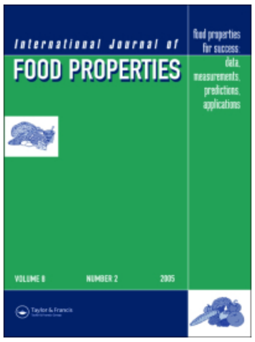

International Journal of Food Properties

ISSN: 1094-2912 (Print) 1532-2386 (Online) Journal homepage: www.tandfonline.com/journals/ljfp20

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To cite this article: E.J. Lujuo, E.M. Mkupasi & H.A. Lamtane (2022) Assessment of the physico-chemical and sensory properties of frozen fillets of tuna and tuna-related fish species marketed along the Tanga and Mtwara coastlines, Tanzania, International Journal of Food Properties, 25:1, 2661-2673, DOI: 10.1080/10942912.2022.2150211

To link to this article: https://doi.org/10.1080/10942912.2022.2150211

Published online: 28 Nov 2022.

INTERNATIONAL JOURNAL OF FOOD PROPERTIES
2022, VOL. 25, NO. 1, 2661–2673
https://doi.org/10.1080/10942912.2022.2150211

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Assessment of the physico-chemical and sensory properties of frozen fillets of tuna and tuna-related fish species marketed along the Tanga and Mtwara coastlines, Tanzania

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ABSTRACT

Tuna and tuna-related fish are valuable marine species lacking standardized quality assessment parameters. This study assessed the physico-chemical and sensory properties of skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), and kawakawa (*Euthynnus affinis*) tuna fish fillets marketed in Tanga and Mtwara, Tanzania. Laboratory AOAC methods evaluated total volatile basic-nitrogen (TVB-N), pH, color (lightness L*), and texture (hardness) properties. The quality index method (QIM) assessed tuna fillets' sensory properties (color, texture, and odor). The pH ranged between 5.60 ± 0.08 and 6.10 ± 0.30, the TVB-N between 34 ± 7.00 mg/100 g and 38.04 ± 10.50 mg/100 g, color lightness (L*) between 24.33 ± 1.82 and 40.10 ± 1.50, and texture (hardness) from 3.84 ± 1.20 N to 8.56 ± 1.84 N. The tuna fillets got an overall score of 2 in the sensory analysis, which indicated good quality according to the QIM. Furthermore, the present study showed significant differences ($p < .05$) between the tuna species in pH, hardness (instrumental), and color lightness properties (L*). There were no significant differences ($p > .05$) in average TVB-N results across all tuna fillets. There were significant correlations among the assessed quality properties. Based on the combined quality properties results and correlation analysis, the tuna and tuna-related fish marketed in the study areas were of good quality. This study recommends the establishment of standardized quality assessment parameters for tuna and related fish species.

ARTICLE HISTORY
Received 14 January 2022
Revised 2 November 2022
Accepted 10 November 2022

KEYWORDS
Tuna; physico-chemical; sensory; quality

Introduction

Tuna and tuna-related fish species in the Scombridae family are among the saltwater products of high nutritional and economic value.[1] The global supply of tuna species accounts for about 20% of the marine captured fisheries, contributing significantly to the livelihood improvement of many communities.[2] In the Tanzania Exclusive Economic Zone (TEEZ), tuna and tuna-related fish species are found up to 200 miles from the shoreline on 223,000 km^2[3] According to,[4] the estimated annual catch of tuna species in the TEEZ in 2018 was 22,171 MT, of which 3,121.03 MT were kawakawa, 593.68 MT were bigeye, and 1,292.73 MT were skipjack. Commercial longline fishermen frequently catch bigeye and yellowfin tuna. Kawakawa and skipjack tuna are primarily caught by artisanal fishermen using longlines and ringnets.[5] The tuna fish species contribute significantly to Tanzania's fishery products despite the paucity of reliable qualitative and quantitative data.

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This article was originally published with errors, which have now been corrected in the online version. Please see Correction (http://dx.doi.org/10.1080/10942912.2023.2267350)

Quality loss is among the post-harvest fish loss challenges that tuna and tuna-related fish species encounter along their value chain. Tuna fish species are rapidly affected by quality degradation because of polyunsaturated fatty acids (PUFAs) in their muscles.[6] The high levels of PUFAs make tuna species' physiological structures unstable, leading to their vulnerability to spoilage and substantial quality changes during freezing and thawing[7]. Quality losses can occur at any stage of the tuna fish value chain, beginning from the capture point[8] and continuing throughout preprocessing, processing, storage, and transportation.[9] Factors such as improper catching, processing, packaging, storage, and distribution practices may cause quality degradation in fish.[9–11]

Fish quality loss has different impacts on the physico-chemical, sensory, and nutritional quality properties[12] They can affect the shelf-life, consumer acceptability, functionality, and safety of fish and fish products[10,13,14] For example, PUFA rancidity produces hydroperoxides that break down and release potentially toxic free radicals[15]. Free radicals are reported to be hazardous and have shown a correlation with inflammatory diseases, cancer, atherosclerosis, and aging conditions in humans-[16,17]. Furthermore, the fish quality changes are also related to histamine production, muscle discoloration, softening and gaping, increased pH, and rancid off-odors that impair their safety and quality.[18] In addition, the tuna fish quality degradation results in lowered economic value.[9]

Due to their perishable nature, tuna fish products need to have the quality of their products closely monitored throughout the value chain in order to safeguard consumers and prevent losses. Despite their high nutritional and economic values, there is a paucity of qualitative data on tuna in the TEEZ. Additionally, the majority of tuna species lack standardized quality assessment criteria. Consequently, this study has attempted to establish the values of pH, TVBN, color, hardness (instrumental), color (sensory), hardness (sensory), and odor (sensory) quality parameters as a way forward to developing standardized quality assessment criteria for these fish species. Furthermore, this study will provide information on the quality and safety of the tuna fillet to consumers, the health sector, regularity bodies, and other stakeholders in the tuna value chain and, importantly, establish a TEEZ tuna fish database. The tuna fillets' physicochemical and sensory quality properties were combined to achieve a reliable, exhaustive, and objective conclusion on their quality.

Materials and methods

Study area

This study was conducted between November 2020 and September 2021 in Tanga (Deep Sea) and Mtwara (Mikindani), the regions having the major tuna landing sites along the coastlines of Tanzania. These sites were selected because the highly valued tropical tuna and tuna-like species seasonally migrate to these coastlines. Many artisanal fishermen of kawakawa and skipjack operate longlines and ring nets on these coastlines.[5] Furthermore, large-scale yellowfin and bigeye tuna fishermen operating longlines catch fish on these coastlines.[5]

Study design

The present study adopted a repeated cross-sectional study design and a non-probability sampling method for fish sample collection. The tuna and tuna-related fish weighing approximately 3–5 kg were identified with the assistance of the fishery officer and collected for the study. The sample size (n) was estimated by the formula $n = Z^2SD^2/e^2$ for the unknown population,[19] where n = size of sample, z = value of standard variate at 95% confidence level (1.96), SD = the standard deviation of the population based on the trial sample (0.16) and e = acceptable error (0.05). Hence, $n = (1.96)^2 \times (0.16)^2/(0.05)^2 = 39$ samples for each site to make a total of 78 samples.

Sample collection, preservation, and transportation

The whole fish was collected from sampling points and approximately 500 g fillets were resected using an electric knife and placed in watertight plastic bags. The sampling bags with fillets were labeled and placed in ice chests with an adequate amount of ice covers layered between samples and immediately transported to the laboratories of the Department of Animal, Aquaculture, and Range Sciences (DAARS) for analysis. Before analysis, the samples were deep frozen at −18°C, a temperature that matched the storage conditions used by fish sales markets and fish landing sites for fresh fish. Sample preparation was according to each testing protocol.

Estimation of pH

A 20 g sample of fish fillet was homogenized with 100 ml of distilled water to create an aqueous solution, and the pH of the solution was measured using a pH meter that was calibrated with buffer solutions of pH 4 and pH 7. The samples were examined in triplicate, and the average result served as the final reading.

Estimation of total volatile basic nitrogen (TVB-N)

An extract for total volatile basic nitrogen (TVB-N) estimation was prepared by homogenizing 100 g of each of the tuna fillet samples. Then 10 ± 0.1 g was weighed and placed into a food-grade stainless steel blender, and 90 ml of 0.6 N perchloric acid was added to the sample. The mixture was blended for two minutes, followed by filtration through Whatman's filter paper number two. Then 50 ml of the collected filtrate was added in Opsis Automatic Distillation equipment set to dose automatically 30 ml of 40% sodium hydroxide and 30 ml of distilled water. The distillation process was started and the distillate was collected over 25 ml of 4% boric acid and placed in a conical flask with a few drops of bromocresol green indicator. The distiller settings were 100% steam for 4.5 minutes. Approximately 150 ml of receiver solution containing volatile base distillate was titrated with standard hydrochloric acid using Jencon's digitrate automatic titration system. The endpoint was determined at pH 5.0 ± 0. Ammonia, triethylamine, and dimethylamine make TVB-N, and each molecule contains one basic nitrogen atom. TVB-N concentration expressed in mg/100 g sample was calculated using the following formula;

$$\frac{\mathrm{TVBN} = (\mathrm{Vs} - \mathrm{Vb})^{*}0.14^{*}2^{*}100}{\text{Weight of sample (g)}}$$

Whereas;	Distillation parameters:		
TVB-N = Total Volatile Basic Nitrogen (mg/100 g)	**Variable**	**Specification**	**Requirement**
NHCL = Normality of HCl (mol/1000 mL)	NaOH	40%	30mls
Vs = Consumption mol/lHCl sample (mL)	Boric Acid	4%	25mls
Vb = Consumption mol/lHCl blank (mL)	SteamHT	100%HT	4.5 minutes
	Water	Distilled	30mls

Before running each sample, a blank was performed by distilling and titrating 50 ml of 0.6 N perchloric acid solution without the fillet extract in the same procedure conditions. Then, duplicate analyses were performed, and the difference within the same sample was less than 2 mg/100 g. Finally, recovery measurements were carried out with NH_4Cl equivalent to 50 mg TVB-N/100 g and gave an average recovery of 99.68% ± 0.70. Thus, the method used fulfills the official requirement number 95/149/EC of the commission of the European communities.

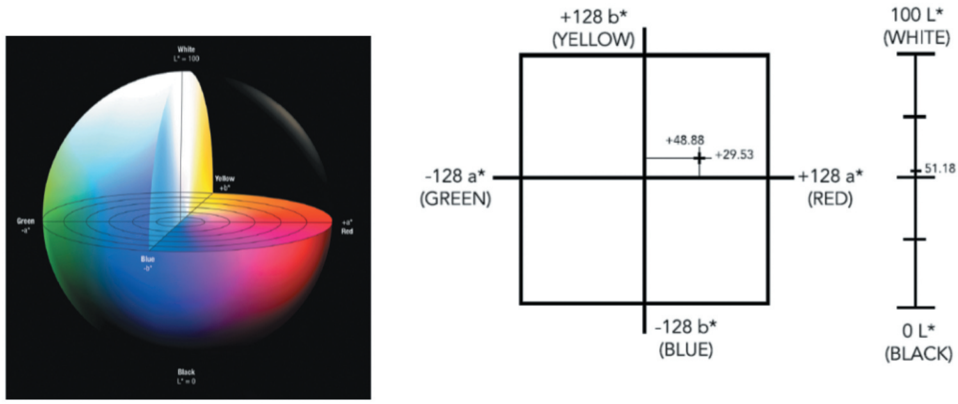

Figure 1. CIE L*a*b* color space: source: Konica Minolta.

Estimation of fillets color properties

The Chromameter CR 400, Konica Minolta Inc., Japan, with 8 mm and 50 mm measuring apertures, was used to measure tuna fillet color properties in the present study. It is a simple, objective, nondestructive, and fast instrument that has recently been widely used in various food industries to measure the color properties of food materials. The instrument describes food using color measurements, adopted by the Commission Internationale d'Eclairage (CIE) in 1976, abbreviated as CIE L*a*b*. The symbol L* represents the color lightness properties with a scale ranging from 0 (dark) to 100 (light), while the symbol a* represents the color redness properties with a scale ranging from −120 (green) to 120 (red). Similarly, the yellow color properties are represented by the symbol b*, which has a scale ranging from −120 (blue) to 120 (yellow).[20]

For the color space, a* values are represented on the X-axis, b* values on the Y-axis, and L* values on the Z-axis (Figure 1). The procedure involved making cross-section cuts on the sample using a shape blade to create even flat surfaces for the Chromameter to take a reading (at least two surfaces). Then, the sample fillets were sliced similarly, with a minimum thickness of 12 mm to 15 mm to ensure correct color readings were taken. Finally, the readings of color lightness properties (L*), color redness properties (a*), and color yellowness properties (b*) were taken on the two flat surfaces created on fillet samples and the average was calculated. This study has adopted color lightness (L*) properties.

Estimation of texture (hardness) properties

The fillet cubes, each measuring roughly 15 mm in thickness and 5 cm in length, were resected from tuna fillet samples and loaded into the fixture of the texture analyzer. The apparatus sheared samples and produced a precise force-deflection graph. The highest point on the chart indicated the maximum shear force produced by the fillet sample. To ensure sample uniformity and create an even distribution of shear weight, the samples were resected in parallel lines and in the same direction as the fibers in the steak. Sample variations were using the same methods each time.

Sensory evaluation of the tuna fillets

A sensory evaluation is a systematic approach to investigating, estimating, analyzing, and explaining the quality properties as judged by the senses of sight, smell, taste, touch, and hearing.[21] A designed quality index method (QIM), a standard for the quick, nondestructive, and rapid approach to sensory evaluation, was used to assess the sensory qualities of the frozen tuna fillets [22]. The quality index criteria evaluated tuna species' fillet color, texture (hardness), and odor quality properties [23,24]. Each index was assigned descriptors or characteristics at three different levels or categories of quality, as indicated in Table 1. The first quality category represented high quality and was assigned code number one (1), with the high-quality characteristics of each species of tuna fillet. The second quality category represented good quality and was assigned code number two (2) with the good-quality characteristics of each tuna species. And finally, the third quality category represented the low-quality characteristics of the tuna species and was assigned code number three (3). The semi-trained laboratory technicians analyzed the color, texture (hardness), and odor quality properties of each of the tuna fillet samples and assigned high (1), good (2), or low (3) quality scores according to their perception. They recorded the results on the scorecards provided. The selected area for sensory evaluation tests was free from distractions, foreign odors, and any other type of analysis.

Data analysis

IBM SPSS Statistics-20 was used to analyze the data. For each variable, descriptive statistics were computed, including average, standard deviation, maximum, and minimum values. The sample means were compared by One-Way ANOVA at a 5% significance level, followed by Post Hoc Turkey's b test. A two-tailed bivariate Pearson's correlation coefficient analysis tested whether there was a relationship between the variables evaluated.

Table 1. Tuna fillets sensory quality attributes (descriptors).

SPECIES	INDEX	1-HIGH QUALITY	2-GOOD QUALITY	3-POOR QUALITY
Yellow Fin	Color	Translucent pale reddish color	Brownish-yellow	Dark brown, very opaque green gray
	Texture	Firm and elastic (springs back quickly on pressing)	Firm, reduced elasticity, flesh soft (doesn't spring back fully on pressing).	Very soft mushy, flesh falling away from the carcass, fingerprints leave impressions
	Odor	No fish smell, neutral, and fresh.	Definite fish smell, stale, slightly brine and fishy oxidized caramel	Very stale, very sour, putrid, very rancid and ammonia, fuel.
Skipjack	Color	Translucent, shiny	Dark red-brownish, Pale pink, light green, iridescent	Dark brown, gray-green, dark green, opaque, cooked appearance
	Texture	Firm and elastic (springs back quickly on pressing)	Firm, reduced elasticity, flesh soft (doesn't spring back fully on pressing).	Very soft mushy, flesh falling away from the carcass, fingerprints leave impressions
	Odor	Game, meaty, seaweed neutral	Oxidized, stale, caramelized, slightly rancid, persistent sour. heavy brine, fruity	Putrid rancid, very stale, pungent, sour, fermented, fruity fecal, sweet cheesy acid, ammonia, fuel.
Bigeye	Color	Bright Red, reddish-pinkish fillets	Dark-red, Reddish-brown, brownish not translucent	Very opaque green-gray, red-pink, honeycomb, curdy (feverish) gray color
	Texture	Firm and elastic (springs back quickly on pressing).	Firm, reduced elasticity, flesh soft (doesn't spring back fully on pressing).	Very soft mushy, flesh falling away from the carcass, fingerprints leave impressions
	Odor	No fish smell, fresh, neutral, slightly seaweedy.	Definite fish smell, light stinky, sweetish, sour, slightly rotten off-odors	Pronounced putrid, rotten, stinking, sulfide, strong off-odors
Kawakawa	Color	Brownish translucent, shiny	Pale pink, Dark red, slight green, iridescent pink-greenish	Dark-brown, gray-green, dark green opaque, honeycomb
	Texture	Firm and elastic (springs back quickly on pressing).	Firm, reduced elasticity, flesh soft (doesn't spring back fully on pressing).	Very soft mushy, flesh falling away from the carcass, fingerprints leave impressions
	Odor	No fish smell, light, neutral, sourish, slight seaweedy fresh odor	Definite fish smell, light stinky, sweetish, sour and slightly rotten off-odors	Pronounced putrid, rotten, stinking, sulfide strong off-odors

Results

Table 2 presents the results of the physicochemical and sensory quality properties of the 84 tuna and tuna-related fish species fillet samples. There were significant differences ($p < .05$) between the tuna species in pH, texture (hardness), and color lightness properties (L*). TVBN and sensory odor properties had no significant differences ($p > .05$) in their average results, while sensory color and sensory texture (hardness) differed significantly among the tuna species. The quality index approach to the sensory evaluation of the tuna fillets gave an overall score of 2, which is good quality as indicated in Table 3. This study observed significant weak, moderate, and strong negative and positive correlations among the tuna and the tuna-related fish properties evaluated. Sensory color properties have a strong relationship with instrumental color lightness properties. In the same way, the hardness (sensory) correlates strongly with the hardness (instrumental) per Table 4.

Discussion

This study reports the quality of tuna fish marketed in Tanga and Mtwara, Tanzania. Most of the evaluated physico-chemical and sensory properties of tuna and tuna-related fish species are within the ranges reported elsewhere. Fresh food materials have specific pH ranges that can be used to monitor their quality.[25] The use of pH properties in monitoring fish quality is more convenient than other properties because it is quick, cheap, reliable, and correlates strongly with physicochemical properties such as color and TVB-N.[26,27] Furthermore, the estimation of pH represents an important factor in the quality evaluation of various foods including sea-foods. The change in hydrogen ion concentrations in fish muscles is a result of the changes in biochemical, bacteriological, and enzymatic processes occurring in fish muscles after capture.[28] These changes have a pronounced impact on fish fillet quality properties.[29] A review by[26] reported correlations between fish freshness and pH during cold storage. Likewise, a study on factors leading to changes in fillet color suggested that fillet color is affected by postmortem glycolysis, particularly by pH drop, which indicates the effects of pH on fillet quality.[7] This study reports a pH range of 5.60 ± 0.08 to 6.10 ± 0.30 in line with the initial pH values of 5.2 to 6.1 reported in fresh tuna.[30,31] explain that the quality deterioration of protein and lipids in fish muscles affects their odor, color, flavor, taste, aroma, nutritional value, and texture. Protein degrades in fish to produce an increase in TVB-N that represents the sum of ammonia, dimethyl amine (DMA), trimethyl amine (TMA), and other volatile nitrogen compounds.[32] TVB-N is widely used to monitor the quality and is also an indicator of fish freshness. Fishy odor and flavor are also accounted for by the presence of these volatile nitrogen compounds in fish several days after the catch.[32] This study reports TVBN values between 34 ± 7.00 mg/100 g and 38.04 ± 10.50 mg/100 g, which are higher than TVBN values reported in other studies. In their study on the quality assessment of ice-stored tropical yellowfin tuna in France, Silbande *et al.*[33] reported TVBN to range from 16.3 ± 0.6 to 20.3 ± 2.0 mg/100 g. Likewise,[34] reported initial TVBN values of 11.93 ± 0.05 mg/100 g in the study on the quality characteristics of Yellowfin tuna in India. However, there are no stipulated TVB-N standardized quality assessment parameters for tuna fish. The higher TVB-N value reported in this study may be due to improper catching, processing, packaging, storage, and distribution practices. Furthermore, prerequisite treatments required specifically for tuna fish at the catch point, such as spiking, bleeding, and placing in ice slurry, may also play a part in the higher TVBN values if not observed.[9,31]

Fish fillet color is a parameter commonly used by consumers to evaluate quality. The fillet color gives the first impression on the fillet quality because discoloration is associated with spoilage [35] The Chromameter CR 400 evaluates the quality of the color based on color lightness properties (L*), color redness properties (a*), and color yellowness properties (b*). This study has adopted color lightness (L*) properties to evaluate the quality of the color of the fillet samples, and the results are variable. Skipjack tuna recorded lower average color lightness properties [L*) values than those reported by[36] in a comparative study of basic characteristics of ordinary and dark muscles in Skipjack tuna.

Table 2. Average pH, TVBN, color, texture (hardness), and sensory results.

			Color lightness properties				Sensory		
Fish Species	PH	TVBN	L*	a*	b*	Texture (hardness) (N)	Texture (hardness)	Color	Odor
Skipjack	6.10 ± 0.30	38.04 ± 10.50	24.33 ± 1.82	6.00 ± 1.20	3.20 ± 0.80	3.84 ± 1.20	2.40 ± 0.60	2.70 ± 0.50	2.50 ± 0.51
Bigeye	6.02 ± 0.33	34.00 ± 7.00	33.42 ± 2.81	4.70 ± 1.10	2.90 ± 1.40	5.40 ± 1.72	1.80 ± 0.60	1.54 ± 0.51	2.30 ± 0.50
Yellowfin	5.60 ± 0.08	36.01 ± 3.94	40.10 ± 1.50	4.80 ± 1.40	3.80 ± 1.20	8.60 ± 1.84	1.00 ± 0.00	1.00 ± 0.00	2.00 ± 0.00
Kawakawa	6.10 ± 0.20	37.00 ± 4.00	25.60 ± 1.84	7.50 ± 1.20	3.50 ± 0.91	5.01 ± 1.34	1.70 ± 0.50	2.40 ± 0.50	2.50 ± 0.51
Total	6.03 ± 0.30	36.11 ± 7.80	29.00 ± 6.00	5.80 ± 1.60	3.20 ± 1.11	5.00 ± 2.00	1.90 ± 0.64	2.10 ± 0.74	2.40 ± 0.50
Sampling Point									
Fish landing site	6.12 ± 0.24	36.32 ± 8.50	26.74 ± 3.70	6.11 ± 1.60	3.20 ± 1.00	4.62 ± 1.60	2.00 ± 0.64	2.40 ± 0.60	2.50 ± 0.50
Market Samples	5.80 ± 0.30	35.50 ± 4.60	35.82 ± 4.51	5.00 ± 1.40	3.20 ± 1.50	6.20 ± 2.20	1.61 ± 0.61	1.20 ± 0.40	2.10 ± 0.23
Total	6.03 ± 0.30	36.11 ± 7.80	29.00 ± 5.51	5.83 ± 1.61	3.20 ± 1.11	5.00 ± 1.90	1.90 ± 0.64	2.10 ± 0.74	2.40 ± 0.50

Table 3. Tuna fillets Post Hoc Turkey's b test results.

	PH		TVBN	Color lightness properties (L*)			Color a* Redness			Instrumental Texture (hardness)		Sensory Color			Sensory Texture (hardness)			Sensory Odor
Fish	Subset for alpha = 0.05		Subset for alpha = 0.05	Subset for alpha = 0.05			Subset for alpha = 0.05			Subset for alpha = 0.05		Subset for alpha = 0.05			Subset for alpha = 0.05			Subset for alpha = 0.05
Species	1	2	1	1	2	3	1	2	3	1	2	1	2	3	1	2	3	1
Yellowfin	5.6		36.01			40.09	4.82				8.60	1			1			2
Bigeye		6.02	33.90		33.42		4.70			5.40			1.54			1.80		2.30
Kawakawa		6.07	37.00	25.60					7.50	5.01				2.40		1.70		2.50
Skipjack		6.10	38.04	24.33				6.00		3.84				2.70			2.40	2.50

Table 4. Correlations physico-chemical and sensory quality properties.

		Color L*	Moisture	PH	Color a*	Sensory Color	Sensory Odor	Instrumental Texture	TVB-N	Sensory Texture
Color lightness properties (L*)	Pearson Correlation	1	0.001	−0.483**	−0.479**	−0.905**	−0.377**	0.434**	−0.196	−0.307**
	Sig. (2-tailed)		0.993	0.000	0.000	0.000	0.001	0.000	0.111	0.008
Moisture	Pearson Correlation	0.001	1	0.103	0.031	−0.001	0.006	0.073	0.043	−0.041
	Sig. (2-tailed)	0.993		0.388	0.796	0.992	0.961	0.541	0.732	0.732
PH	Pearson Correlation	−0.483**	0.103	1	0.218	0.427**	0.566**	−0.180	0.249*	0.132
	Sig. (2-tailed)	0.000	0.388		0.063	0.000	0.000	0.128	0.042	0.266
Redness	Pearson Correlation	−0.479**	0.031	0.218	1	0.388**	0.165	−0.087	0.151	0.040
	Sig. (2-tailed)	0.000	0.796	0.063		0.001	0.163	0.466	0.223	0.735
Sensory Color	Pearson Correlation	−0.905**	−0 .001	0.427**	0.388**	1	0.300**	−0.342**	0.164	0.225
	Sig. (2-tailed)	0.000	0.992	0.000	0.001		0.010	0.003	0.186	0.055
Sensory Odor	Pearson Correlation	−0.377**	0.006	0.566**	0.165	0.300**	1	−0.232*	00.189	0.192
	Sig. (2-tailed)	.001	0.961	0.000	0.163	0.010		0.048	.125	0.104
Texture (hardness)	Pearson Correlation	0.434**	0.073	−.0180	−0.087	−0.342**	−0.232*	1	−0.263*	−0.807**
	Sig. (2-tailed)	0.000	0.541	0.128	0.466	0.003	0.048		0.032	0.000
TVB-N	Pearson Correlation	−0.196	0.043	0.249*	0.151	0.164	0.189	−0.263*	1	0.176
	Sig. (2-tailed)	0.111	0.732	0.042	0.223	0.186	0.125	0.032		0.154
Sensory Texture (hardness)	Pearson Correlation	−.307**	−0.041	0.132	0.040	0.225	0.192	−0.807**	0.176	1
	Sig. (2-tailed)	0.008	0.732	0.266	0.735	0.055	0.104	0.000	0.154	

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Kawakawa tuna species had color-lightness properties (L*] in line with the values recorded by [37] in their study on nutritional, textural, and quality attributes of white and dark muscles of little tuna. Yellowfin tuna had higher color lightness properties [L*) than those reported by,[34] in a study on the quality characteristics of Yellowfin tuna in India. Each of these studies has reported different initial L*a*b* values and therefore there is a need for standardized CIE L*a*b* color space assessment parameters.[38]

Hardness and firmness are significant factors that affect the textural characteristics of tissue muscles. The hardness properties are considered the most significant-quality properties in indicating product freshness and guiding decisions on the commercial value of meat.[11,39] Numerous inter-related chemical, physical, and structural factors can affect fish muscle texture (hardness). [11,40] Softening and gaping of muscle tissues are quality defects used to indicate meat freshness linked to structural changes.[11] Moreover, structural changes affect fillet palatability and hence consumer acceptability of the fillet. [41]. Others reported tuna fillet texture [hardness) using techniques other than the Warner Bratzler shear compression method.[37] study on nutritional, textural, and quality attributes of the white and dark muscles of kawakawa, they reported *a* hardness of 3.40 ± 0.23 N in the white and 3.74 ± 0.15 N in the dark meat based on the texture profile analysis (TPA] method. In a study on physicochemical quality parameters of raw yellowfin tuna, hardness values measured by a universal testing machine with a cylindrical probe ranged from 23.210 ± 0.21 N to 26.788 ± 0.4 N.[34] These values are higher than the present study's yellowfin hardness values of 8.60 ± 1.84 N.

Based on the quality index method of sensory evaluation, the present study shows yellowfin tuna to have the highest quality properties of the rest of the tuna species, followed by bigeye. Kawakawa and skipjack had almost equal quality scores. Using the quality index approach[41]reported that the color of tuna steaks gradually turned from red to dark red with a decrease in freshness.

The Pearson correlation coefficient assessed the linear relationship among the tuna fish species' quality properties evaluated in this study. It indicates the change in fish fillets' quality attributes with changes in physico-chemical and sensory quality properties that often interlink and influence one another.[42] For example, the variations in pH have been known to correlate well with other quality properties such as hardness, color, odor, and TVBN. [11,40] The current study has shown a moderate positive relationship between TVBN and pH with a correlation coefficient of 0.249*. The findings of this study agree with those on correlations between fish freshness and pH during cold storage, which reported a strong correlation between pH and TVBN with a correlation coefficient of 0.97.[26] The quality of fish degrades with an increase in pH and TVBN. The correlation coefficient of 0.483** revealed a significant negative moderate association between pH and color lightness properties (L*). The pH causes discoloration of the fish fillets by supporting the oxidation of myoglobin DeoxyMb and OxyMb to MetMb [42,43], which causes the fillet color to turn dark and reddish-brown. The dark-red and reddish-brown colors of tuna fillets in this study were considered good quality in the quality index categories indicated in Table 1. Moreover, this study has shown a weak negative relationship between pH and instrumental hardness with a correlation coefficient of −0.180. Changes in pH were reported to have an impact on the hardness of the fillets[44,45] discovered an inverse relationship between muscle toughness and pH, with unacceptable levels of toughness occurring at lower pH levels. The relationship between hardness and sensory color was significant, with a correlation coefficient of −0.342**. Furthermore, hardness (sensory) and hardness [instrumental) had a strong correlation coefficient of −.807**. Thus, these findings agree with the findings reported by [46,47] and [6].

Conclusion

The present study observed higher average TVBN values than the reported values elsewhere. The pH properties were in line with other studies, while the color lightness properties (L*] and texture (hardness) were variable. There is interlink of pH with TVBN, color lightness (L*), instrumental hardness, and odor sensory properties. The study also revealed a strong relationship between sensory and instrumental properties. Based on the quality properties results and correlation analysis, tuna and tuna-related fish marketed in the study areas were of good quality. The good-quality conclusion of this study is solely on the study's results, references made, and sensory analysis because there are no stipulated standardized parameters to guide the tuna fish quality assessment.

Recommendations

This study recommends the establishment of standardized quality assessment parameters for tuna and tuna-related fish species. For high-quality tuna and tuna-related fish, it is inevitable to implement policies to safeguard the quality and provide education on proper fish handling practices to all the stakeholders, particularly fish handlers in the tuna fish value chain.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Sokoine University's Department of Aquaculture, Animal and Range Sciences (DAARS) laboratories, Tanzania's Deep Sea Fishing Authority (DSFA), and Mbeya University of Science and Technology (MUST).

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