) to 6.96 (wholesalers), and the Total Volatile Basic Nitrogen (TVBN) ranged from 5.40 mg/100g (importers) to 112.62 mg/100g (fish shops). 81.82% of the samples had TVBN levels below the threshold of 25 mg/100g. Fish from importers were of satisfactory microbiological quality, those from fishermen and fish shops were of acceptable quality, and those from wholesalers were of unsatisfactory quality. *Salmonella* was not detected in any sample. This study revealed that fish quality varies depending on the different actors involved and therefore different practices in the commercialization chain. Frozen fish upon entry into the country were of better quality, followed by locally freshly caught fish, fish marketed by fish shops and finally by fish from wholesalers. Our results highlight the need to strengthen awareness campaigns and training on good hygiene, fishing, and commercialization practices, especially for local fishing stakeholders.

Keywords: Fish, post-fishing handling, freshness, physicochemical quality, microbiological quality

Introduction

The quality of fish products includes not only their protein content, especially essential amino acids, and their polyunsaturated fatty acids, but also their freshness and sanitary quality (Prache *et al.*, 2021). In 2022, the global fish production amounted to 185.4 million tonnes, of which 91 million tonnes came from capture fisheries, with China as the leading producer (FAO, 2024). In Africa, fish consumption is of utmost importance as it represents an excellent alternative to meat protein (Van Hecke & Vanderleenen, 2023). In Togo, fish availability is ensured by local fishing, with a production of approximately 25,000 tons per year, and by imports to cover estimated needs of around 70,000 tons per year (Ali *et al.*, 2016). The supply of fish is quite varied, ranging from pelagic to demersal species (FAO, 2007), and from fresh and frozen fish to dried or smoked fish, allowing for distribution to distant areas through various trading channels (FAO, 2007; Van Hecke & Vanderleenen, 2023). However, fresh fish is a highly perishable commodity (Anihouvi *et al.*, 2005) and its preservation after harvesting, particularly in commercialization chains, represents a major challenge due to the lack of refrigeration infrastructure (Fall *et al.*, 2019). Indeed, the lack of control over

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good hygiene practices and the lack of refrigeration in fish commercialization chains (Akilimali *et al.*, 2019; Bediang *et al.*, 2020; Brito *et al.*, 2021) have a significant negative impact on fresh and frozen fish quality, resulting in a loss of freshness, an increase in total volatile basic nitrogen, and microbial growth (Assogba *et al.*, 2018a). Microbial growth leads to risks of histamine poisoning, which is a real public health problem. Indeed, histamine exposure deserves particular attention because it is most often the primary cause of numerous foodborne illness outbreaks associated with fish consumption (Guillier *et al.*, 2015). Previous studies, notably those by Bediang *et al.* (2020) and Bouka *et al.* (2020) in Togo, revealed significant microbial contamination of fresh fish sold at the fishery harbour of Lomé and high histamine levels in smoked fish. The health consequences of this exposure include food poisoning with moderate to severe effects. Symptoms include hives, edema, skin rashes, nausea, vomiting, abdominal cramps and diarrhea, headaches, and respiratory difficulties (FAO/WHO, 2013). The highest histamine levels are due to post-fishing bacterial contamination and proliferation (Diop *et al.*, 2010), with storage temperatures of 7°C to 15°C being a contributing factor (Dalgaard, 2007 cited by Ka, 2015). Post-fishing processing is therefore a critical step in ensuring the food safety of fresh and frozen fish. It is thus important to assess fish quality based on different post-fishing practices in order to improve those with risks. This research was conducted to evaluate the physicochemical and microbiological qualities of fresh and frozen fish throughout the post-fishing chain.

Methods

Study Area

The study was conducted in Togo, primarily in the coastal area (Figure 1), which is dominated by artisanal marine fishing and related activities. The Togolese coastal area defined for this study is the coastline extending 56 km from Kodjoviakopé to Aného (Les Amis de la Terre-Togo, 2023), and the cities of Lomé and Aného. The coastline includes several landing sites for local fisheries, the most important being those at Kodjoviakopé, Ablogamé, Kpémé, Goumoukopé, and Aného. Both Lomé and Aného have fresh fish markets, the most significant being those at Lomé fishing harbour, Adawlato, and Aného. The city of Lomé also houses the Port of Lomé, which serves as an entry point for frozen fish imported into Togo.

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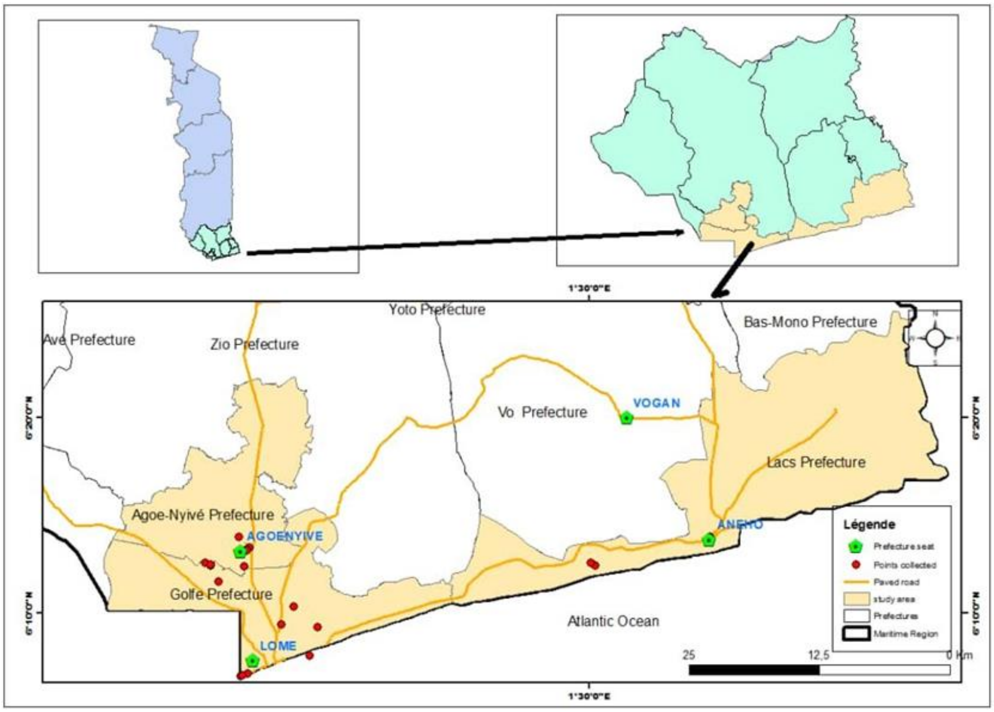

Figure 1: Study area

Sample Collection and Preparation

Sample collection and analysis were conducted from September to November 2025. Fresh and frozen fish samples were collected from fishermen, wholesalers, importers and fish shops. The sampling used a mixed approach, combining a reasoned non-probabilistic selection of collection sites with a random probabilistic selection of actors present at each site during sample collection. Thus, 42 actors were sampled at targeted landing sites (Kodjoviakopé, Ablogamé, Kpémé, fishery harbour) and commercialization sites (fresh fish markets at the fishing harbour of Lomé, in Aného and in Adawlato, fish shops) for fresh and frozen fish, selected based on their importance. Based on defined criteria, including type of actor, grouping of actors on the same collection site, similarity of commercialization conditions and practices, and species of fish collected, 22 composite samples of fresh and frozen fish were formed. Samples of local fresh fish, anchovies (*Engraulis encrasicolus*), sardinella (*Sardinella aurita* and *Sardinella maderensis*), and other small pelagic (*Selene setapinnis*) were mixed according to actor group, species and sampling site to form composite samples (Table 1). Approximately 500g to 1kg of sample was collected per actor. The resulting composite sample (approximately 2.5kg to 3kg) was divided into two parts: one was sent to the Laboratory of Microbiology and Quality Control of Foodstuffs (LAMICODA) of the University of Lomé for microbiological

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analyses and the other to the Food Quality Control Laboratory of the Togolese Institute of Agronomic Research (ITRA) for physicochemical analyses.

Table 1: Sampling scheme of local fresh fishes

Collection sites	Actors	Total number of actors	Species collected	NSA	TNSC	NCS
n = 3						
Site 1 (E1)	BF	**Fishermen N = 12**	*S. setapinnis**	1	3	1
Site 2 (E2)	BF		*S. setapinnis*	1	3	1
Site 3 (E3)	BF		*S. setapinnis*	1	3	1
Site 4 (E4)	SF		*E. encrasicolus**	1	3	1
n = 5						
Site 10 (E10)	WS	**Wholesalers N = 15**	*Sardinella sp*.*	1	5	1
Site 11 (E11)	WS		*E. encrasicolus*	1	5	1
Site 12 (E12)	WS		*S. setapinnis*	1	5	1
		Total			**27**	**7**

n = number of actors sampled per site, BF = Beach fishermen, SF = Seining fishermen, WS = Wholesalers, E1…E12 = Composite samples, NSA = Number of samples per actor, TNSC = Total number of samples collected, NCS = Number of composite samples. *The fish species vary and depend on the fishing gear used.

Imported fish, mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*) were collected per actor according to available batches (Table 2). Fish collected at three different parts of a batch were mixed according to actor, species and sampling site to form composite samples. The composite sample was divided into two parts: one was sent to the Laboratory of Microbiology and Quality Control of Foodstuffs (LAMICODA) of the University of Lomé for microbiological analyses and the other to the Food Quality Control Laboratory of the Togolese Institute of Agronomic Research (ITRA) for physicochemical analyses.

Table 2: Sampling scheme of imported frozen fishes

Collection sites	Actors	Total number of actors	Species collected	NSA	TNSC	NCS
n = 1						
Site 5 (E5)	IMP	**Importers N = 5**	*T. trachurus*	3	3	1
Site 6 (E6)	IMP		*S. scombrus*	3	3	1
Site 7 (E7)	IMP		*T. trachurus*	3	3	1
Site 8 (E8)	IMP		*T. trachurus*	3	3	1
Site 9 (E9)	IMP		*S. scombrus*	3	3	1
n = 1						
Site 13 (E13)	FSH	**Fish Shops N = 10**	*T. trachurus*	3	3	1
Site 14 (E14)	FSH		*S. scombrus*	3	3	1
Site 15 (E15)	FSH		*T. trachurus*	3	3	1
Site 16 (E16)	FSH		*T. trachurus*	3	3	1
Site 17 (E17)	FSH		*S. scombrus*	3	3	1
Site 18 (E18)	FSH		*T. trachurus*	3	3	1
Site 19 (E19)	FSH		*S. scombrus*	3	3	1
Site 20 (E20)	FSH		*T. trachurus*	3	3	1

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Site 21 (E21)	FSH		*S. scombrus*	3	3	1
Site 22 (E22)	FSH		*T. trachurus*	3	3	1
		Total			**45**	**15**

n = number of actors sampled per site, IMP = Importers, FSH = Fish shops, E5…E22 = Composite samples, NSA = Number of samples per actor, TNSC = Total number of samples collected, NCS = Number of composite samples.

Sampling was carried out using coolers, dry ice, sterile sampling bags, Bunsen burners, knives, alcohol and sterile gloves. Once collected, samples were transported directly to the laboratories.

Laboratory Analyses

Composite samples of fresh and frozen fish were analyzed separately. The freshness of fish was assessed by inspecting and scoring the skin, eyes, flesh and gills on a scale of 0 to 3, according to Regulation (EC) N° 2455/70. Fresh fish were inspected directly, while frozen fish were thawed in a refrigerator before inspection. For each set of fish, an average score was calculated and reported on a scale of 0 to 3. Fishes were then classified into categories: Extra (freshness level of 2.7 or higher), Category A (freshness level of 2 or higher but less than 2.7), Category B (freshness level of 1 or higher but less than 2), and Category C (fish not meeting the requirements for classification in Extra, A, or B) (European Communities, 1970).

The Total Volatile Basic Nitrogen (TVBN) content was determined by steam distillation according to Regulation (EC) N° 2074/2005 (European Communities, 2005). Fish flesh was collected and ground homogeneously in a blender. 10g of the grounded sample was weighed into a flask and 90ml of perchloric acid was added. The mixture was vigorously shaken for 2 minutes using a stirrer. The resulting solution was filtered through filter paper.

50ml of the filtrate was collected into a flask. A few drops of phenolphthalein and 6.5ml of sodium hydroxide solution were added. The mixture was then distilled and the distillate was collected in an Erlenmeyer flask containing 100 ml of boric acid and a few drops of Tashiro reagent. The solution in the Erlenmeyer flask was then titrated with 0.05 N hydrochloric acid solution. A blank test was performed with 50ml of perchloric acid. The TVBN content, expressed in mg/100 g, was calculated using the formula:

$$\mathrm{TVBN}\left(\frac{\mathrm{mg}}{100\mathrm{g}}\right) = \frac{[(\mathrm{V1} - \mathrm{V0}) \times 0.14 \times 2 \times 100]}{\mathrm{M}}$$

V1 (ml) = Volume of 0.05N hydrochloric acid for the sample
V0 (ml) = Volume of 0.05N hydrochloric acid for the blank
M (g) = Mass of the sample

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The pH was determined by the potentiometric method according to ISO 2917:1999. Fish flesh was collected and ground homogeneously using a blender. 20g of the grounded sample was weighed into a flask and 50ml of distilled water was added. The mixture was vigorously shaken for 30 minutes using a stirrer. The pH was then read at a temperature of 25°C using a previously calibrated pH meter.

Microbiological analysis was performed using the routine methods of the French Standardization Association (AFNOR) described by Soncy *et al.* (2015). Fish samples were collected aseptically and placed directly into a sterile bag. Tryptone salt (TS) was added at a ratio of 90ml per 10g of sample. The mixture was homogenized using a Stomacher. The resulting solution, with a concentration of 1/10, was left at room temperature for 45 minutes for reactivation. The solution was then subjected to a series of decimal dilutions by adding 1ml of the concentrate solution or 1ml of the previously diluted solutions to 9ml of TS. The diluted solutions were used to inoculate various culture media (PCA, VRBL, TBX, Baird Parker, EPT, Rappaport, Hektoen, SS, Kligler) depending on the target microorganisms. The culture media were then incubated for the appropriate time and temperature for each microorganism. Total Flora was incubated at 30°C for 24 to 72 hours, Total Coliforms at 30°C for 24 hours, *Escherichia coli* at 44°C for 24 hours, *Staphylococcus aureus* at 37°C for 24 to 48 hours, and *Salmonella* at 37°C for 24 hours. Microorganisms were enumerated by counting characteristic colonies on culture media and the number was expressed in CFU/g. The microbiological results were interpreted according to a three-class scheme for Total Flora, Total Coliforms, *Escherichia coli* and *Staphylococcus aureus*, and according to a two-class scheme for *Salmonella sp.* (Couture *et al.*, 2019).

Statistical Data Analysis

The data were organized using Excel 2013 and analyzed using R4.4.1 software. The Shapiro-Wilk test was used to check the normality of the data, and the Levene test was used to check the homogeneity. Neither condition was met, so the Kruskal-Wallis test was used to assess significance. Dunn's post-hoc test with Benjamini-Hochberg adjustment was then used to compare the different groups of actors. The Mann-Whitney U test and the T-test were used to compare the groups pairwise. Spearman's correlation test was used to analyze the correlation between pH and TVBN, and the binomial test was used to determine the compliance of the samples with the TVBN threshold value set at 25 mg/100g. For all analyses, the significance level of 5% was used.

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Results

Fish freshness according to actors

The determination of the freshness index (Figure 2) allowed for the classification of fish taken from beach fishermen (I=3) and importers (cold containers on arrival) (I=3) in the Extra category, those taken from seining fishermen (I=2.4) and fish shops (I=2.2) in category A, and those taken from fish wholesalers and processors (I=1.8) in category B.

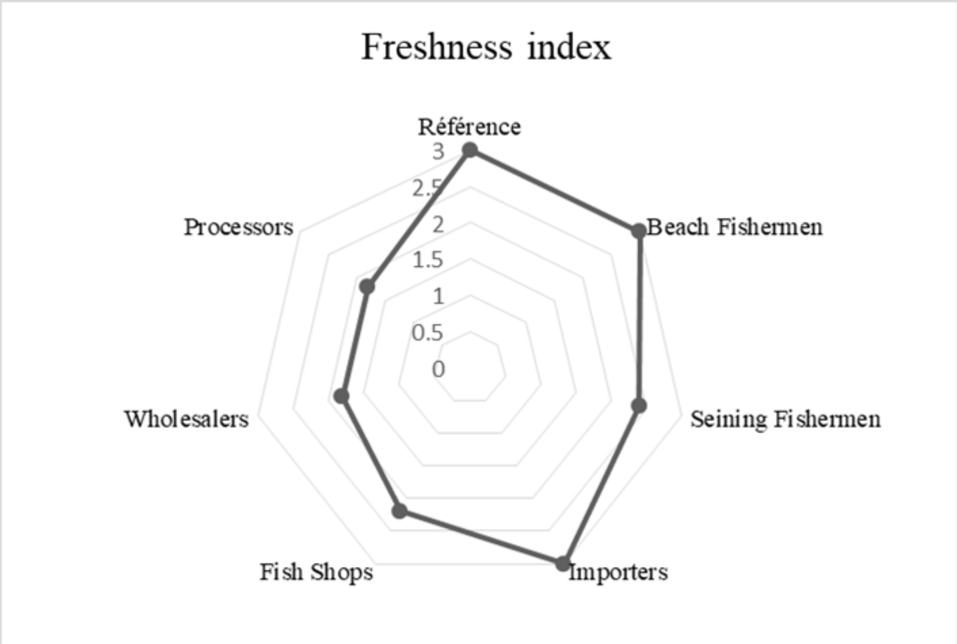

Figure 2: Freshness index according to different actors

pH of fish according to actors

The pH varies from 5.72 (importers) to 6.96 (wholesalers). Figure 3 shows the distribution of fish pH according to actor groups (G1 = Fishermen, G2 = Importers, G3 = Wholesalers, G4 = Fish shops). Fish collected from importers (cold containers upon arrival) recorded the lowest pH average (pH=6.00). Those collected from fishermen, wholesalers and fish shops showed the highest pH average values (pH=6.85, pH=6.89 and pH=6.57 respectively), which were not significantly different from each other (p = 0.06).

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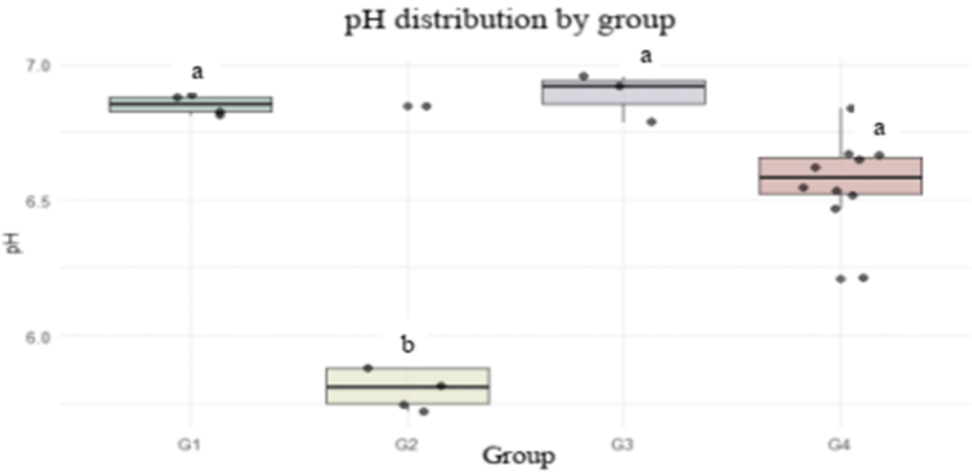

Figure 3: Distribution of fish pH by actors groups G1 (fishermen), G2 (importers), G3 (wholesalers), G4 (fish shops)

Identical letters indicate that the groups are not significantly different from each other. Different letters indicate that the groups are significantly different from each other at 5% significance level.

Total volatile basic nitrogen TVBN of fish according to actors

Total volatile basic nitrogen rates ranged from 5.40 mg/100g (importers) to 112.62 mg/100g (fish shops). Figure 4 shows the distribution of fish TVBN according to actor groups (G1 = Fishermen, G2 = Importers, G3 = Wholesalers, G4 = Fish shops). The average rate of fish from importers (5.75 mg/100g) was the lowest and was not significantly different ($p = 0.1548$) from the average rate of fish from fishermen (8.66 mg/100g). The average rate of fish from fish shops (41.10 mg/100g) was the highest and was not significantly different ($p = 0.9371$) from the average rate of fish from wholesalers (27mg/100g).

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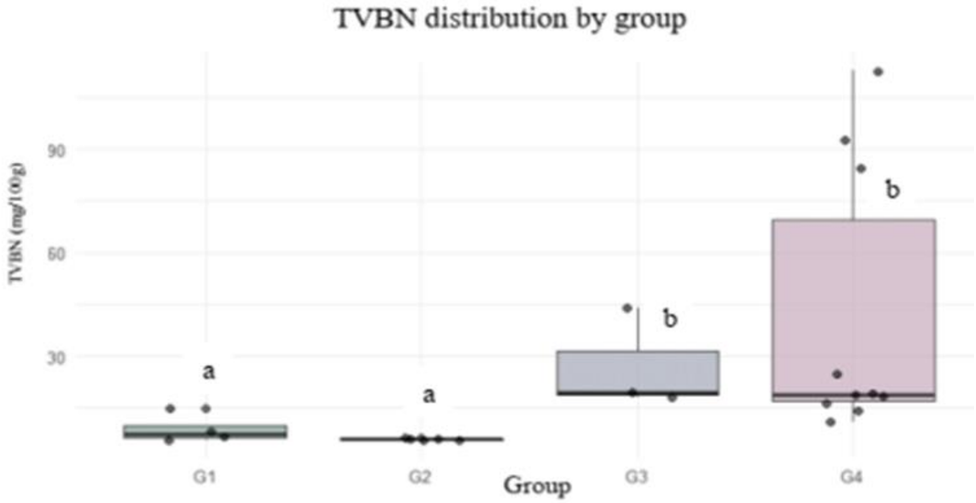

Figure 4: Distribution of fish TVBN by actors groups G1 (fishermen), G2 (importers), G3 (wholesalers), G4 (fish shops)

Identical letters indicate that the groups are not significantly different from each other. Different letters indicate that the groups are significantly different from each other at 5% significance level.

No significant relationship was established between pH and TVBN (rho = 0.158 and p = 0.478). The majority of samples analyzed (81.82%) had a TVBN content below the threshold of 25 mg/100 g (Figure 5).

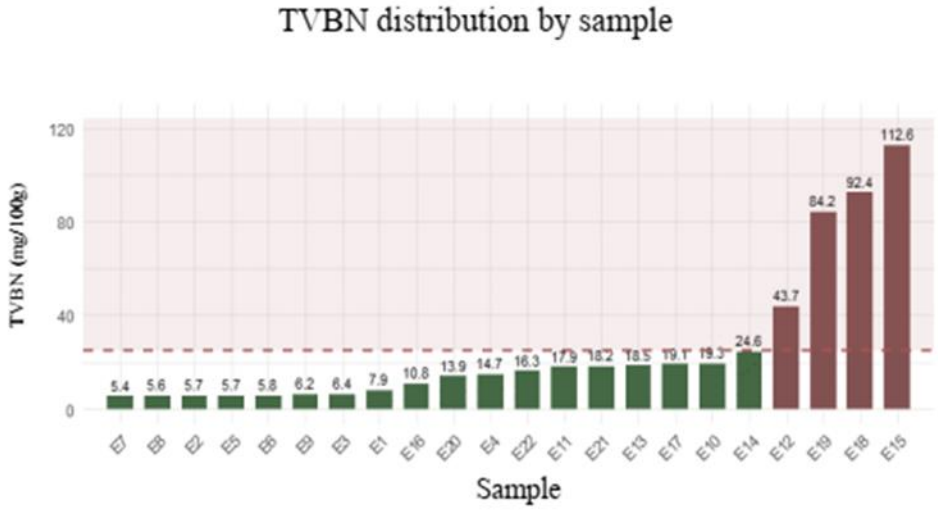

Figure 5: Distribution of TVBN per sample with respect to the threshold of 25 mg/100g

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Microbiological quality of fish according to actors

Tables 3 and 4 show the microbiological profile of fish according to actors and the compliance rate of samples based on microbiological standards. Fish taken from importers (2.96 x 10^4 CFU/g) had the lowest total microbial count and fish taken from wholesalers had the highest (5.91 x 10^6 CFU/g). Fish taken from wholesalers, fishermen (1.98 x 10^6 CFU/g) and fish shops (5.33 x 10^5 CFU/g) had total microbial counts that were not significantly different from each other ($p = 0.103$). The total coliform count revealed that samples from fishermen (1.18 x 10^3 CFU/g) and wholesalers (9.33 x 10^2 CFU/g) were significantly more contaminated than samples from fish shops ($p = 0.0257$) and importers ($p = 0.0333$). The enumeration of *Escherichia coli* showed that fish from fishermen and wholesalers were significantly more contaminated than samples from fish shops and importers ($p = 0.0021$). The *Staphylococcus aureus* count showed that samples from wholesalers had the highest level of contamination, followed in decreasing order by samples from fishermen, fish shops and importers ($p = 0.01768$). *Salmonella* was not detected in any sample.

Table 3: Microbiological profile of fishes according to actors

Actors	Composite Samples	Total Flora (CFU/g)	Total Coliforms (CFU/g)	*Escherichia coli* (CFU/g)	*Staphylococcus aureus* (CFU/g)	*Salmonella sp.* (CFU/g)
Criteria (Couture *et al.*, 2019)		m = 10^6 M = 10^7	m = 10^1 M = 10^2	m = 10^1 M = 10^2	m = 10^3 M = 10^4	m = 0 M = 0
Fishermen (n = 12)	E1	3 x 10^6	1 x 10^3	7 x 10^1	<10^2	ND*
	E2	8.4 x 10^4	2 x 10^1	10^1	<10^2	ND
	E3	4.1 x 10^6	1.5 x 10^3	<10^1	<10^2	ND
	E4	7.4 x 10^5	2.2 x 10^3	5 x 10^1	10^2	ND
Importers (n = 5)	E5	2.3 x 10^4	<10^1	<10^1	<10^2	ND
	E6	4 x 10^4	<10^1	<10^1	<10^2	ND
	E7	3.7 x 10^4	<10^1	<10^1	<10^2	ND
	E8	4.4 x 10^4	<10^1	<10^1	<10^2	ND
	E9	4.2 x 10^3	4 x 10^1	<10^1	<10^2	ND
Wholesalers (n = 15)	E10	4.4 x 10^5	4 x 10^2	2 x 10^1	<10^2	ND
	E11	2.3 x 10^6	1.6 x 10^3	1.5 x 10^3	3.5 x 10^3	ND
	E12	1.5 x 10^7	8 x 10^2	4.3 x 10^2	7 x 10^2	ND
Fish shops (n = 10)	E13	8 x 10^4	<10^1	<10^1	<10^2	ND
	E14	1.5 x 10^6	<10^1	<10^1	<10^2	ND
	E15	3.4 x 10^6	3 x 10^1	<10^1	<10^2	ND
	E16	1.4 x 10^4	9 x 10^1	<10^1	<10^2	ND
	E17	8.8 x 10^2	<10^1	<10^1	<10^2	ND
	E18	5.3 x 10^4	<10^1	<10^1	<10^2	ND
	E19	2.6 x 10^4	<10^1	<10^1	<10^2	ND
	E20	1 x 10^5	3 x 10^1	<10^1	<10^2	ND
	E21	2.7 x 10^4	<10^1	<10^1	<10^2	ND
	E22	1.3 x 10^5	1.4 x 10^2	2 x 10^1	<10^2	ND

ND* = Not Detected, n = number of actors sampled

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Table 4: Compliance rate of samples from different actors according to microbiological standards and overall assessment of batches analyzed

Actors	**Sample conformity percentage (%)**					Overall Assessment*
	Total Flora (CFU/g)	Total Coliforms (CFU/g)	*Escherichia coli* (CFU/g)	*Staphylococcus aureus* (CFU/g)	*Salmonella sp.* (CFU/g)	
	$m = 10^6$	$m = 10^1$	$m = 10^1$	$m = 10^3$	m = 0	
Fishermen (G1)	50%	0%	50%	100%	100%	Acceptable Quality
Importers (G2)	100%	80%	100%	100%	100%	Satisfactory Quality
Wholesalers (G3)	33%	0%	0%	67%	100%	Unsatisfactory Quality
Fish shops (G4)	80%	60%	90%	100%	100%	Acceptable Quality

*Determined according to two-class interpretation for *Salmonella sp*. and three-class interpretation for other germs (Couture *et al.*, 2019).

The results of pH, TVBN and microbiological analysis are summarized in Table 5 with means and standard deviations.

Table 5: Summary of pH, TVBN and microbiological analysis results

Groups	pH	TVBN (mg/100g)	Total Flora (CFU/g)	Total Coliforms (CFU/g)	*E. coli* (CFU/g)	*S. aureus* (CFU/g)
Fishermen (G1)	$6,85^{a} \pm 0,036$	$8,66^{a} \pm 4,13$	$1,98.10^{6a} \pm 1,89.10^{6}$	$1,18.10^{3a} \pm 9,16.10^{2}$	$3,5.10^{1a} \pm 3.10^{1}$	$1.10^{2a} \pm 0$
Importers (G2)	$6,00^{b} \pm 0,476$	$5,75^{a} \pm 0,3$	$2,96.10^{4b} \pm 1,63.10^{4}$	$1,6.10^{1b} \pm 1,34.10^{1}$	$1.10^{1b} \pm 0,00$	$1.10^{2a} \pm 0,00$
Wholesalers (G3)	$6,89^{a} \pm 0,091$	$27,0^{b} \pm 14,5$	$5,91.10^{6a} \pm 7,92.10^{6}$	$9,33.10^{2a} \pm 6,11.10^{2}$	$6,5.10^{2c} \pm 7,64.10^{2}$	$1,43.10^{3b} \pm 1,81.10^{3}$
Fish shops (G4)	$6,57^{a} \pm 0,164$	$41,1^{b} \pm 39,0$	$5,33.10^{5a} \pm 1,11.10^{6}$	$3,5.10^{1c} \pm 4,45.10^{1}$	$1,1.10^{1b} \pm 0,32.10^{1}$	$1.10^{2a} \pm 0,00$

In each column, means with identical letters are not significantly different from each other. Those with different letters are significantly different from each other at 5% significance level.

Discussion

Fish freshness according to actors

The maximum freshness of fish taken from beach fishermen (Figure 2) could be attributed to fishing techniques, minimal time spent between capture and landing, and landing method. Fish arrive mostly alive at the landing site, unlike seining fishing with longer periods (on average 3 to 6 hours according

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to our field surveys) between capture and landing, while refrigeration is not practiced on board pirogues. Investigations by Bellec *et al.* (1989) on artisanal fishing in West Africa showed that the freshness of local fish on landing is closely linked to fishing techniques and gear. The freshness of fish collected in containers from importers could be attributed to the control of refrigeration from fishing to exportation, and therefore demonstrates the satisfactory quality of frozen fish imported into Togo. Freshness decreases as fish progresses through the commercialization chain, from importers and fishermen to distributors. The studies of Bellec *et al.* (1989) and Bokossa *et al.* (2022) showed that the absence or variation of temperature in the cold chain negatively impacts fish freshness, resulting in a decrease in the freshness index. The decreased freshness index could also be attributed to a sometimes long duration of fish in refrigeration or freezing, leading to aging. However, the fact that the inspected samples belonged to classes Extra, A, and B indicates the acceptable freshness of fresh and frozen fish sold in the study area. Our results are consistent with those of Assogba *et al.* (2025).

pH of fish according to actors

The pH distribution (Figure 3) shows values below neutral, demonstrating the acceptable freshness of fresh and frozen fish, as any value above neutral indicates decomposition of nitrogen compounds and therefore a loss of freshness (Farzana *et al.*, 2014). The lowest pH average recorded at importers could be due to controlled refrigeration and confirms the maximum freshness of imported frozen fish. This low pH could slow down microbial growth within these samples, thus enhancing their quality. Rosset (2001) showed that low pH prevented the growth of *Listeria monocytogenes* and that foods stored in acidic conditions are safe. The pH averages recorded at fishermen, wholesalers and fish shops indicate the beginning of a degradation of nitrogen compounds, which could be linked to microbial proliferation. According to Assogba *et al.* (2018a), although several factors, including rate of glycogenolysis, species, temperature, and slaughtering conditions, can cause pH variation, microbial proliferation remains the most significant factor. However, pH values recorded in this study remain within acceptable limits and are consistent with the results of Brito *et al.* (2021), who found pH levels ranging from 6.1 to 6.8 in their study on the quality of fish sold in Benin.

Total volatile basic nitrogen (TVBN) of fish according to actors

The distribution of total volatile basic nitrogen (Figure 4) shows low levels found in fish from importers and high levels in fish from fish shops. The low levels at importers could be mainly due to autolysis of fish tissues. They could be linked to control of the cold chain during the import process, thus reflecting the freshness and quality of frozen fish imported into Togo. Brito *et*

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al. (2021) in Benin found that imported fish had a significantly lower TVBN content than local fish. The TVBN rate increases as fish progresses through the commercialization chain and moves from one actor to the next. This could be due to breaks in the cold chain or temperature variations, and poor hygiene and handling conditions, leading to microbial growth. The study of Bokossa *et al.* (2022) demonstrated the effects of temperature variation in commercialization chains of frozen fish, and the study of Akilimali *et al.* (2019) showed the negative impact of inappropriate commercialization conditions on fresh fish quality. High levels of TVBN (Figure 5) were found in some samples from wholesalers (E12 = 43.71mg/100g) and fish shops (E15 = 112.62mg/100g; E18 = 92.4mg/100g; E19 = 84.2mg/100g). These levels, significantly exceeding the threshold of 25mg/100g, could be due to breaks in the cold chain, long storage in freezing and microbial growth. They indicate a loss of freshness and quality of these fish. Consuming these non-compliant fish can be dangerous, as microbial growth could lead to a risk of histamine poisoning. Diop *et al.* (2010) showed that the highest histamine levels in fish were linked to post-fishing bacterial contamination and growth. However, the majority (81.82%) of samples analyzed remained acceptable (Figure 5). This could be due to efforts made by each actor, aware of the perishability of fresh fish, to ensure that it is used or processed quickly in a context where cold storage options are almost non-existent or expensive. Kouamé *et al.* (2019) demonstrated the importance of processing, especially smoking, as a preservation alternative to the perishability of fresh fish.

Microbiological quality of fish according to actors

The microbiological profile of samples analyzed (Table 3) shows that imported frozen fish had a lower level of contamination than locally fresh fish. Fish from importers remained within standards and were satisfactory concerning Total Flora, Total Coliforms, *Escherichia coli*, *Staphylococcus aureus* and *Salmonella*. Fishes from fishermen and fish shops were unsatisfactory concerning Total Coliforms, acceptable concerning Total Flora and *Escherichia coli*, and satisfactory concerning *Staphylococcus aureus* and *Salmonella*. Fish from wholesalers were unsatisfactory concerning Total Flora, Total Coliforms and *Escherichia coli*, but acceptable concerning *Staphylococcus aureus*. In summary, the microbiological quality was satisfactory for importers, acceptable for fishermen and fish shops and unsatisfactory for wholesalers (Table 4). The satisfactory quality of imported frozen fish could be attributed to hygiene practices and control of the cold chain, which inhibits microbial growth. This quality decreased at the level of fish shops, as they were secondary and tertiary distributors of imported frozen fish. According to Assogba *et al.* (2018b), this is due to breaks in the cold chain or variations in storage temperatures out of the required standards. The

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high contamination of local fresh fish, especially with germs resulting from hygiene failures, reflects deficiencies in practices from fishing to commercialization (Bediang *et al.*, 2020). According to Bellec *et al.* (1989), Akilimali *et al.* (2019), and Bignoumba *et al.* (2022), fishing techniques, landing methods (particularly direct landing on the ground in unsanitary environments), poor maintenance of gear and utensils, unsanitary sales outlets, poor hygiene practices, and inadequate cold chain management are all factors that negatively impact the microbiological quality of local fresh fish. This should incite the relevant authorities to strengthen awareness campaigns, training in good practices, and sanitary controls. The samples analyzed in this study were free of *Salmonella*, demonstrating their safety given the pathogenicity of this bacterium (Van Immerseel *et al.*, 2005). This is encouraging, but continuous monitoring remains essential to prevent any risk. Our microbiological results are consistent with those of N'Guessam *et al.* (2018), Akilimali *et al.* (2019), Brito *et al.* (2021) and Bokossa *et al.* (2022), who found that both local and imported fresh fish were contaminated with various bacteria but still remained of acceptable microbiological quality. These authors also highlighted the negative impact of inadequate hygiene and refrigeration practices on the microbiological quality of seafood products.

Conclusion

The study revealed that the quality of fresh and frozen fish marketed in the coastal area of Togo varies depending on the actors involved. Frozen fish upon entry into the country were of better quality, followed by locally freshly caught fish, fish marketed by fish shops and finally by fish from wholesalers. From a microbiological standpoint, imported frozen fish were of satisfactory quality, unlike fish from wholesalers, which were highly contaminated by germs resulting from hygiene failures. This raises questions about handling and commercialization conditions of locally fresh fish and the measures to be implemented to ensure safe products for consumption. Authorities and relevant services should not only strengthen awareness campaigns, training in good practices, and sanitary inspections, but also promote safe fish handling by improving fishing techniques and post-fishing infrastructures for the local fishery sector. In perspective, this study should be extended to a larger number of stakeholders across different fishing seasons, and to non-coastal areas where fresh fish from inland fisheries coexist with imported frozen fish. It should also be complemented by an assessment of different practices from fishing to commercialization according to various actors.

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