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Impact of Thermal Processing Procedures on Technological Properties and Nutritional Value of Sea Cucumber

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ABSTRACT

This study aimed to assess the impact of boiling and drying on the qualitative characteristics of *Holothuria tubulosa*, a commercially significant and prevalent sea cucumber species throughout the Egyptian Mediterranean coastline. The proximate composition, physicochemical properties, water activity, fatty acid profile, amino acid content, volatile flavor compounds, microbiological characteristics, and sensory quality were assessed in fresh, boiled, and dried samples of *H. tubulosa*. Findings indicated that *H. tubulosa* was classified as a low-carbohydrate, low-fat, and high-protein food. The bulk of fatty acids decreased after the thermal process, whereas specific particular saturated fatty acids and polyunsaturated fatty acids diminished during the drying process. Additionally, there was a notable reduction in saturated fatty acids following processing temperatures. A total of 34 volatile flavor chemicals were found, mostly categorized as aldehydes, alcohols, aromatic compounds, ketones, terpenes, and others. Thermal processing procedures significantly influenced the quality features of sea cucumbers. Based on physicochemical, microbiological, and sensory quality analyses, the maximum allowable limits set by national and international standards were not exceeded by either raw or processed *H. tubulosa* samples. This suggests that the samples were safe and may have nutritional value as a nutritious food source for human consumption.

INTRODUCTION

Sea cucumber (*Holothuria tubulosa*) a marine invertebrate is among the most prevalent sea cucumbers in the Mediterranean Sea. Sea cucumber has been utilized for an extended period throughout the Middle East and Asia for culinary and medicinal purposes, since it has over 50 compounds of vitamins, amino acids, and minerals. It is not traded nor preserved in its fresh state due to autolytic enzymes and is typically offered in pickled or dried form **(Pasquini *et al.*, 2023)**.

Sea cucumbers (*Holothuria tubulosa*) exhibit a superior proximate composition and a varied fatty acid profile, notably in n-3 polyunsaturated fatty acids (PUFAs), such as DHA and EPA. The consumable integument of *H. tubulosa* is regarded as a nutritious food for consumers due to its significant nutritional attributes, including eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), atherogenicity index (AI), thrombogenicity index (TI), and the n-3PUFA/n-6PUFA ratio. The skin's ability to prevent and neutralize free radicals was noteworthy. Additionally, a variety of *H. tubulosa* components may have a beneficial impact on the maintenance or bolstering of antioxidant systems and may be thought to have antioxidant potential **(Zmemlia *et al.*, 2020)**.

The desiccation of sea cucumber is a fundamental method to prolong its shelf life while preserving qualitative attributes by diminishing moisture content, hence limiting microbial and enzymatic activity and averting autolysis. A prevalent technique for drying sea cucumbers is convection drying using hot air, noted for its simplicity and cheap operational expenses. The decomposition of some bioactive compounds and the shrinkage of dried materials are some of its disadvantages. The most common method used worldwide to preserve around 80% of the entire sea cucumber crop is sun drying **(Li *et al.*, 2018)**. Numerous research initiatives were undertaken to improve the quality of sea cucumber species **(Li *et al.*, 2018; Talab *et al.*, 2024)**. The objective of this study was to clarify the nutritional benefits of *H. tubulosa*, a common species of sea cucumber found along the Mediterranean Sea coast of Egypt, for consumers by analyzing and contrasting the effects of boiling and drying on its proximate composition, amino acid and fatty acid profiles, and volatile taste compounds.

MATERIALS AND METHODS

Preparation and processing of raw materials

Sea cucumbers (*Holothuria tubulosa*) were collected from the Mediterranean coast of Egypt, specifically Miami Island in Alexandria Governorate (Lat: 31.2368499, Long: 26.0572625), exhibiting average weight and length measurements of (74.58±9.34) grams and (65±1.10) centimeters, respectively. Samples were promptly packed in an ice box and transferred within three hours to the Fish Processing and Technology Laboratory at the National Institute of Oceanography and Fisheries (NIOF) in El-Kanater El-Khairia, Qaliubia Governorate. Upon arrival, sea cucumber specimens were first categorized and identified by two biologists specializing in invertebrates, utilizing morphological traits and spicule examination. The body walls of the sea cucumber specimens were separated from the viscera and thoroughly rinsed with distilled water to remove sand and debris, yielding around 43%. Subsequently, samples were categorized into three categories, with each group comprising 50 individuals: raw, boiling, and dried. The body wall was subsequently sectioned into small pieces (1-1.5 cm), heated at 100°C for 5 minutes, and dried at 40°C for four days. The desiccated material was pulverized and subjected to sieving through a ≤ 600 µm mesh. The powder was preserved in a sealed dark bottle at

4°C until subsequent examination. All chemicals were of analytical grade and were procured from Sigma-Aldrich, GmbH Taufkirchen, Germany. Despite various recommendations for the governance of sea cucumbers, no ethical protocols have been established. In our research, we ensured that all specimens were treated with respect and compassion, utilizing ethically sound procedures.

Analytical methodologies

The proximate composition and trimethylamine nitrogen (TMA-N) of the sea cucumber were evaluated according to **AOAC (2005)** standards. The water activity in sea cucumber samples was evaluated using a portable Rotronic HP23-AW water activity meter **(Schiraldi *et al.,* 1996)**. Total volatile basic nitrogen (TVB-N), thiobarbituric acid (TBA), and pH value were quantified according to **Pearson (1991)**. The total bacterial count was assessed following the methodology of **Downes and Ito (2001)**. Sensory evaluations of sea cucumbers were performed after boiling the samples at 100°C for 5 minutes, as stated by **Hou *et al.* (2014)**. Texture analysis of *H. tubulosa* samples was performed at the National Research Center in Giza, Egypt. The measurement was conducted subsequent to sectioning the body wall into 1 cm x 1 cm x 1 cm cubes using a texturometer (Brookfield, CT3-10 kg, USA) equipped with a cylindrical probe (TA.AACC36).

Fatty acid analysis was performed at the National Research Center in Giza, Egypt. The methodology for obtaining lipids from *H. tubulosa* samples were subjected to cold extraction, and fatty acids were identified using gas chromatography (GC-FID) with an HP 6890 plus gas chromatograph, featuring a Supelco™ SP-2380 capillary column and detected by a flame ionization detector (FID), in accordance with modified methods from **Zahran and Tawfeuk (2019)**.

Amino acids derived from *H. tubulosa* were analyzed at the National Research Center in Giza, Egypt, employing the LC 3000 amino acid analyzer, a high-performance instrument produced by LC Biochrom EPPDROP, Germany **(AOAC, 2005)**.

Headspace sampling (HS-SPME) and gas chromatography-mass spectrometry (GC-MS) analyses of volatile chemicals were performed at the National Research Center in Giza, Egypt. Volatile chemicals in *H. tubulosa* samples were analyzed according to **Centonze *et al.* (2019)** using solid-phase microextraction (SPME) using an Agilent 8890 GC System connected to an Agilent 5977B GC/MSD mass spectrometer. All data were reported as the mean value of three duplicate samples±SD (Microsoft Office Excel, 2010).

RESULTS AND DISCUSSION

Biometric assessments of sea cucumbers

Biometric measurements of raw, boiling, and dehydrated *H. tubulosa* are depicted in Table (1). The results indicated a significant difference (P<0.05) in lengths and weights among fresh, boiled and dried samples of *H. tubulosa*. Conversely, the dimensions and mass of fresh *H. tubulosa* diminished to roughly 58% during boiling. While the weight and length of *H. tubulosa* had further diminished from 85 and 61% at the conclusion of drying duration, length, and weight of sea cucumbers, respectively. The average weights (g), lengths (cm), and widths (cm) of raw, cooked, and dried *H. tubulosa* were assessed (70.17, 13.17, 2.83g), (32.96, 6.25, 2.11cm), and (11.55, 5.32, 1.77cm), respectively. The results obtained align with those reported by **Cakli *et al.* (2004)**.

Table 1. Effect of boiling and drying on biometric measurements, chemical composition, texture, physical, chemical and microbial properties of sea cucumber

Parameter	Raw	Boiled	Dried
Biometrical measurements			
Weights	70.17±3.25	32.96±2.44	11.55±1.10
Lengths	13.17±2.20	6.25±1.15	5.32±1.01
Widths	2.83±0.25	2.11±0.23	1.77±0.10
Chemical composition			
Moisture (%)	84.96±1.49	65.13±1.12	21.30±1.10
Protein (%)	8.45±1.01	15.35±1.00	51.91±1.03
Lipid (%)	0.32±0.11	3.12±0.10	3.77±0.13
Ash (%)	5.33±0.53	13.32±0.43	15.75±0.50
Carbohydrates (%)	0.94±0.25	3.08±0.27	7.27±0.20
Energy (Kcal/100g)	38.97±1.03	93.69±1.01	255.66±1.15
Texture profile			
Hardness (N)	6.20±1.25	2.62±1.55	12.29±3.25
Adhesiveness (g.cm)	8.00±1.85	1.00±0.01	0.00±0.00
Cohesiveness	0.27±0.12	0.89±0.10	0.82±0.09
Gumminess (N)	1.68±0.05	2.33±1.15	10.08±2.01
Resilience	0.03±0.01	0.71±0.09	0.44±0.04
Springiness (mm)	35.00±3.48	7.72±2.15	6.49±2.44
Chewiness (g.cm)	601.00±6.12	183.00±3.15	667.00±6.15
Physical, chemical, microbial parameters			
pH value	8.21±1.05	8.01±1.19	7.01±1.11
TVBN (mg N/100g)	12.58±2.45	14.37±2.20	23.12±2.48
TMA (mg N/100g)	1.20±0.21	1.01±0.24	1.19±0.15
TBA (mg MDA/kg)	0.14±0.06	0.24±0.05	0.29±0.05
TBC (cfu/g)	3.79×10^4	2.65×10^4	2.01×10^4
Water activity (aw)	0.97±0.01	0.66±0.03	0.32±0.05

Chemical constituents of sea cucumbers

Chemical composition of raw, boiling, and dehydrated *H. tubulosa* is presented in Table (1). The data collected indicated that fresh, boiling, and dried *H. tubulosa* comprises (84.96%, 65.13%, 21.30%) moisture; (8.45%, 15.35%, 16.21%) protein; (0.32%, 3.12%, 3.77%) lipid; (5.33%, 13.32%, 15.75%) ash; (0.94%, 3.08%, 42.97%) carbohydrates and (38.97, 93.69, 255.66 Kcal/100g) energy, respectively. Our results indicated a substantial difference (*P*<0.05) in moisture, protein, lipids, ash, carbohydrate, and calorie values among fresh, boiled, and dried *H. tubulosa*. The results obtained are predominantly congruent with findings from a limited number of research on some species of the Holothuridae family of sea cucumbers **(Talab *et al.*, 2024)**. On the other hand, **Cakli *et al.* (2004)** discovered that fresh, boiled, and dried *H. tubulosa* comprises 86.74, 66.17, and 20.47% moisture; 8.18, 15.00, and 66.45% protein; and 0.16, 0.41, and 0.60% lipid, respectively. In addition, **Zmemlia *et al.* (2020)** discovered the moisture, protein, lipid, and energy content of *H. tubulosa* were 80.77, 7.07, 10.21%, and 13.64 kcal/g wet weight. The levels of moisture, protein, fat, and ash in *H. tubulosa*, *H. Polii* and *H. mammata* taken from the Aegean Sea in Turkey exhibited variations of 81.24 to 85.24%, 7.88 to 8.82%, 0.09 to 0.18%, and 5.13 to 7.85%, respectively **(Aydin *et al.*, 2011)**. Our research indicated that dried sea cucumbers had high protein and ash levels, accompanied by low fat content. Similar results for dried sea cucumber were observed by **Truongs and Le (2019)** about six varieties of dried sea cucumber products obtained from different countries.

Physicochemical and microbiological assessment of sea cucumbers

Alterations in physicochemical and microbiological quality of raw, boiled, and dried *H. tubulosa* is presented in Table (1). The pH value, total volatile basic nitrogen (TVBN), trimethylamine (TMA), thiobarbituric acid (TBA), total bacterial count (TBC), and water activity of raw, boiled, and dried *H. tubulosa* exhibited a statistically significant difference (*P*<0.05) between fresh and thermally processed samples.

The pH value, total volatile basic nitrogen (TVBN), trimethylamine (TMA), thiobarbituric acid (TBA), total bacterial count (TBC), and water activity of raw, boiled, and dried *H. tubulosa* reported values of 8.21, 8.01, 7.01; 12.58, 14.37, 23.12 mg/100g; 1.20, 1.01, 1.19 mg/100g; 0.14, 0.24, 0.29 mg MDA/kg; 3.79 x 104, 2.65 x 104, 2.01 x 104 cfu/g, and 0.97, 0.66, 0.32 aw, respectively.

Cakli *et al.* (2004) corroborated similar findings, indicating that raw, boiled, and dried *H. tubulosa* exhibits pH values of 8.45, 4.47, 7.30; TVBN levels of 18.90, 9.80, 29.80 mg/100g; TMA concentrations ranging from 4.11 to 3.56 mg/100g, and TBA values of 0.18, 0.27, 0.38 mg MDA/kg, respectively. The specimens of raw and processed *H. Sanctori* did not surpass the maximum allowable thresholds as indicated by **Ludorff and Meyer (1973)**, who noted that spoiled samples contain over 35mgN/ 100g TVBN. Conversely, the **FAO (1986)** reported that, spoiled samples exceed 8mgN/ 100g TMA-N. Additionally, **Schormüller (1969)** stated that the consumption limit for TBA value ranges from 7 to 8mg malonaldehyde/kg. The results obtained align with the findings of **Cakli *et al.* (2004)** and **Talab *et al.* (2024)**. **Li *et al.* (2022)** asserted that frozen storage is inappropriate for *Apostichopus japonicus*, despite the TVB-N value being initially low, as it rose to 13.405±0.917 mg/100g by day 7, remaining below the maximum acceptable limit of ≤30 mg/100g.

Sea cucumber texture assessment

The texture of sea cucumber is a crucial determinant of consumer acceptance and a vital criterion for evaluating its quality. Post-harvest circumstances significantly influence the functional structure and tissue characteristics **(Veena *et al.*, 2022)**. Texture profile study of fresh, boiled, and dried *H. tubulosa* samples are provided in Table (1). The results indicated that the boiling process greatly (P<0.05) enhanced cohesiveness, gumminess, and resilience, but it significantly (P<0.05) reduced hardness, adhesiveness, springiness, and chewiness of *H. tubulosa* tissue specimens. Conversely, the drying procedure significantly (P<0.05) enhanced hardness, cohesiveness, gumminess, resilience, and chewiness, while it significantly (P<0.05) reduced adhesiveness and springiness of *H. tubulosa* tissue specimens (Table 1). The autolysis of sea cucumber during storage is attributable to the loss of fish protein and diminished water-holding capacity resulting from a decline in textural characteristics **(Li *et al.*, 2022)**. Comparable findings from texture profile study of dried sea cucumber were documented by **Truongs and Le (2019)**.

Fatty acids profiles of sea cucumbers

Fatty acids (FA) are believed to contribute nutritionally to benthic food webs. Fatty acids and their ratios function as indicators to validate and monitor food sources and trophic relationships in diverse aquatic ecosystems **(Coelho *et al.*, 2011)**. Table (2) illustrates the fatty acid profile of fresh, boiled, and dried *H. tubulosa* samples. The results indicated considerable variance (P<0.05) following thermal processing procedures. The results indicated that the most significant reduction in fatty acids occurred following the thermal process, whereas certain specific saturated and polyunsaturated fatty acids diminished after the drying process. A substantial drop (P<0.05) in saturated fatty acids (SFAs) was observed during processing, with levels declining from 64.39% in raw samples to 28.47% in boiled samples and 8.33% in dried samples. A significant increase (P<0.05) in UFAs was detected, rising from 35.61% in raw samples to 64.17% and 91.68% in boiled and dried samples, respectively. Comparable results were documented by **Aydin *et al.* (2011)** and **Zmemlia *et al.* (2020)**. Sea cucumbers are low in fat, predominantly consist of polyunsaturated fatty acids, and are high in protein, with protein levels varying from 40% to 60%.

Sea cucumbers demonstrate a diminished metabolic rate and are incapable of synthesizing long-chain fatty acids. They instead accumulate these fatty acids by ingesting their dietary sources, which may influence their chemical composition and nutritional properties **(Gajdosechova *et al.*, 2020)**.

Table 2. Effect of boiling and drying on fatty acid profile of sea cucumber

Abbreviation	Fatty acids (% of total fatty acids)	Raw	Boiled	Dried
Saturated fatty acid (SFA)				
C13:0	Tridecanoic	12.12±0.45	nd	nd
C14:0	myristic acid	nd	1.20±0.17	nd
C15:0	Pentadecanoic	nd	1.45±0.19	nd
C16:0	palmitic acid	21.15±3.21	7.09±1.90	8.33±1.91
C17:0	Heptadecanoic	nd	1.42±0.15	nd
C18:0	stearic acid	10.86±0.22	4.49±0.98	nd
C20:0	arachidic acid	nd	2.23±1.05	nd
C21:0	Henicosanoic	nd	1.49±0.10	nd
C22:0	Behenic	nd	1.34±1.11	nd
C23:0	Tricosanoic	0.14±0.05	3.20±0.88	nd
C24:0	Lignoceric	20.12±2.01	4.56±0.90	nd
Unsaturated fatty acid (USFA)				
C14:1	Myristoleic	nd	1.20±0.01	nd
C15:1	cis-10-pentadecenoic	nd	2.88±0.77	4.05±0.81
C16:1 *n*9	palmitoleic acid	nd	4.90±0.74	nd
C16:1 *n*7	palmitoleic acid	nd	2.30±1.07	nd
C17:1	cis-10-heptadecenoic	nd	1.39±1.01	1.62±0.85
C18:1n9c	oleic acid	16.67±3.85	nd	13.08±0.48
C18:1n9t	elaidic acid	nd	5.07±0.55	nd
C18:1cis	oleic acid 1cis	nd	4.94±0.51	nd
C18:2 cis	oleic acid 2cis	nd	4.02±1.07	nd
C18:2n6t	linolelaidic acid	nd	1.49±0.04	nd
C18:2*n*6c	linoleic acid	nd	nd	20.98±1.89
C18:3*n*3	α- linolenic acid	nd	2.01±1.05	2.40±1.01
C18:3*n*6	γ-linolenic acid	nd	1.09±0.04	nd
C20:1	gadoleic acid	nd	6.63±0.91	nd
C20:3*n*3	eicosapentaenoic acid	18.94±1.71	4.43±1.01	3.65±0.10
C20:3*n*6	homo- γ -linolenic	nd	2.00±0.11	nd
C20:4*n*6	arachidonic acid	nd	4.05±0.65	38.95±4.25
C20:5n3	cis-5,8,11,14,14-eicosapentaenoic (EPA)	nd	5.44±0.71	6.95±1.12
C20:2n6	Eicosadienoic	nd	5.03±0.70	nd
C22:1 *n*9	erucic acid	nd	3.59±0.13	nd
C22:2 n3	cis-4,7,10,13,16,19-docosahexaenoic (DHA)	nd	1.71±0.09	nd
Saturated fatty acids		**64.39**	**28.47**	**8.33**
Unsaturated fatty acids		**35.61**	**64.17**	**91.68**

In contrast, **Nishanthan *et al.* (2018)** illustrated that processing resulted in a significant reduction of total saturated fatty acids (SFA) and unsaturated fatty acids (UFA), while simultaneously elevating the total polyunsaturated fatty acids (PUFA) in several sea cucumber species studied. The variations in the fatty acid composition of sea cucumbers may stem from the accessibility of dietary sources such as phytoplankton, which is considered a main food source for sea cucumbers and is rich in saturated fatty acids, particularly C18:0. This may also be linked to other aspects, including climate circumstances, habitat ecosystems, and reproductive habits **(Taboado *et al.*, 2003)**.

Amino acid compositions of sea cucumbers

The amino acid profiles of raw, boiled, and dried sea cucumbers (*H. tubulosa*) are presented in Table (3).

Table 3. Effect of boiling and drying on amino acid profiles (mg/g protein) of sea cucumber

Amino acids	Raw	Boiled	Dried
Aspartic acid	3.35±0.23	2.98±0.25	8.42±1.12
Glutamic acid	106.80±5.32	76.36±4.35	78.41±4.32
Serine	95.53±4.14	97.53±4.19	77.36±4.11
Proline	83.35±3.12	77.29±3.49	60.74±3.51
Alanine	111.05±2.10	122.24±2.15	103.24±3.45
Tyrosine	17.68±1.10	17.52±1.19	20.68±1.33
Cystiene	1.07±0.12	0.85±0.05	1.80±0.15
Glycine	171.88±6.33	186.75±6.12	142.50±6.01
∑NEAA	**590.71±6.48**	**581.52±6.14**	**493.15±5.32**
Histidine	88.96±3.22	98.28±3.11	85.63±2.09
Phenylalanine	19.53±1.25	23.06±1.15	16.83±1.11
Isoleucine	15.16±1.10	13.45±1.05	14.88±1.09
Lysine	17.30±1.13	26.85±1.25	17.73±1.22
Leucine	24.45±2.12	21.24±2.01	27.95±2.17
Arginine	104.09±2.15	94.24±2.11	72.46±2.31
Valine	13.66±1.35	19.97±1.09	14.86±1.11
Methionine	16.81±1.48	21.05±1.42	16.02±1.45
Theronine	60.07±2.45	52.73±2.20	52.88±2.15
∑EAA	**360.03±5.11**	**370.87±5.17**	**319.24±4.95**
∑AA	**950.74±7.35**	**952.39±7.10**	**812.39±6.15**
EAA/NEAA	**0.61**	**0.64**	**0.65**

EA: Essential amino acids; NEAA: Non-essential amino acids; ΣEAA: Total essential amino acids; ΣNEAA: Total non-essential amino acids; ΣAA: Total amino acids.
Tryptophan has not determined because it is destroyed during the acid hydrolysis reaction.

The total amount of amino acids (ΣAA) exhibited substantial variation (P<0.05) based on processing temperatures, with reported values of 950.74, 952.39, and 812.39 (mg/g protein) for fresh, boiled, and dried *H. tubulosa*, respectively. Conversely, the ΣAA values of dried sea cucumber were much lower than those of fresh and cooked samples. The significant concentrations of non-essential amino acids (NEAA) in fresh, boiled, and dried *H. tubulosa* samples. The amino acid composition of *H. tubulosa* included glycine (171.88, 186.75, 142.50), alanine (111.05, 122.24, 103.24), glutamic acid (106.80, 76.36, 78.41), and serine (95.53, 97.53, 77.36). The essential amino acids (EAA) comprised arginine (104.09, 94.24, 72.46), histidine (88.96, 98.28, 85.63), and threonine (60.07, 52.73, 52.88). Moreover, the ratio of essential amino acids (EAA) to non-essential amino acids (NEAA) in fresh, boiled, and dried for *H. tubulosa* were 0.61, 0.64, and 0.65, respectively. However, **Öztürk and Gündüz (2018)** observed analogous findings, suggesting that the brief processing duration of the samples contributed to the preservation of amino acid losses, whereas NEA exhibited the highest values (P< 0.05) in dried sea cucumbers due to its polar structure. Tryptophan is readily digested as an essential amino acid, while the flavor of sea cucumbers is attributed to certain amino acids such as aspartate, glutamate, glycine, alanine, and serine. The flavor of microwave-cooked sea cucumbers is attributed to serine, aspartate, and proline.

Volatile taste compounds of sea cucumber

Volatile chemicals are essential determinants in the acceptance and consumption of seafood, particularly in light of the growing global demand. Consequently, numerous investigations are underway to isolate and describe these natural chemicals and to ascertain the quantities of aldehydes, alcohols, ketones, and esters for their various applications in food technology **(Zhang *et al.*, 2020)**. This work employed GC-MS to identify the volatile chemicals in sea cucumbers (*H. tubulosa*). Volatile substances of fresh, boiled, and dried of *H. tubulosa* are displayed in Table (4).

A total of 34 chemicals, mostly categorized into six principal classes, were identified. The chemicals are categorized based on their chemical structure into aldehydes, alcohols, aromatic compounds, ketones, terpenes, and others.

A total of 34 chemicals were identified in these fresh, boiled, and dried samples of *H. tubulosa* samples comprising 2 aldehydes, 7 alcohols, 17 aromatic compounds, 2 ketones, 3 terpenes, and 3 other compounds. Nonetheless, the profiles of fresh, boiled, and dried *H. tubulosa* samples exhibited significant variability among types, with around 17 chemicals identified in both raw and processed samples (Fig. 1).

Conversely, four natural compounds were undetected in *H. tubulosa* samples were identified in the boiling and dried specimens, potentially attributable to the thermal processing temperatures. Moreover, specific venture capitalists in *H. tubulosa* disappeared after the boiling and drying procedure, but certain volatile chemicals were detected, or their concentration increased following this thermal treatment.

Table 4. GC–MS integration parameters of volatile compounds (expressed as area units (AU) x $10^8 g^{-1}$ of sample) of raw, boiled, and dried *H. tubulosa*

Natural compounds	Raw	Boiled	Dried
Aldehydes (2)			
Nonanal	0.67	1.31	nd
Decanal	0.36	nd	nd
Total	**1.03**	**1.31**	**0**
Alcohols (7)			
Cyclopentanol	5.89	nd	2.97
1-(1-Butyny) cyclopentanol	0.92	nd	nd
1-Heptanol	6.27	nd	1.82
1-Butylcyclohexanol	0.63	2.98	2.87
1-Propylcyclohexanol	nd	0.83	0.83
2-Pentadecyn-1-ol	1.16	3.42	1.42
1-Dodecyn-4-ol	0.36	4.17	1.91
Total	**15.23**	**11.4**	**11.82**
Aromatic compounds (17)			
Benzene	10.27	4.56	11.26
Toluene	6.85	6.44	15.56
Hexamethylcyclotrisiloxane	8.35	5.50	4.51
Ethylbenzene	1.46	nd	nd
p-Xylene	9.42	nd	5.69
o-Xylene	8.1	nd	4.59
Methyl N-hydroxybenzenecarboximidoate	1.62	nd	nd
Octamethyltetrasiloxane	5.73	4.79	4.26
p-Cymene	0.70	2.01	2.52
β-Terpinyl acetate	1.42	4.85	5.71
Isomenthone	3.42	6.58	2.64
Decamethylcyclopentasiloxane	2.07	1.51	1.48
p-Menthan-3-one	1.35	1.66	nd
Estragole	2.80	3.97	2.28
Carvone	2.56	3.89	0.87
Dodecamethylcyclohexasiloxane	0.93	0.85	0.79
Tetradecamethylcycloheptasiloxane	0.25	nd	nd
Total	**67.3**	**46.61**	**62.16**
Ketones (2)			
(+)-2-Bornanone	1.04	5.15	3.3
Pulegone	4.19	2.86	nd
Total	**5.23**	**8.01**	**3.3**
Terpenes (3)			
β-Myrcene	nd	nd	1.82
β-Pinene	nd	nd	1.08
γ-Terpinene	nd	nd	0.64
Total	**0**	**0**	**3.54**
Others (3)			
2,2-Dimethyl-3-octyne	2.00	8.59	6.78
Eucalyptol	5.78	21.89	12.43
Methyl caprylate	0.56	0.93	nd
Total	**8.34**	**31.41**	**19.21**

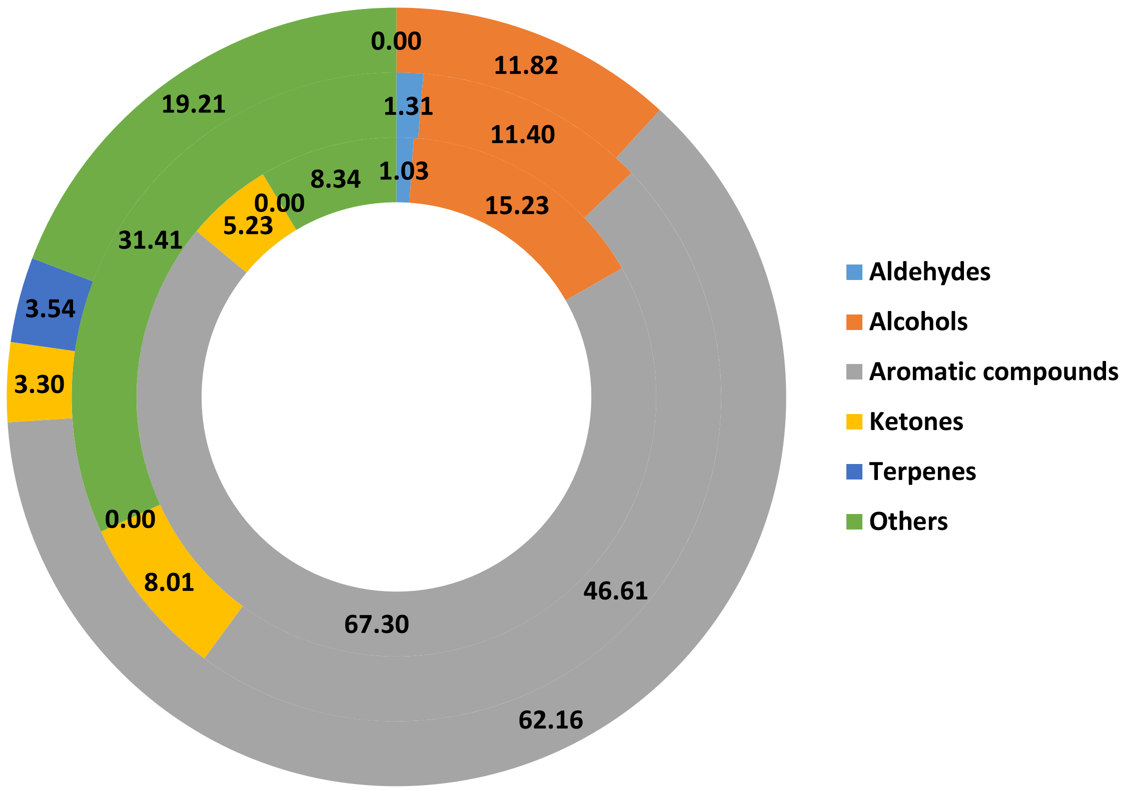

Fig. 1. Volatile compounds groups of raw, boiled, and dried *H. tubulosa*

Li *et al.* (2022) demonstrated analogous results, revealing that a total of 73 signal peaks of volatile compounds (VCs) were detected across all sea cucumber samples, with certain VCs vanishing due to the addition of seasonings, while some volatile compounds were either observed or exhibited increased concentrations after the soaking process. During the drying process, four new natural chemicals are formed: β-Myrcene, β-Pinene, γ-Terpinene, and 1-Propylcyclohexanol. Terpenes exhibit diverse biological effects, including anticancer, antibacterial, anti-inflammatory, antioxidant, and antiallergic characteristics **(Masyita *et al.*, 2022)**. On the other hand, **Hu *et al.* (2021)** discovered that boiling significantly enhanced the total quantity of volatile chemicals in shrimp, with the boiling and subsequent drying stages being essential for augmenting flavor quality. Sixty-two compounds were found utilizing the HS-SPME-GC–MS method, and the taste compounds in the sea cucumber samples were comprehensively detected and described under varied polar separation conditions **(Li *et al.,* 2024)**. In contrast, **Zhang *et al.* (2020)** observed that aldehydes are key constituents of the volatile taste chemicals present in sea cucumber. **Dong *et al.* (2015)** identified that the principal varieties of volatile compounds (VCs) in sea cucumbers comprised aldehydes, alcohols, aromatics, and other substances that emitted almond, whiskey, robust, and fatty aromas. Aldehydes enhanced freshness owing to their sensory attributes. **Song *et al.* (2024)** illustrated that the flavor profiles of seasoned and control sea cucumbers were significantly distinct, with 2-nonanol, myrcene, beta-phellandrene, terpinen-4-ol, alpha-terpineol, piperitone, cineole, and linalool contributing most substantially to the flavor development characteristic of both seasoned and control sea cucumbers.

Sensory characteristics of sea cucumber

Fig. (2) depicts the effect of boiling and drying on the volatile taste compounds of sea cucumber. The results demonstrated no significant (P>0.05) variations in odor, texture, taste, and overall acceptability between the boiling and dried samples of *H. tubulosa*. Dried *H. tubulosa* products exhibited superior color and attractiveness scores compared to boiled samples because to their darker hue. These findings are consistent with those of **Öztürk and Gündüz (2018)**.

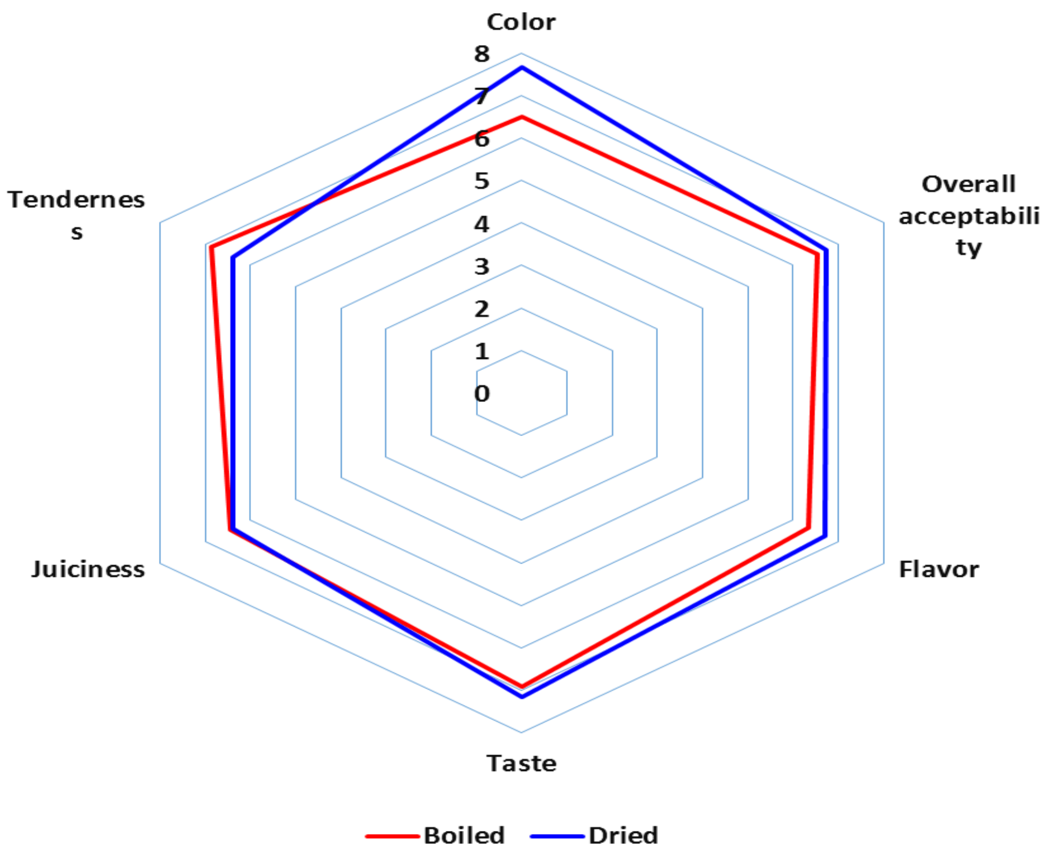

Fig. 2. Effect of boiling and drying on sensory evaluation of sea cucumber

CONCLUSION

In conclusion, the proximate composition and fatty acid profile of *H. tubulosa* can be significantly affected by diverse thermal processing techniques such as boiling and drying. Both raw and processed *H. tubulosa* samples did not exceed the maximum permissible limits established by national and international standards, as determined by physicochemical, microbiological, and sensory quality assessments, thereby affirming their safety and potential nutritional advantages as a healthy food choice for human consumption. To improve the quality of final dried sea cucumber goods, it is crucial to examine the optimization of the boiling and drying processes.

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