JSAES
Journal of Sustainable Agricultural and Environmental Sciences
Print ISSN : 2735-4377
Online ISSN : 2785-9878
Homepage: https://jsaes.journals.ekb.eg/

Research Article

Using Ultrasound and Microwaves as Pretreatment with Pressing Extraction to Improve the Quantity and Quality of Fish Oil from Salmon By-Products

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Article info: -

- **Received:** 9 August 2025
- **Revised:** 22 September 2025
-**Accepted:** 29 September 2025
- **Published:** 5 October 2025

Keywords:
Salmon fish, by products, Press, oil, Waste, pretreatment, and extraction

Abstract:

This research aims to reduce fish waste and lower extraction temperatures. Shorter processing times can lead to cost savings and increased efficiency in fish oil production. It also aims to determine the effect of pretreatments, such as ultrasonic extraction (UAE) and microwave extraction (MAE), on oil yield and quality. Ultrasound and Microwave assisted with extraction of fish oil from salmon by-products. Ultrasound promotes cell disruption through acoustic cavitation, and microwave irradiation facilitates rapid Extraction rate and tissue softening. Oil was extracted using a press at varying pressures to assess how mechanical force and pretreatment, such as (UAE) and (MAE) interact to affect extraction efficiency and oil quality. The results showed that all pretreatments significantly improved oil yield compared to untreated samples, with microwave pretreatment at high pressure yielding the highest amount of oil. Using Microwave assisted extraction decreased excreted time and increased oil yield by 18%. Ultrasound treatment affected the TSFA percentage by decreasing it to 12.25% of TFA, whereas microwave treatment had no effect on TSFA content 14.63%. Microwave treatment decreased the amounts of both palmitic and myristic acids to 8.93% and 1.41%, respectively. The results revealed that Omega 3 fatty acids are represented by about 23.30% and increased by ultrasound treatment by about 24%, whereas no effect appears on 63 fatty acids by microwave treatment.

1. Introduction

The critical role of combining non-thermal pretreatments with controlled pressing to maximize both the quantity and quality of fish oil extracted from waste, supporting the development of more sustainable and value-added processes in the fish processing industry.

Pre-treatment and process parameters applied to the raw material in pressing method play a major role in terms of oil yield. The pre-processes mentioned include peeling, drying, solvent or enzymatic treatment of raw material; the process parameters are feeding rate, the diameter of the restriction dye, temperature, rotation speed (Savoire et al., 2013; Chemat et al., l 2015)

The ultrasound (US) is one of the fastest and efficient methods of extraction, which is largely capturing industrial applications. Applying the principle of “acoustic cavitation” results in the disruption of cell wall and an increase in the mass transfer of cell contents, thereby increasing the yield as a whole (Khanashyam et al., 2023).

Ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), supercritical fluid extraction (SFE) and pulsed electric fields (PEF) are examples of the most used examples of green and safe technologies. Despite having clear advantages over conventional methodologies, it is considered that optimization studies are still needed to avoid the development of oxidative processes that reduce the quality of the products obtained (Pateiro et al., 2020).

UAE creates bubbles in the solvent with high temperatures and pressures, which lead to different pressure areas, forcing the liquid out of cells. The efficiency of ultrasound depends on the ultrasonic frequency and intensity, temperature, pressure, and processing time (Liao et al., 2018).

MAE method of fish fat extraction led to 90% reduction in the extraction time, less residues, negligible lipid oxidation compounds, and reduced solvent consumption with greater precision, accuracy, and robustness (Costa and Bragagnolo, 2017).

Press is preferred due to its wide usage areas, simple use, lack of manpower, low cost, environmentally friendly, lack of harmful organic solvents and high-quality production possibilities. In addition, generally the product is not applied to heat treatment, therefore, as mentioned in the study, high-quality oils are obtained. In the pressed process oil extraction relies solely on the pressure. No, or very little, heat is added to the paste to assist in the extraction presses are usually mechanically operated and often consist of a screw device that is tightened against the paste to extract the oils. Pressing usually produces a lower yield, but higher quality of oil (Uitterhaegen, 2017).

The advantages of mechanical oil extraction include simple use, rapid realization of the process that leads to the short duration of the process, use of small quantities of raw materials, application of different oilseeds and low cost. Also, as a by-product protein, rich press cake is obtained (Singh et al., 2000).

Using pressing, oil extraction yield increased and characterization of quality. The optimum conditions at pressing time were 180 min., oil productivity was 18.00%, and extraction efficiency were 98.46% at constant

pressure (Fouda, 2018).

Increased press extraction temperatures for almond, walnut, and peanut oils generally improve oil yield by increasing the rate of extraction but negatively impact quality, leading to higher peroxide values (PV), increased acidity, and reduced tocopherol (antioxidant) and total polyphenol (antioxidant) content. While fatty acid profiles remain largely stable across temperatures, higher temperatures contribute to oil degradation and a less desirable flavor profile, favoring lower-temperature extraction for high-quality, nutritionally rich oils (Rabadán et al., 2018).

The samples were used from fresh Salmon waste about 1000g from each of the (head, skin, viscera, backbone, frames and cuts off). This waste recorded more than 22% of the total mass from salmon fish with used modern extract machine. in this experiment the results revealed the fresh salmon waste have more than 16% of oil fish per one kg of salmon waste. The oil weight from Salmon waste for (head, skin, viscera, backbone, frames and cuts off). was increased with pressing time increase as well as oil productivity increased. The optimum conditions at pressing time were 200 min, for all salmon waste components. Oil productivity fluctuated according to waste sources was 190, 210, 86, 188, 178 and 90 g.oil/1000 g. by head, skin, off cuts, terming, viscera, and backbone frames, Salmon by-products, oil productivity was ranged between 8.60 to 21.00%, High contents of functional EPA (20:5 ω 3) and DHA (22:6 ω 3) for oil fish at constant pressure (Fouda, 2020).

Fish processing waste contains valuable byproducts which may include: fish oil (ω-3 fatty acids), proteins and amino acids, chitosan, chitin, collagen and gelatin, cosmetics, natural pigments, enzymes, animal feed, and soil fertilizers and he noticed that on the other hand, fish wastes are of high economic and nutritional value because they contain minerals from 0,8-2%, fat up to 25%, and protein between 15-30% (Ghaly et al., 2013).

Storage conditions and antioxidant treatment (e.g., addition of rosemary extract or tocopherols) significantly improved oxidative stability during shelf life. Enzymatic hydrolysis, especially when combined with mild physical pretreatment, has also been effective in preserving the native structure of omega-3 fatty acids (Pérez-Palacios et al., 2024).

The quality of fish oil is influenced by several factors, including the raw material, extraction method, pretreatment process, and storage conditions. Common quality indicators include peroxide value (PV), which reflects primary oxidation; p-anisidine value (p-AV), which indicates secondary oxidation; acid value (AV), showing the extent of hydrolysis; iodine value (IV), measuring unsaturation level; and TOTOX value (2×PV + p-AV), a total oxidation index (El-Masry et al., 2024).

Drying at moderate levels was found to enhance oil stability and improve extraction efficiency, while high-intensity ultrasound increased EPA and DHA content but slightly raised oxidation markers. Moreover, the PUFA/SFA and omega-6/omega-3 ratios are widely used nutritional indices to assess oil health quality. A PUFA/SFA ratio above 0.4 and an omega-6/omega-3 ratio below 5 are considered desirable (FAO/WHO 2023).

The quality of fish oil is typically assessed through parameters such as peroxide value (PV), acid value (AV), iodine value (IV), anisidine value (p-AV), and the total oxidation value (TOTOX), which indicate the degree of primary and secondary oxidation (Kamal et al., 2024).

The overall aims of this study were to determine the amount and quality of fish oil extracted from salmon wastes resulted from butchering, cutting and splitting processes before salmon smoking using (hydraulic press) and determined the effect of some of pretreatment like (Ultrasound assistant extraction (UAE)-Microwave assistant extraction (MAE) on the oil yield and oil quality.

2. Materials and Methods

2.1. Materials

2.1.1. Salmon Varieties and characteristics

Salmon is a popular food fish. There are seven species of commercially important salmon. The type of salmon species in this experiment was Atlantic salmon (Salmon salar), as shown in **Figure 1**. This species of salmon is composed of a high percentage of water and other byproducts, approximately 46%. The edible portion represents approximately 54%. The percentage of waste in fish in **Table 1** includes the following:

Figure 1. The salmon fish.
Source: Author's Photography.

Table 1. Percentages and Weights of salmon fish by-products.

Salmon fish	Weight average	
	(g)	(%)
Whole body	500	100%
Head	75	15%
Skin	25	5%
Viscera	30	6%
Trimmings	50	10%
Off-Cuts	10	2%
Backbone	40	8%
Salmon Slice	270	54%

2.1.2 Salmon By-products

By-products are parts of the fish that are removed before the fish reaches the final consumer in order to improve their keeping qualities, reduce the shipping weight or increase the value of the main fish product. They include blood, viscera, heads, bones, skin, trimmings and fins.

Selman fish by-products were obtained from the waste of a private salmon smoking factory; a sample weight of 500 g was taken. Three replicates were made for each process. As shown in **Figure 2. And Table 1.**

Figure 2. The salmon By-product.
Source: Author's Photography.

2.2. Methods

2.2.1. Pre-treatment on Salmon By-products

The material was exposed to Ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), drying (DR), and (Control).

2.2.2. Ultrasound-assisted extraction (UAE)

Apply ultrasound treatment using Crest Ultrasonic Cleaner at a temperature of 30 °C, Frequency (60 MHz) for 60 minutes. When turned on, it generates high-frequency sound waves (usually 25–45 kHz) that create tiny vacuum bubbles in the liquid. These bubbles rapidly form and collapse — a process called acoustic cavitation. This releases energy that gently but powerfully scrubs the surface of materials or breaks down cell structures, making it useful for pretreating biological samples, like fish waste, to help extract oil more efficiently. All of the Crest Ultrasonic Cleaner specifications are described in Table 2.

The Ultrasonic Cleaner Model D operates using high-frequency sound waves to clean items efficiently. When the machine is turned on, it generates ultrasonic waves in a tank filled with a cleaning solution. These waves create microscopic bubbles that implode on the surfaces of the items, a process called cavitation. This action removes dirt, grease, and other contaminants even from hard-to-reach areas. The cycle typically lasts a few minutes, leaving the objects thoroughly cleaned without manual scrubbing as shown in Figure 3 and Table 2. Crest Ultrasonic Cleaner specifications.

Figure 3. Crest Ultrasonic Cleaner.

Table 2. Crest Ultrasonic Cleaner specifications**.**

Specification	Details
Ultrasonic Frequency	45 kHz or 132 kHz options, with frequency sweep for uniform energy distribution (Sonics Online)
Ultrasonic Power	From ~80 W (P230D) to ~300 W (P2600D)
Heater	Adjustable from ~20 °C to 80 °C; digital timer-controlled heater up to 80 °C (175 °F)
Timer	Digital timer, 0–99 min or continuous operation
Degas Function	Included on "D" models for removing dissolved gases
Tank Material	Deep-drawn stainless steel with rounded corners
Drain Valve	Included on units ≥ 2.5 gallons
Warranty	2 years on parts and labor; lifetime heater warranty on many units
Construction	Stainless steel housing, ETL/CSA/CE listed
Tank	is 9.5' x 5.25" x 4" deep

2.2.3. Microwave-assisted extraction (MAE)

Applying microwave treatment using a sineo MDS-6G set at a temperature of 60°C for 5 minutes. The microwave speeds up cell wall rupture and helps release oil efficiently, improving yield and reducing time of the process.

Microwave-assisted extraction (MAE) uses microwave energy to heat solvents in contact with the materials to extract bioactive compounds. The microwaves cause rapid heating, which breaks cell walls. This process increases extraction efficiency and reduces time compared to traditional methods. The mixture is then filtered to separate the extract; the mechanism of MAE is shown in Figure 4 and Table 3.

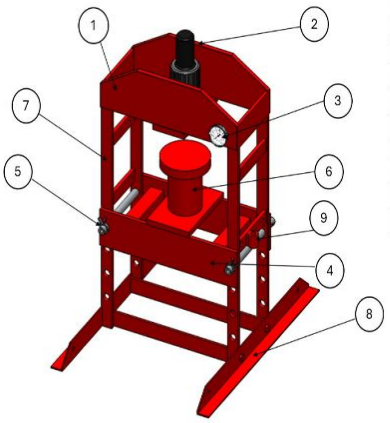
Figure 4. Microwave electric oven.

Table 3. Described the microwave specifications

Parameter	Specification
Power	220-240 VAC 50/60Hz 8A
Microwave frequency	2450MHz
Installed power	1800W
Maximum output power	1000W, non-pulse continuous automatic variable frequency control
Turntable design	Load 8 MP-100 closed digestive vessels at same time
Pressure measurement and control system	Piezoelectric crystal pressure sensor, pressure control range :0-10MPa (1500 psi), accuracy ± 0.01MPa
Temperature measurement and control system	High-precision platinum resistor temperature sensor, temperature range :0-300°C, accuracy ±1°C
Outer vessel material	Explosion-proof outer vessel made of aerospace composite fiber
Inner vessel material	TFM material
Chamber exhaust system	High-power anticorrosion axial fan, exhaust speed: 3.1 m3/min
Operating ambient temperature	0-40 °C
Working environment humidity	15-80%RH
Whole physical size	450 x 515 x 510 mm (W x D x H)
Net weight	40 KG

2.2.4. Pressing Extraction

A press is used to create mechanical pressure. The raw material is placed in a press, and pressure is applied to squeeze the oil at a low temperature to avoid decreasing oil's quality. Figure 5 shows a press machine. A 500-gram sample is subjected to low pressure and constant force on a circular base with a diameter of 15 cm, so that the pressure on the surface of the sample remains constant, where only fish oil is extracted. This is a mechanical force sufficient to break the fish cells and release the oil without leaving residues or impurities from the tissues.



No	Part Name
1	Head support
2	Head Strock
3	Force gauge
4	Table frame
5	Table holding –PIN
6	Bed
7	Side support
8	Floor support
9	Link

Figure 5. Hydraulic press machines.
Source: Author's drawing.

2.3. Measurements

The quality of the extracted salmon fish oil was evaluated using a series of standardized analytical methods to assess its oxidative status, chemical stability, and molecular composition under various pretreatment conditions. The pretreatment, Oxidation Indicators were Conducted in the laboratory of the National Research Center, Food Industries Department. Data File HAMDY2025\FISH_3000003.D at 6/3/2025 12:03:50 PM by using Fish oil chromatography is a process used to separate and identify. Chromatography enables the separation of the different components of fish oil, such as saturated and unsaturated fatty acids, triglycerides, vitamins, and other compounds.

2.3.1. Oxidation Indicators

Peroxide Value (PV): Indicates the presence of primary oxidation products (hydroperoxides). Measured according to AOAC (2000) by reacting the oil with potassium iodide in an acetic acid–chloroform solution and titrating with sodium thiosulfate and the peroxide value was calculated according to the following equation:

$$\text{Peroxide value, (meq Q,/Kg)} = \frac{(b-s)\times N}{W} \times 100 \ldots..(1)$$

Where:
B = ml of Na_2S_2O; used in blank
S = ml of Na_2S_2O, used in sample

N = Normality of $Na_2S_2O_3$ solution.
W = Weight of sample (g)

p-Anisidine Value (p-AV): Reflects secondary oxidation (mainly aldehydes), determined based on AOAC (2000) by reacting the oil with a p-anisidine reagent in isooctane and measuring absorbance at 350 nm. P-Ansidine value was calculated using the following equation:

$$\rho - \text{Ansidine} = \frac{25\ (1.2\ As - Ab)}{W} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

As = Absorbance of the fat solution after reaction with the ρ -ansidine reagent.
Ab = Absorbance of the fat solution.
W = Weight of sample (g).

TOTOX Value: A comprehensive measure of total oxidation, calculated according to Rossel (1983) as:

$$TOTOX\ value\ =\ 2PV + P - Ansidine\ value \ldots\ldots (3)$$

Where:

PV = Peroxide value
P-AV-P-Ansidine value

2.3.2. Chemical Properties

Acid Value (AV): Indicates the level of free fatty acids, determined using AOAC method (2000). Acid value was calculated according to the following equation:

$$\text{Acid value, (mg KOH/g)} = \frac{V \times N \times 56.1}{Weight\ of\ sampel(g)}$$

Where:

V = Volume of KOH (ml)
N = Normality of KOH
56.1 molecular weight of KOH

Iodine Value (IV): Reflects the degree of unsaturation in the oil. Determined using the Hanus solution as described by AOAC (2000). It was calculated according to the following equation:

$$\text{Iodine value} = \frac{(B - S) \times N \times 126.9}{W}$$

Where:

B = ml of Na_2S_2O, used in blank.
S = ml of Na_2S_2O, used in sample
N = Normality of Na2SO3 solution.
126.9 = Atomic weight of iodine
W = Weight of sample (g).

Saponification Number (SN): Indicates the average molecular weight of triglycerides. Measured according to AOAC (2000) by the equation:

$$\text{Saponification value} = \frac{(B - A) \times N \times 56.1}{W}$$

Where:

A = Volume of hydrochloric acid (0.5 N) required by blank
B = Volume of hydrochloric acid (0.5 N) required by sample
56.1 = Equivalent weight of the KOH
N = Normality of KOH solution
W = Weight of sample (g)

2.3.3. Physical Properties

Specific Gravity: Measured using a pycnometer.

Refractive Index: Determined using a digital refractometer following AOCS Method Cc 7-25. (at 25 °C)

3. Results and Discussion

3.1. Effect of pretreatment on extraction Performance quality and oil extraction efficiency of oil extracted from fish by-products

Figure 6 shows the pretreatment before extraction process. The sample of 500 g. exposed to microwave frequency at 900 MHz for 5 min to rising the temperature; the measurement was 60 °C Also ultrasound frequency at 60 kHz for 60 min. to raise the temperature measurement to 30°C. Control sample exposed to normal air temperature 27°C Exposure time 5 min. All these parameters lead to an increase in the extraction efficiency from 83% with ultrasound to 91% with microwave pretreatment, while it decreased with the control to 75%.

The pretreatment (Microwave and Ultrasound treatment) with pressing across all measured oil extraction performance metrics which effect on extraction performance quantity of fish oil. Specifically, the oil yield increased from 100 g with ultrasound to 110 g with microwave, and the oil percentage rose from 20% to 22%. Additionally, the required extraction time significantly decreased from 50 to 35 minutes when using microwave treatment. As a result, the Extraction rate enhanced from 2 g/min with ultrasound to 3.14 g/min for microwave respectively as shown in Figure 7.

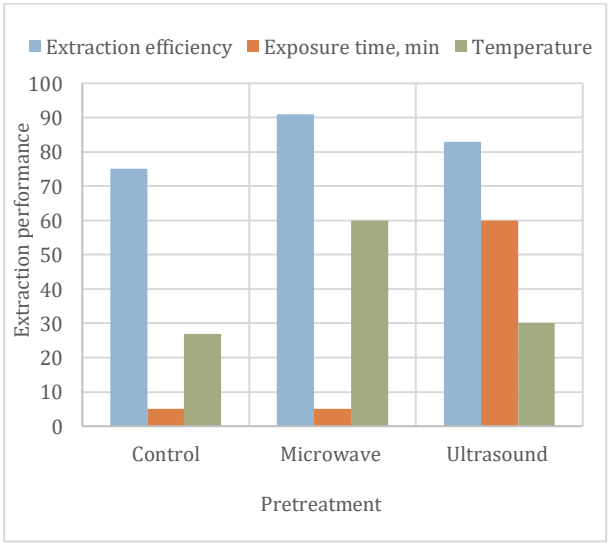


Figure 6. The pretreatment conditions with pressing extraction efficiency.
Source: Authors' determination

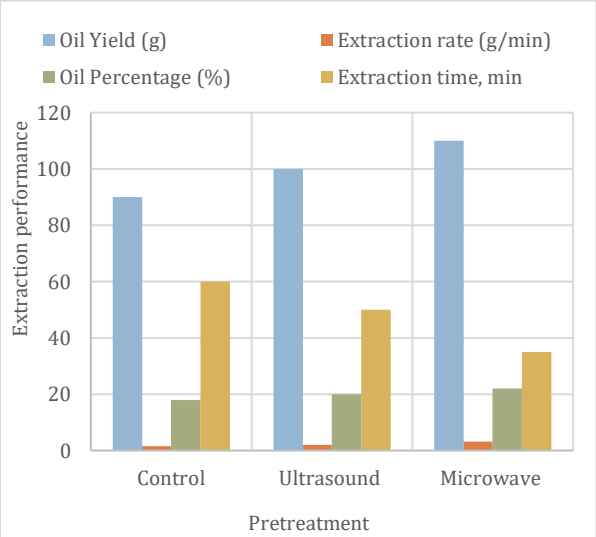
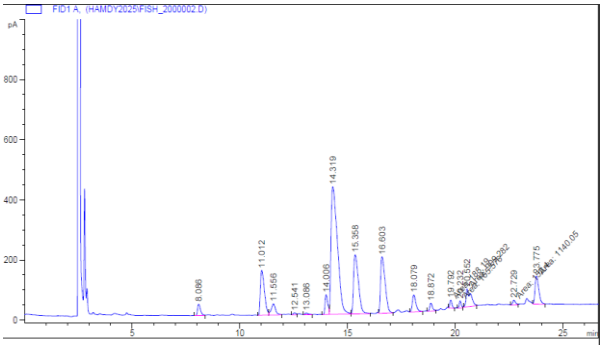


Figure 7. Effect of different pretreatments with pressing extraction on performance quantity of oil extracted from fish by-products.
Source: Authors' determination.

3.2. Physical and chemical properties of oil extracted from fish by-products

The chromatographic analysis shown in Figure 8 and Table 4 illustrates the separation of the components of fish oil, such as saturated and unsaturated fatty acids, triglycerides, vitamins, and other compounds.



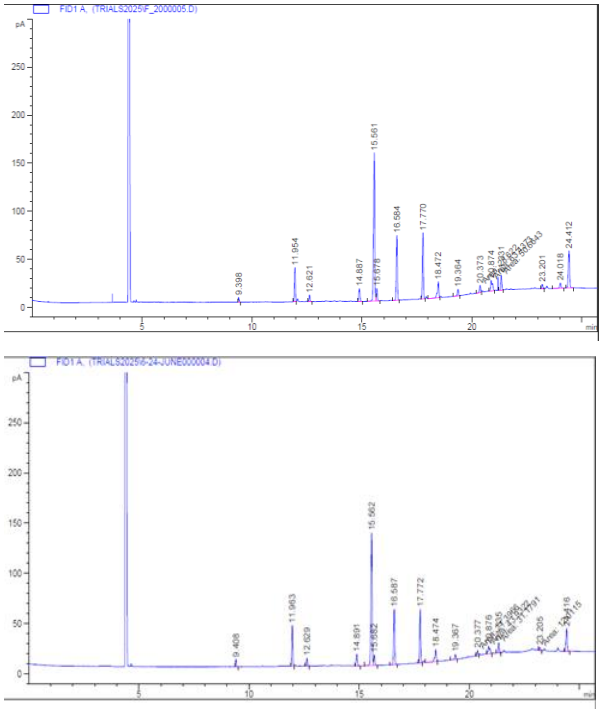


Figure 8. The chromatographic analysis of the oil extracted from fish waste with control, ultrasound, and microwave pretreatment.

In Figure 9, the results indicate obvious differences in the physicochemical properties of the oil extracted using ultrasound (U1) and microwave (M1) techniques. The specific gravity values were very close (0.915 for U1 and 0.916 for M1), as were the refractive index values (1.4654 and 1.4651, respectively), suggesting a similar general composition of the extracted oils. However, the acid value was higher in the microwave-extracted oil (1.36 mg/g) compared to ultrasound (1.02 mg/g), indicating a greater degree of hydrolytic degradation. Additionally, the peroxide value increased from 1.51 to 1.77 meq/kg, and the p-anisidine value rose from 3.85 to 6.38, suggesting more secondary oxidation products in the microwave-treated oil. Consequently, the TOTOX value (a combined oxidation index) was also higher in the microwave method (9.92) compared to ultrasound (6.87), reflecting a greater oxidative impact on the oil's stability. These results are in agreement with El-Masry et al. (2024).

Table 4. Fish oil components extracted from salmon by-products with control and pretreatment.

Fatty acids	Control	Microwave	Ultrasound
Myristic acid (C14:0)	1.66	1.41	1.72
Palmitic acid (C16:0)	9.1	8.93	6.21
Palmitoleic acid (C16:1)	2.47	1.78	1.25
Stearic acid (C18:0)	2.62	3.14	2.91
Oleic acid (C18:1,Cis)	40.77	36.34	34.87
Elaidic acid (C18:1,trans)	ND	2.75	2.61
Linoleic acid (C18:2)	14.4	13.8	13.78
α-Linolenic acid (C18:3 n3)	12.99	12.56	13.12
Arachidic acid (C20:0)	1.16	1.15	1.41
cis-11-eicosenoic acid (C20:1 n-9)	3.06	3.76	4.23
cis-11,14,17-Eicosatrienoic acid (C20:3 n-3)	0.87	1.55	2.92
cis-8,11,14-Eicosatrienoic acid (C20:3 n-6)	0.76	2.24	0.94
cis-5,8,11,14,17-Eicosapentaenoic acid (C20:5 n-3)	4.18	3.15	3.65
cis-13-docosenoic acid (C22:1)	0.7	0.86	1.18

Table 4. continued

cis-4,7,10,13,16,19-Docosahexaenoic acid (C22:6 n-3)	5.26	6.58	9.19
Total saturated fatty acids (Sat FA)	14.54	14.63	12.25
Total unsaturated fatty acids (TUSFA)	85.46	85.37	87.74
Total monounsaturated fatty acids (TMUSFA)	47	45.49	44.14
Total polyunsaturated fatty acids (TPUSFA)	38.46	39.88	43.6
Total omega-3 fatty acids (ω3FA)	23.3	23.84	28.88
Total omega-6 fatty acids (ω6FA)	15.16	16.04	14.72
Trans fatty acids (Trans FA)	ND	2.75	2.61

The results in Figure 10 showed that myristic acid (C14:0) was slightly higher in the ultrasound-extracted oil (1.72%) compared to microwave (1.41%). In contrast, the palmitic acid (C16:0) content was significantly higher in the microwave-extracted oil (8.93%) than in ultrasound (6.21%), indicating a greater concentration of saturated fatty acids with microwave treatment. The amount of palmitoleic acid (C16:1), a monounsaturated fatty acid, also increased from 1.25% in ultrasound to 1.78% with microwave, suggesting an influence of microwave on unsaturated fat composition. Finally, stearic acid (C18:0) showed a slight increase in the microwave-treated sample (3.14%) compared to ultrasound (2.91%) respectively. The results were agreement with Pérez-Palacios et al. (2024)

The results compare the fatty acid composition of oils extracted using ultrasound (U1) and microwave (M1) pretreatments. Arachidic acid (C20:0), a saturated fatty acid, was higher in the ultrasound-extracted oil (1.41%) compared to the microwave (1.15%). Similarly, cis-11-eicosenoic acid (C20:1 n-9), a monounsaturated fatty acid, decreased from 4.23% in U1 to 3.76% in M1, indicating a reduction in this type of fatty acid with microwave treatment. On the other hand, cis-11,14,17-eicosatrienoic acid (C20:3 n-3), a polyunsaturated omega-3 fatty acid, showed a significant drop from 2.92% in ultrasound to 1.55% in microwave, possibly due to thermal degradation. In contrast, cis-8,11,14-eicosatrienoic acid (C20:3 n-6), an omega-6 fatty acid, increased notably from 0.94% to 2.24% with microwave treatment, respectively, as shown in Figure 11. The results were agreement with Liao et al, (2018)

The results showed the value of Oleic acid (C18:1, cis) increased slightly with microwave treatment (36.34%) compared to ultrasound (34.87%), indicating enhanced extraction of this monounsaturated fat. Elaidic acid (C18:1, trans) also showed a slight increase from 2.61% to 2.75%. Linoleic acid (C18:2) remained nearly unchanged between the two methods. However, α-linolenic acid (C18:3 n-3), an important omega-3 fatty acid, decreased slightly from 13.12% in ultrasound to 12.56% in microwave respectively as shown in Figure 12. The results were in agreement with the findings of) Khanashyam et al. 2023).

The level of eicosapentaenoic acid (EPA, C20:5 n-3) decreased from 3.65% with ultrasound to 3.15% with microwave extraction. Similarly, docosenoic acid (C22:1) dropped from 1.18% to 0.86%. A notable decrease was observed in docosahexaenoic acid (DHA, C22:6 n-3), which declined from 9.19% in ultrasound to 6.58% in microwave-treated oil. Additionally, as shown in Figure 13.

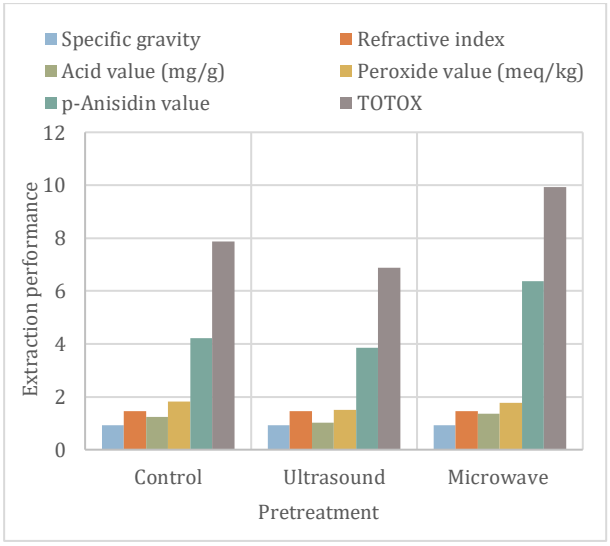


Figure 9. Effect of pretreatment with pressing extract on physicochemical value of oil extracted from fish by-products.
Source: Authors' determination

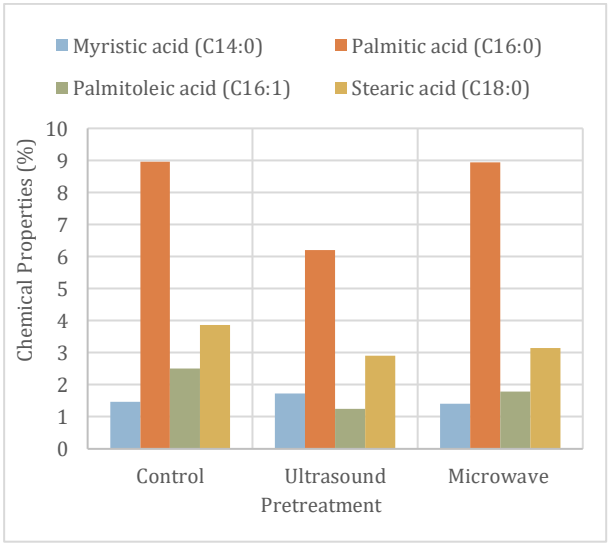


Figure 10. Effect of pretreatment with pressing extract on fatty acid concentration.
Source: Authors' determination

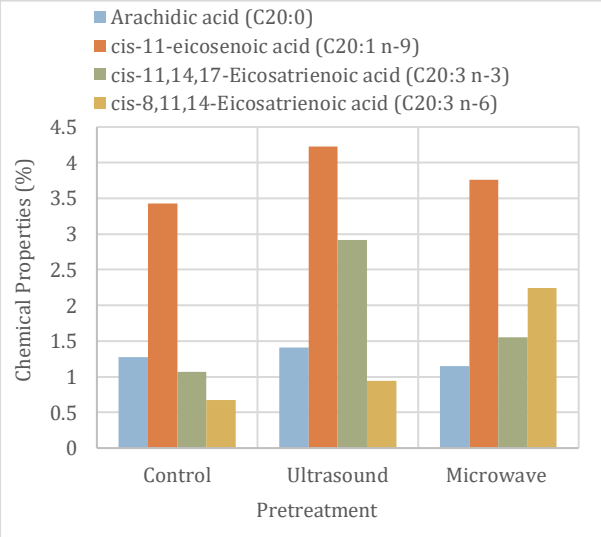


Figure 11. Effect of pretreatment with pressing extract on fatty acid concentration 2.
Source: Authors' determination

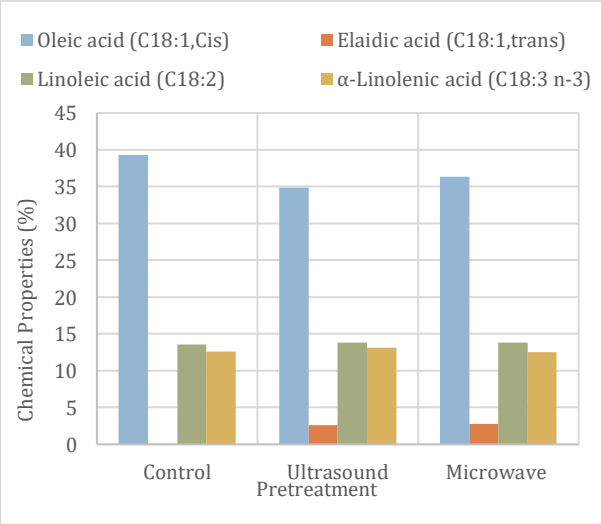


Figure 12. Effect of pretreatment with pressing extract on fatty acid concentration 3.
Source: Authors' determination

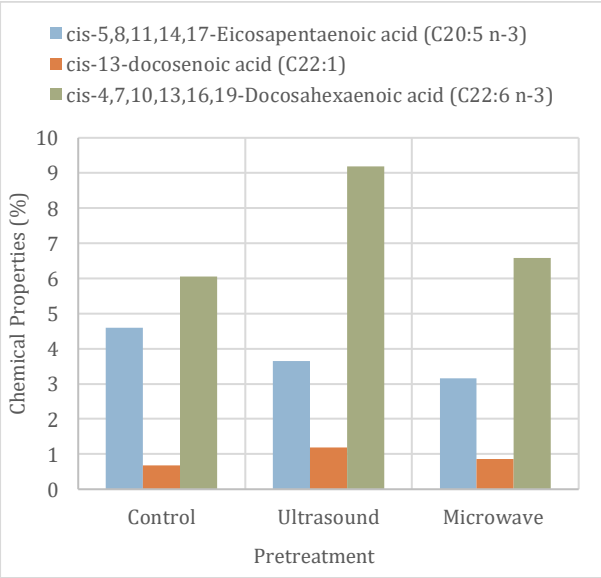


Figure 13. Effect of pretreatment with pressing extract on fatty acid components.
Source: Authors' determination

3.4. The fatty acid composition of oil extracted from Salmon fish by-products by different methods

The fatty acid composition of oil extracted from Solomon fish by-products by different methods is presented in Figure 14 and Figure 15. The results indicated that the total saturated fatty acids in Control treatment are 14.54% of total fatty acids, and the major saturated fatty acid is palmitic (C16:0), which represented about 9.1% of total fatty acids. The second one is stearic (C18:0) 2.62%, followed by myristic (C14:0) at 1.66% and arachidic (C18:0) 1.16% of TFA. Ultrasound treatment affected the TSFA percentage by decreasing it to 12.25% of TFA, whereas microwave treatment had no effect on TSFA content 14.63%.

Microwave treatment decreased the amounts of both palmitic and myristic acids to 8.93% and 1.41%, respectively. Where their treatment increased stearic acid content to 3.14% but had no effect on arachidic acid content 1.15%. On the other hand, ultrasound treatment decreased palmitic acid content to 6.21%. in contrast, this treatment increased the amount of Stearic, myristic and arachidic acids to 2.91, 1.72 and 1.41% of TFA, respectively, compared with Control treatment. Ultrasound treatment was more effective in decreasing palmitic and stearic acid and had a slight effect on decreasing myristic and arachidic acids. From the results in Figure 14, it could be concluded that ultrasound treatment decreased the amount of TSFA in fish oil extracted from salmon fish by-product to 12.25% of TFA compared with the control treatment 14.54%, whose microwave treatment had no effect on TSFA content 14.63%. These results are agreement with (Perez-Paldocios et al. 2024).

In relation to monounsaturated fatty acids (MUSFA), the recalls in Figure 14, indicated that some changes in MUSFA content occurred due to microwave and ultrasound treatments. Palmeoleic acid (C16:1) and oleic acid (C18:1 cis) are decreased from 2.47% and 40.77% of control to 1.78% and 36.34% of microwave treatment and to 1.25% and 34.87% of ultrasound treatment, respectively. Whereas eicosenoic acid (C20:1) and decosenoic acid (C22:1) are increased from 3.06 and 0.7% of control to 3.76 and 0.89% of microwave treatment and to 4.23 and 1.18% of ultrasound treatment.

Ultrasound treatment was more effective at decreasing MUSFA than microwave treatment. IMUSEA was decreased by microcurrent and ultrasound treatments from 47.0% of the control to 45.49% and 44.14% of these treatments, respectively.

Microwave and ultrasound treatments appeared to be another direction of polyunsaturated fatty acids. PUSFA was increased from 38.46% of total fatty acids for control to 39.88% for microwave treatment and to 43.6% for Mithasand treatment. The maim Polyunsaturated fatty acids represent more than 10% of linoleic and linolenic acids in 14.4% and 12.99% of the control treatment. A slight decrease occurred due to microwave treatment. The amount of linoleic decreased to about 13.8% due to microwave and ultrasound treatment. In the arrangement of fatty acid content,

DHA and EPA represent about 5.26% and 4.18%. Ultrasound treatment was extremely effective on DHA content; it increased DHAP content from 5.26% to 9.19%, but microwave treatment increased DHA content to 6.58%. On the other side, microwave treatment decreased EPA content to 3.15%.

Ultrasound treatment increases the TPUSFA to 43.6% of TFA comparing by microwave treatment 39.88% and control 38.469%.

The results in Figure 15 revealed that Omega 3 fatty acids are represented by about 23.30% and increased by ultrasound treatment by about 24%, whereas no effect appears on 63 fatty acids by microwave treatment. In relation to 66 FA, the effect of treatment was change; ultrasound treatment decreased 66 FA content by 3%, but microwave treatment increased this group of FA by about 6%. These results are concurrent with those obtained by (Khanashyamet d. 2023).

Trans fatty acids, or trans fats, ore unsaturated fats with a trans configuration at one or more double bonds. They occur naturally in small amounts in meat and dairy products from animals, but the primary source in most diets is artificial trans fats, created industrially by hydrogenating liquid vegetable oils to make them more solid. Trans fats increase bad LDL cholesterol and decrease good LDL cholesterol, raising the risk of heart disease. Microwaving and some processing (frying, baking, shortening) help the formation of trans fats.

Concerning to trans fatty acids, the results revealed that the very bad effect of microwave and ultrasound treatment on oil extracted from salmon fish by-products was the formation of trans fatty acids. Trans fatty acids did not appear in the control treatment, while in the samples treated with microwave and ultrasound treatment, trans fatty acids appeared in high amounts. Microwave and ultrasound treatment led to the formation of trans fatty acids by 2.75% and 2.61% of total fatty acids. These amounts are much higher than that stipulated maximum level of CAC.

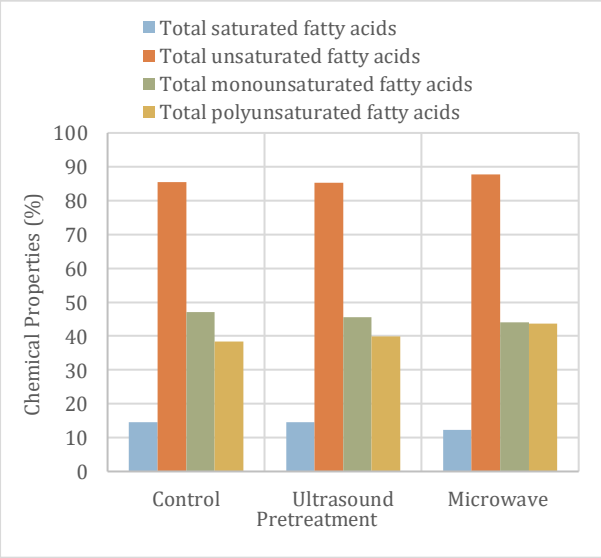


Figure 14. Effect of the pretreatment method on the composition of saturated, unsaturated, and monounsaturated fatty acids in oil extracted from salmon by-products.
Source: Authors' determination

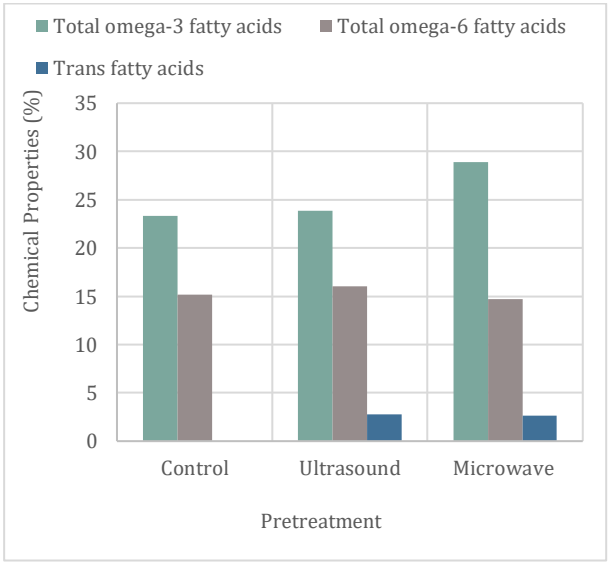


Figure 15. Effect of the pretreatment method on the composition of omega-3, omega-6, and trans fatty acids in oil extracted from salmon by-products
Source: Authors' determination.

4. Conclusion

Microwave and ultrasound treatment of salmon waste samples with pressing improves fish oil extraction percentage to 22, 20 and 18%, resulting in higher extraction yields of 110, 100 and 90 g per 500 g waste sample for Microwave, ultrasound, and no treatment, respectively. faster extraction time was 35 and 50 min., while the control treatment took about 60 min., and improved extraction of specific omega-3 compounds. These processes also enhance mass transfer, facilitate lipid release, and improve oil quality, resulting in a higher content of unsaturated fatty acids and improved oxidative stability. while microwave treatment improves extraction speed and yield, it also increases the risk of thermal degradation and oxidation, which may compromise the nutritional quality of sensitive PUFAs in the extracted salmon oil. A balance between efficiency and oil quality must be considered when selecting the optimal extraction method.

Acknowledgement: The research was supported by Academy of Scientific Research and Technology (ASRT) “Next Generation Scholars” Scholarship Program (8th round 2021)

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