

A mini review on the processing, characterization, health benefits, and applications of patin fish oil products (*Pangasius* sp.)

^{1,6}Kusbandari, A., ^{1,2,3,*}Rohman, A., ⁴Martien, R. and ⁵Lestari, L.A.

¹Faculty of Pharmacy, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

²Center of Excellence Institute for Halal Industry and Systems, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia

³Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

⁴Department of Pharmaceutics, Faculty of Pharmacy, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

⁵Department of Nutrition and Health, Faculty of Medicine, Public Health, and Nursing, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

⁶Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Universitas Ahmad Dahlan, Yogyakarta 55166, Indonesia

Article history:

Received: 2 August 2024

Revised: 21 January 2025

Accepted: 5 March 2025

Published: 9 February 2026

Keywords:

Applications,
Products,
Extraction,
Patin fish oil,
Purification,
Physicochemical properties

DOI:

[https://doi.org/10.26656/fr.2017.10\(1\).172](https://doi.org/10.26656/fr.2017.10(1).172)

This open access article is licensed under the CC BY 4.0



Abstract

The patin fish (*Pangasius* sp.) is a freshwater species known for its high oil yield, making it a precious resource for producing fish oil. Oil from this species, patin fish oil (PFO), is rich in omega-3 and omega-6 polyunsaturated fatty acids (ω -3 and ω -6 PUFA), which are valuable for human health. This review aimed to provide a scientific description of the nutritional contents, processing, production, purification, physicochemical properties, and health benefits of PFO and its application in the pharmaceutical and food industries. PFO can be derived from different fish parts, including the head, flesh, belly fat, offal, and bones. Methods for extracting PFO, such as maceration, dry rendering, wet rendering, Soxhlet extraction, ultrasound-assisted extraction (UAE), microwave-assisted extraction (MAE), direct pressing, and steaming, have their benefits and drawbacks. The extracted fish oil takes the form of crude oil, which requires another step to purify it. Purification will enhance the quality of the fish oil according to food-grade fish oil standards, in this case, the International Fish Oil Standards (IFOS), and ensure that the final oil is free of impurities. Filtering, settling, centrifugation, degumming, neutralization, bleaching, deodorization, and esterification involved in the purification process allow the oil to be preserved from degradation and retain its nutrients. Fish oil (FO) can be characterized utilizing the AOAC INTERNATIONAL method, which includes tests for acid, peroxide, iodine, saponification, anisidine, and fatty acid values. In the pharmaceutical industry, PFO can provide neuroprotective and antioxidant effects, improve cardiovascular health, boost the immune system, and treat cosmetic and skin conditions, such as photoaging, skin cancer, hypersensitivity, dermatitis, cutaneous wounds, and melanogenesis. Meanwhile, it can be used in the food industry's nutritional supplements, products, and preservatives. FO products on the market come in soft capsule and emulsion forms. With its unique properties, PFO holds the potential for the health and pharmaceutical industries, positioning it as a promising product for the future.

1. Introduction

Fish oil (FO) products from freshwater sources are less abundant than those from the sea (Sasongko *et al.*, 2022). Compared to other freshwater species, the patin fish (*Pangasius* sp.), enjoyed directly or used in various dishes, such as fillets and smoked preparations, yields

significantly more oil. Patin fish cultivation often produces a variety of by-products, such as heads, skin, bones, abdominal fat, offal, and trimmings (Amri *et al.*, 2021). While the flesh of the fish can be processed as food or prepared as FO, which is applied to food supplements, cosmetics, and pharmaceuticals (Rohman *et al.*, 2021), its by-products can be processed into

*Corresponding author.

Email: abdul_kimfar@ugm.ac.id

fishmeal as animal feed. In particular, the residual fish oil holds excellent potential for developing value-added products (Kamini *et al.*, 2016).

Patin fish contains 16.08% proteins, 5.75% fats, 1.5% carbohydrates, 0.97% ash, and 75.7% water (Wafa *et al.*, 2021). The oil derived from this species is low in omega-3 fatty acids but high in omega-6 and omega-9 (Thammapat *et al.*, 2010). Omega-3 fat is a nutrient the human body needs to boost intelligence and strengthen the immune system (Pasini *et al.*, 2022). Furthermore, it has antioxidant properties essential for warding off free radicals (Samsul *et al.*, 2024). Omega-6 is an essential fatty acid important for preventing the risk of thrombotic cardiovascular events, protecting cell membranes, and keeping cholesterol in balance (Harris *et al.*, 2009). Finally, omega-9 can reduce LDL and increase HDL in the bloodstream (Kamini, 2016). Patin fish oil (PFO) contains 49.344% saturated fatty acids (SFA) and 54.524% unsaturated fatty acids.

Fish flesh can be processed into food products and fish oil. Extraction and purification processes are required to obtain good-quality fish oil. Extraction separates the intended components from the mixture (Ivanovs and Blumberga, 2017). It can be done by maceration (Mendez and Concha, 2018), Soxhlet extraction (Sahena *et al.*, 2010), ultrasound-assisted extraction (UAE) (Kumar *et al.*, 2021), microwave-assisted extraction (MAE) (Afolabi *et al.*, 2018), supercritical fluid extraction (SFE) (Perretti *et al.*, 2007; Gedi *et al.*, 2015), enzymatic hydrolysis (Deepika *et al.*, 2014), direct pressing (Ikhsan *et al.*, 2022), and rendering (Ponphaiboon *et al.*, 2018).

Extraction results in FO in the form of crude fish oil (CFO), which usually fails to fulfill food quality standards, such as the International Fish Oil Standards (IFOS). To meet standards for the CFO, refining is performed to obtain clear, odorless oil with good taste, eye-catching appearance, and long shelf life (Merkle *et al.*, 2017). This involves filtration, degumming (Pan *et al.*, 2018), neutralization, bleaching, and deodorization (Ningsih *et al.*, 2024).

2. Methods

This review used several databases, including Scopus, PubMed, Web of Science, Google Scholar, and DOAJ, to explore relevant literature using the keywords "fish oil," "patin fish oil," or "*Pangasius* sp." AND "processing of fish oil," AND "characterization of fish oil," AND "health benefits of fish oil" or "patin fish oil," AND "application of products in the pharmaceutical and food industries." Abstracts or full papers from original

articles or review articles were carefully evaluated before being included as references in this review.

3. Processing and production of patin fish oil

Harvesting abundant yields of patin oil from patin fish involves a series of steps that blend traditional and modern techniques. This process includes washing to remove impurities, weighing both before and after extraction to determine the yield, and using various methods for extraction and purification. These stages are illustrated in Figure 1.

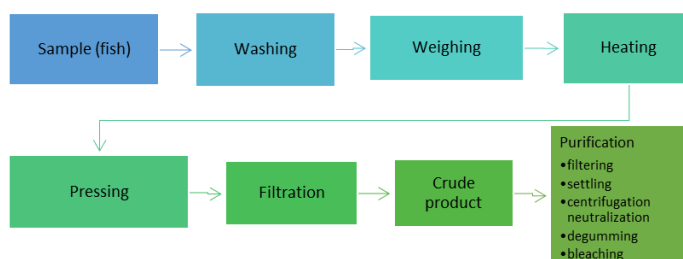


Figure 1. Processing PFO.

Extraction isolates substances from solids or fluids, employing a solvent that will extricate the desired substance without extricating other substances. It is utilized to partition substances from sources for purification or non-stop filtration of substances. Extraction of FO can be performed through both conventional and modern methods. Traditional methods include solvent extraction (SLE) (Dulanlebit, 2023), dry and wet rendering, and mechanical expression (Rahman *et al.*, 2023). In contrast, modern methods include supercritical fluid extraction (SFE), instant controlled pressure drop (DIC), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and pulsed electric field (PEF) (Usman *et al.*, 2022).

Rendering is a method of extracting oil with high water content. There are two types of rendering: wet and dry rendering. While wet rendering applies high temperature and water steam pressure and produces significant quantities of oil or fat, dry rendering is carried out without water addition (Kamini *et al.*, 2016). Dry rendering is a cost-effective method involving hydraulic pressing and a cooker dryer, making it a valuable investment despite the higher operational cost (Rahman *et al.*, 2023). The high pressure applied in the method facilitates the extraction of liquid oil from the tissue. This process uses petroleum ether, gasoline, carbon disulfide, carbon tetrachloride, benzene, or n-hexane as solvents. Ideally, the amount of solvent that evaporates should not exceed 5%, as this can impact the solvent extraction system as a whole and the quality of the oil (Putri *et al.*, 2019). As this method uses many solvents and takes an extended period, ecofriendliness has become a concern that needs to be considered (Rohim *et al.*, 2024).

Soxhlet extraction (SE) and maceration are two standard extraction methods. These methods use a solvent to extract compounds from solid materials. These methods are popular as they are simple and need no supervision (Lopez-Bascon and Luque de Castro, 2020). SE is particularly advantageous as it allows for the continuous transfer of analytes from the sample into a fresh solvent, producing higher analyte yields (Li et al., 2019). In addition, it is a non-stop, high-productivity, automatic, fast extraction strategy that needs less solvent than maceration or percolation (Zhang et al., 2018). However, SE uses hazardous and flammable organic solvents, potentially releases toxic compounds during extraction, utilizes more expensive, higher-purity solvents, and involves tedious work, which constitutes a disadvantage (Lopez-Bascon and Luque de Castro, 2020).

MAE is an extraction method that uses electromagnetic waves at frequencies between 0.3 - 300 GHz, with a short extraction time, less solvent, and little energy (Dulanlebit, 2023). The interaction of microwaves with polar compounds, such as water and organic components, produces warmth through ionic conduction and dipole turn instruments. This process involves the concurrent exchange of heat and mass to make a synergistic impact that quickens extraction and

upgrades the extraction yield (Afolabi et al., 2018; Zhang et al., 2018). Other extraction methods include SFE (Gedi et al., 2015) and enzymatic hydrolysis (Deepika et al., 2014). Various extraction methods are illustrated in Figure 2, and their benefits and disadvantages are detailed in Table 1. The selection of the extraction method will affect the oil yield and characteristics, including the fatty acid content, anisidine index, acid value, saponification index, iodine content, and peroxide index. Table 2 provides PFO data on these characteristics.

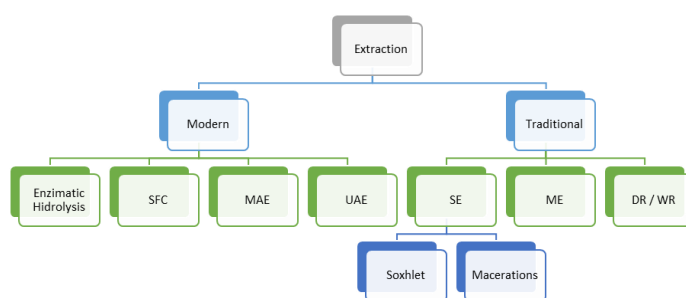


Figure 2. Method of extraction. SFC: Supercritical Fluid Extraction, MAE: Microwave-Assisted Extraction, UAE: Ultrasound-Assisted Extraction, SE: Soxhlet Extraction, ME: Maceration Extraction, DR: Dry Rendering, WR: Wet Rendering.

These different methods, as summarized in Table 3, have been conducted. The yield results indicate that wet

Table 1. The benefits and disadvantages of the extraction method.

Method of extraction	Benefits	Disadvantages
Dry rendering	<ul style="list-style-type: none"> short time can use an industrial scale 	<ul style="list-style-type: none"> The heat will cause denaturation
Wet rendering	<ul style="list-style-type: none"> low cost does not use organic solvents 	<ul style="list-style-type: none"> Long time for extraction not suitable for compounds thermolabile cannot use agitation (stirring) to speed up the extraction
Soxhlet	<ul style="list-style-type: none"> efficient and effective for determining the oil or fat content of an ingredient, because the solvent used can be recovered extraction is a relatively short time 	<ul style="list-style-type: none"> produce emissions of toxic substances the solvent used must be of high-purity high cost
Maceration	<ul style="list-style-type: none"> simple economical easy extraction without a heating process safety 	<ul style="list-style-type: none"> needs many solvents long time small yield
Pressured liquid extraction	<ul style="list-style-type: none"> easy short 	<ul style="list-style-type: none"> expensive cost can only be used for analysis
Supercritical fluid extraction	<ul style="list-style-type: none"> solvent (CO₂) is expensive solvent can be recycled short time extraction automatic does not require advanced filtration 	<ul style="list-style-type: none"> loss of target compounds due to improper solvent selection requires special equipment, specialized skills not suitable for compounds thermolabile.
Microwave-assisted extraction	<ul style="list-style-type: none"> short time can be used at the industrial and laboratory level 	<ul style="list-style-type: none"> not suitable for compounds or non-polar solvents solvents with high viscosity not ideal for compounds thermolabile, high cost need special skills to operate

Table 2. Methods and physicochemical properties.

Method	Purification agent	Peroxide value (meq/kg)	Acid value	LOD value (g I ₂ /100 g)	Saponification value	Anisidine value (meq/kg)
Dry rendering	-	4.87±0.145	2.64±0.09	81.9±1.19	196.75±1.45	8.93±0.16
	activated carbon 2%	4.29±0.08	1.92±0.07	81.99±1.28	194.87±2.05	7.07±0.06
	bentonite 2%	3.76±0.13	2.42±0.10	80.46±1.06	189.48±2.77	5.95±0.11
Dry rendering	-	10.40	-	17.87	108.84	-
Maceration with hexane (Wet samples)	-	9.59	5.27	-	135.21	-
Maceration with chloroform (Wet samples)	-	7.18	2.55	-	287.71	-
Maceration with ethyl acetate (Wet samples)	-	9.61	7.01	-	221.74	-
Maceration with hexane (dried samples)	-	5.14	5.27	-	137.83	-
Maceration with chloroform (dried samples)	-	8.88	8.86	-	287.64	-
Maceration with ethyl acetate (dried samples)	-	10.84	10.57	-	187.84	-
Soxhlet (n-hexane)	-	15.67	15.6	-	144.28	-
Soxhlet (chloroform)	-	17.92	8.84	-	268.59	-
Soxhlet (Ethyl acetate)	-	14.30	12.41	-	192.05	-
wet rendering	bentonite 7%	0.00	-	-	-	2.28±0.16
	-	6.40±0.11	-	146.42±0.0	-	-
	bentonite 3%	4.88±0.06	-	185.56±33.86	-	-
	bentonite 1%	5.79±0.04	-	185.56 ±33.86	-	-
	citric acid 3% + NaOH 9.5% + bentonite 1%	6.08±0.18	-	168.34±2.97	-	-
	NaCl 8% + NaOH 1 N + bentonite 2%	5.52±0.26	-	185.25± 8.94	-	-
	-	4.26±0.13	-	141.83±7.04	-	-
Dry rendering	bentonite 3%	1.60±0.14	-	188.50±6.01	-	-
	bentonite 1%	2.14±0.16	-	205.31±12.70	-	-
	citric acid 3% + NaOH 9.5% + bentonite 1%	3.89±0.19	-	163.47±1.46	-	-
	NaCl 8% + NaOH 1 N + bentonite 2%	3.82±0.10	-	173.81±12.84	-	-
	-	2.77±0.15	-	-	-	2.86±0.2
Modified dry rendering	-	2.77±0.15	-	-	-	2.86±0.2
Soxhlet (diethyl ether)	-	4.146±0.29	1.469±0.00	61.187±0.53	162.964±0.00	-
Wet rendering	-	3.308±0.43	1.523±0.00	49.345±0.51	186.697±0.011	-
Acid silage	-	4.645±0.48	1.442±0.00	51.708±0.36	177.555±0.50	-
MAE	-	2.081±0.70	1.402 ± 0.00	54.439±0.59	195.286±0.654	-

samples yield less than dry samples due to the drying process, where water evaporates, leaving the water content negligible. This small water content impacts the penetration of the solvent into the sample. In wet maceration, ethyl acetate solvent yields higher results

than hexane and chloroform due to its higher polarity, attracting more polar compounds. Meanwhile, dry maceration yields lower results as polar compounds may have been reduced, with less attraction of ethyl acetate. Research also distinguishes between wet and dry

rendering methods (Kamini *et al.*, 2016). Rendering is an extraction method to remove oil trapped in the cell wall by breaking the cell wall using heating (Rohim *et al.*, 2024) and high pressure. Using both heating and high pressure will affect the yield and quality of the oil. Compared to Soxhlet extraction, pressing yields less patin fish oil.

Table 3. Extraction method.

Method	Sample/solvent	Yield (%)
Maceration of wet fish	n-hexane	16.18±11.73
	chloroform	14.66±15.13
	ethyl acetate	23.89±8.85
Maceration of dry fish	n-hexane	21.40±7.67
	chloroform	25.14±4.49
	ethyl acetate	15.82±2.11
Soxhlet	n-hexane	50.43±2.78
	chloroform	32.42±1.95
	ethyl acetate.	32.15±3.45
UAE	n-hexane: isopropanol	42.71±0.44
MAE	ethyl acetate: methanol	42.08±0.90
Dry rendering	innards	45.17

Fish oil purification follows extraction, involving the removal of impurities and undesirables to produce a purified product (Anandganesh *et al.*, 2016). Fish oil may have a pleasant odor and flavor, an uninteresting color, and limited shelf life, which can be costly to consumers (Mendez and Concha, 2018). Therefore, purification is performed to improve the quality of the fish oil to meet food-grade fish oil standards and ensure that the finished oil is impurity-free (Kamini *et al.*, 2016). Impurities in the oil can reduce the oil's quality (Firestone, 2011). In addition to impurities, fish oil purification removes water, affecting the oil's susceptibility to oxidation. Purification with bentonite will decrease the levels of free fatty acids and affect the characteristics of fish oil. Bentonite can potentially cause a fat hydrolysis reaction, which may reduce the quality of the fish oil (Indah *et al.*, 2022). Its capacity to absorb free fatty acids lends bentonite a greater effectiveness in purification than activated carbon. Purification may also use magnesium silicate (a synthetic absorbent containing 63.4% SiO₂, 31.0% MgO, and H₂O₄) to prevent inactive materials and impurities from affecting adsorption, causing the yellow color of the oil to change to transparent. The quality of magnesium silicate can be improved to achieve the IFOS standards (Suseno *et al.*, 2021). In addition, H5-NZA adsorbent provides an enhanced quality that demonstrates superior performance over zeolite adsorbent, where the quality increases with increasing adsorbent composition (Handoko *et al.*, 2023). Purification can be done mechanically through filtering, settling, centrifugation, and chemically through neutralization, degumming, and bleaching (Bija *et al.*,

2017).

Degumming can remove impurities such as phospholipids, proteins, and carbohydrates from the oil, improving its quality and stability (Hurtada *et al.*, 2020; Gharby, 2022). These impurities can make the oil unstable and give it an unpleasant flavor. The process involves removing gums and sludges containing phosphatides, proteins, residue, carbohydrates, water, and resins without reducing the amount of free fatty acids in the oil (Huang and Sathivel, 2010). The extent of phosphorus removal varies depending on the type of fish oil. While it does not alter the free fatty acid content, degumming can decrease the peroxide value for all fish oils and increase the anisidine value, especially in sardine oil, for which a significant increase was observed. A general rise usually follows the degumming process in fish oil oxidation. Degumming primarily affects the nutritional value of fish oil, although insignificantly, by altering its specific chemical and physical properties (Estiasih *et al.*, 2017).

Neutralization, another step in purification, is pivotal for removing impurities aimed explicitly at eliminating free fatty acids (FFAs) from crude oil (Anandganesh *et al.*, 2016). This method involves using NaOH (sodium hydroxide), crucial in separating free fatty acids from oil or fat storage. Alkaline or other reagents facilitate the formation of soap and aid in the coagulation of materials consisting of undesirable ingredients (Shabanikakroodi *et al.*, 2015; Rahman *et al.*, 2023). NaOH treatment improves fish oil quality and safety by reducing free fatty acids and contaminants while preserving its nutritional benefits, especially essential fatty acids (Putri *et al.*, 2021). The application of NaOH in neutralization is extensively valued for its simplicity, cost-effectiveness, and efficiency. The oil quality can also be maintained by combining activated carbon and deodorizers. Neutralization can produce high-quality fish oil with improved taste, color, odor, shelf life, and market value, giving it applicability in the pharmaceutical and food industries (Nascimento *et al.*, 2015; Simat *et al.*, 2019).

Bleaching in the oil refining process aims to brighten the oil's color, remove gums, and absorb colloidal peroxides that may develop during degradation (Sari *et al.*, 2015). Rather than altering its nutritional contents, bleaching primarily eliminates impurities and enhances the oil's color and clarity (Hemp *et al.*, 2023). Adsorbents such as bentonite (Nadhiro *et al.*, 2018) and activated charcoal (Indah *et al.*, 2022) are used in bleaching. Adding bentonite to the oil refining process will lower the levels of peroxides (Suseno *et al.*, 2015), free fatty acids, p-anisidine, and acids (Rohman *et al.*,

2021). However, while adding adsorbents can extend shelf life, it may affect the oil's taste, fragrance, and color. The overall bleaching process is done in such a way as to ensure that the oil retains its beneficial fatty acids and other nutrients throughout storage and processing (Ayu *et al.*, 2020).

Deodorization is another critical step in the oil refining process, primarily aimed at enhancing the quality of edible oils by removing undesirable odors and flavors (Greyt *et al.*, 2024). It can be performed physically, chemically, and biologically. Physical deodorization involves using adsorbents such as activated charcoal and zeolite. Activated charcoal is stable, recyclable, and has a large pore structure and surface area, effectively absorbing compounds that cause fishy odor in fish oil (Chen *et al.*, 2016). Zeolite, a microscopic crystal composed of silicon, aluminum, and oxygen, can absorb trimethylamine (TMA), a compound responsible for unpleasant odor in fish oil (Chung and Lee, 2009). Deodorization at a low temperature (90°C) with constant stirring at 250 rpm for 10 minutes in 5% ethanol, added with 0.03% H₂SO₄ (98%), can produce fish oil with an odor and taste that meets standards (Demydova *et al.*, 2021). Unlike physical deodorization, chemical deodorization involves adding acid or alkaline compounds to the fish oil to prevent or eliminate the fishy odor caused by lipid oxidation. Pan *et al.* (2018) found that adding 3% β-cyclodextrin to puffer fish skin gelatin reduced fishy odor and volatile compound levels. However, chemical deodorization methods have disadvantages, including environmental pollution and limited effectiveness against certain odor-causing compounds. These methods are most effective for liquid substances. Lastly, biological deodorization utilizes microbes, such as yeasts and *Staphylococcus* bacteria. Yeasts can absorb and convert fishy-smelling substances into oil. The advantages of using yeasts are that it is safer, economical, and capable of producing unique odors (Su *et al.*, 2022). Deodorization can be conducted through molecular distillation (MD), steam distillation (SD), liquid-liquid extraction (LLE), the addition of green tea polyphenols (GTP), and adsorption using zeolites or diatomite, activated carbon (AC), or bentonite (BT) (Song *et al.*, 2018). Low-temperature liquid-liquid extraction, for instance, can protect the oil from oxidation and degradation. This method can reduce the acid and peroxide values and maintain the omega-3 fatty acid content. Additionally, the organic solvent nanofiltration technique has demonstrated apparent effects on the deodorization of fish oil, showing promise for the fish oil refining industry (Masrukan *et al.*, 2024).

4. Physicochemical properties

AOAC INTERNATIONAL standardization of fish oil covers acid, peroxide, iodine, saponification, anisidine, and fatty acid profiles. High acid and peroxide values mean lower oil quality and stability. This results in rancidity due to the transformation of triglycerides into free fatty acids and glycerol. The higher the peroxide and free fatty acid levels, the greater the level of damage (Lestari *et al.*, 2022). Peroxide values vary with extraction methods, temperature, and heating (Sembiring *et al.*, 2018). In addition, saponification value helps detect oil or fat adulteration by showing the sizes of the fatty acid molecules that make up triglycerides. A low saponification value indicates a significant molecular weight. Meanwhile, anisidine value can indicate the presence of oxidation processes in oil. A high anisidine value indicates lower oil quality (Pandiangan, 2021). These physicochemical parameters are further detailed in Table 2.

Fatty acids (FA) are long-chain hydrocarbon components of lipids, serving essential functions for the human body. The fish diet, fish age, season, location, and natural cycles influence the FA content in fish. Gas chromatography (GC), which is sensitive, relatively specific, highly reproducible, and quick in analysis, is used to determine the composition of PFO, including the FA content. To analyze them, non-volatile FAs must first be converted into more volatile methyl ester (FAME) forms using derivatization techniques (Guntarti *et al.*, 2020). Converting fatty acids into FAME, resulting in non-polar properties and low molecular weight, will simplify the analysis process. FAs are easily derivatized because their polar components will form hydrogen bonds, causing problems in adsorption. Fatty acids are composed of saturated and unsaturated fatty acids. Saturated fatty acids (SFA) consist of tridecanoic, palmitic, stearic, arachidic, eicosanoic, behenic, heneicosanoic, tricosanoic, and lignoceric acids, while unsaturated fatty acids contain omega-9, omega-6, and omega-3 (Sari *et al.*, 2017). Unsaturated fatty acids are classified into monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). MUFA comprise palmitoleic acid, linolenic acid, myristoleic acid, cis-10-heptadecanoic acid, oleic acid, and nervonic acid, whereas PUFA encompass linoleic acid, cis-8,11,14-eicosatrienoic acid, cis-11,14,17-eicosatrienoic acid, cis-5,8,11,14-eicosatetraenoic acid, EPA (cis-5,8,11,14,17-eicosapentaenoic acid), and arachidonic acid (Indah *et al.*, 2022). Fatty acid content is influenced by the fish species, feeding, fish parts used, extraction methods, and purification. The FA content in PFO is detailed in Table 4.

Table 4. Fatty acid composition of PFO.

Sample	Purification agent	Content				
		ω -3	ω -6	SFA	MUFA (%)	PUFA
Flesh	-	0.50%	19.44%	27.51%	47.24	25.25%
Flesh	-			46.09%	35.38	11.91%
Viscera	-			41.89%	12.22	33.94%
Viscera (wet rendering)	bentonite 3%	465.47 (μ g/mL)	613.73 (μ g/mL)	9999.62 (μ g/mL)		1126.14 (μ g/mL)
	bentonite 1%	1231.84 (μ g/mL)	460.79 (μ g/mL)	3033.81 (μ g/mL)		1692.63 (μ g/mL)
	citric acid 3% + NaOH 9.5% + bentonite 1%	66.73 (μ g/mL)	1338.47 (μ g/mL)	8761.47 (μ g/mL)		6952.39 (μ g/mL)
	NaCl 8% + NaOH 1 N + bentonite 2%	149.48 (μ g/mL)	856.41 (μ g/mL)	4755.86 (μ g/mL)		4910.97 (μ g/mL)
	bentonite 3%	-	1095.81 (μ g/mL)	5864.48 (μ g/mL)		5900.03 (μ g/mL)
Viscera (dry rendering)	bentonite 1%	44.19 (μ g/mL)	1155.52 (μ g/mL)	7036.51 (μ g/mL)		5984.92 (μ g/mL)
	citric acid 3% + NaOH 9.5% + bentonite 1%	-	864.47 (μ g/mL)	6316.24 (μ g/mL)		4887.14 (μ g/mL)
	NaCl 8% + NaOH 1 N + bentonite 2%	129.38 (μ g/mL)	837.90 (μ g/mL)	4567.31 (μ g/mL)		4424.43 (μ g/mL)
	bentonite 3%	-	1095.81 (μ g/mL)	5864.48 (μ g/mL)		5900.03 (μ g/mL)
Viscera fat	-	-	-	32.33%	28.33	10.04%
Liver and fatty tissues	-	-	-	46.89%	38.13	11.99%
Head (<i>Pangasianodon hypophthalmus</i>)	bentonite 1%	2.28%	-	46.76%	-	53.24%
Belly flap (<i>Pangasianodon hypophthalmus</i>)	bentonite 1%	3.35%	-	37.30%	-	62.79%
Viscera (<i>Pangasianodon hypophthalmus</i>)	bentonite 1%	2.11%	-	45.62%	-	54.38%
Head (<i>Pangasius djambal</i>)	bentonite 1%	3.15%	-	37.08%	-	62.92%
Belly flap (<i>Pangasius djambal</i>)	bentonite 1%	1.45%	-	47.27%	-	52.74%
Viscera patinjambal	bentonite 1%	2.95%	-	38.03%	-	61.97%
Flesh (<i>Pangasius micronemus</i>) Sg Lembing	-	3.1%	13.9%	34.80%	41.40	18.3%
Flesh (<i>Pangasius micronemus</i>) Sg Kanchong	-	4.7%	12.8%	41.50%	35.80	19.3%
Flesh (<i>Pangasius micronemus</i>) Tg. Pulai	-	3.2%	13.0%	40.0%	35.80	17.7%
Flesh (<i>Pangasius nasutus</i>) Peramu	-	1.3%	6.5%	32.0%	44.40	9.3%
Flesh (SE)	-			8.530 \pm 1.005%	2.752 \pm 0.392	19.158 \pm 1.710%
Flesh (WR)	-			10.634 \pm 0.714%	1.554 \pm 0.153	13.236 \pm 0.789%
Flesh (AS)	-			17.330 \pm 1.508%	4.860 \pm 0.725	8.600 \pm 0.573%
Flesh (MAE)	-			13.570 \pm 2.50%	7.997 \pm 0.193	12.137 \pm 1.216%

Finally, proximate analysis quantifies the carbohydrate, protein, water, ash, and fat contents in oil (Putri *et al.*, 2020), which are influenced by the environment, fish age, size, sex, and species. Ash content, in particular, reflects the oil's inorganic

components (minerals). Patin fish (*Pangasius* sp.) contains 16.08% protein, 5.75% fat, 2.5% carbohydrates, 0.97% ash, and 75.5% water (Bisenius *et al.*, 2020). Panagan *et al.* (2012) reported that PFO contains 0.21–2.48% EPA and 0.95–0.96% DHA. The SFA content

was 35.13%, the MUFA content was 36.55%, and the PUFA content was 13.93%. The belly contains 36.21% fat, while the offal was reported to contain up to 93.32% FA (Thammapat *et al.*, 2010), with 26.22% palmitic acid and 40.14% oleic acid. Another study reported a total saturated fatty acid content of 49.344% and a total unsaturated fatty acid content of 54.524%, including 39.101% MUFA and 15.423% PUFA (Pandiangan, 2021). The approximate analysis results for the phytonutrient of PFO are detailed in Table 5.

5. Health benefits of patin fish oil

PFO contains fatty acids, vitamins, and other nutrients beneficial for cardiovascular health, brain health, and neurological function. It has anti-inflammatory properties, reduces the risk of eye disease, improves the immune system, helps prevent periodontal and dental diseases, depression, and anxiety (Back and Hansson, 2019), and helps treat ulcerative colitis (Marton *et al.*, 2019). FO can significantly reduce LDL cholesterol levels (Fathony *et al.*, 2022). The omega-3 polyunsaturated fatty acids (PUFAs) contained in FO are beneficial for treating cardiovascular disease (CVD), preventing all-cause mortality and sudden cardiac death (Bowen *et al.*, 2016), thereby reducing CHD mortality (Fonda *et al.*, 2016). It can also support mental health conditions (Wani *et al.*, 2015). Depression, one of these conditions, is a multifactorial disorder whose causes include a deficiency of omega-3 fatty acids. In addition, omega-3 fatty acid supplements improve symptoms of eye disease, a common chronic condition characterized by eye pain and visual disturbances, which can decrease the quality of life (Wang and Daggy, 2017). DHA, one of the omega-3 fatty acids, may optimize photoreceptor membrane fluidity, retinal integrity, and visual function in the eye (Querques *et al.*, 2011), thereby playing a vital role in photoreceptor cells in the retina (Shindou *et al.*, 2017). Together with EPA and ALA, other omega-3 fatty acids, DHA, are also essential for brain function (McNamara and Almeida, 2020). In the brain, DHA affects neurotransmitters (Dighriri *et al.*, 2022). Omega-3 may reduce Alzheimer's disease (AD) and stress on brain development and function (Hartnett *et al.*, 2023),

enhance adult memory (Nadine *et al.*, 2016), improve mood, and protect against cognitive decline (Kokubun *et al.*, 2020).

The immune system is the body's defense system that protects the organism from attacks by pathogens, such as viruses or bacteria. Omega-3 fatty acids increase the targets for phagocytosis, thereby increasing the phagocytic capacity of macrophages to ingest certain types of particles. This increase comes from the changes in the composition and structure of the macrophage cell membrane due to the incorporation of omega-3 fatty acids. These macrophage cells are essential to the innate immune system (Gutiérrez *et al.*, 2019). Omega-3 triggers changes in gene regulation in macrophages. Treating THP-1-derived macrophages with DHA or EPA induces changes in gene expression in response to LPS activation (Ndou *et al.*, 2017). As precursors of lipid mediators of inflammation, they can limit or modulate the inflammatory response and help prevent or reduce experimental arthritis (Athanassiou *et al.*, 2020). These fatty acids can also prevent the increase of TNF- α after surgery in patients with digestive system tumors (Jamali *et al.*, 2024).

6. Application of patin fish oil products in the pharmaceutical and food industries

Patin fish has attracted considerable attention for its potential applications in the pharmaceutical, cosmetic, and food industries due to its PUFA, including DHA and EPA, α -linolenic acid (ALA), and linoleic acid contents. In the pharmaceutical sphere, it can be used as a neuroprotective agent (Nengah *et al.*, 2024), antioxidant, and heart disease treatment (Lubis *et al.*, 2024). Meanwhile, its potential applications in cosmetics include photoaging treatments, skin cancer, allergy, dermatitis, cutaneous wounds, and melanogenesis (Huang *et al.*, 2018). Its high PUFA content, which provides anti-inflammatory effects, makes it a suitable ingredient for hand and body cream preparations (Shabanikakroodi *et al.*, 2019). It is also suited for treating localized skin conditions like psoriasis and UV-induced erythema. Additionally, PFO has been combined with turmeric extract to improve oxidative stress,

Table 5. Phytonutrient content of PFO

		Parameter			
Protein level (%)	Carbohydrate level (%)	Lipid level (%)	Ash (%)	Moisture content (%)	
16.71	6.08	0.25	0.81	76.15	
16.08	1.5	5.75	0.97	75.7	
0.32±0.03	0.17±0.16	88.19±0.28	0.05±0.00	14.41±0.33	
2.14±0.02	-	73.23±0.01	-	-	
1.75±0.02	-	77.64±0.01	-	-	
13.49±0.01	-	9.59±0.02	-	-	
12.70±0.01	-	11.71±0.03	-	-	

including malondialdehyde (MDA) and superoxide dismutase (SOD). The combination's ability to significantly alleviate oxidative stress indicates its potential therapeutic benefits against metabolic disorders (Nengah *et al.*, 2024). As for the food industry, patin fish's potential applications include nutritional supplements, products, and preservatives (Lubis *et al.*, 2024).

Incorporating PFO in food products benefits health. These benefits especially come from PFO unsaturated fatty acid contents, including DHA and EPA (Jamshidi *et al.*, 2020). PFO can be used as a health supplement in soft capsules or emulsion forms (Sukmiwati *et al.*, 2020). PFO in syrup preparations is also used as an alternative for stunting prevention (Samsul *et al.*, 2024). Fish oil can be formulated into margarine (Hastarini *et al.*, 2021) and biscuits (Ilza and Sukmiwati, 2020). It can be used as collagen (Sadi and Yoga, 2021) and even further processed into biodiesel (Yupitasari *et al.*, 2020). It is essential to determine the role of omega-3 fatty acids, particularly DHA, in primary care practices (Troesch *et al.*, 2020). Contents such as PUFA (DHA and EPA), α -linolenic acid (ALA), and linoleic acid are essential for ameliorating the severity of some skin disorders, such as photoaging, skin cancer, allergy, dermatitis, cutaneous wounds, and melanogenesis (Huang *et al.*, 2018), improving body composition, and counteracting obesity-related metabolic changes, as in modulating lipid metabolism (Albracht-Schulte *et al.*, 2018) and inhibiting several aspects of inflammation (Calder, 2013).

7. Conclusion

Patin fish contains proteins, carbohydrates, and fatty acids, such as omega-3, omega-6, and omega-9. Various extraction methods can be used to extract oil from this species. Of those methods, the dry rendering and direct press methods are the most widely used due to their simplicity, the products' safety for consumption, the use of samples in bulk, and enormous yields. Extraction is followed by purification or refining, aiming to produce high-quality oil that meets IFOS standards. This process uses bentonite, activated charcoal, zeolite, or magnesium silicate as a cleaning agent. The nutrients in the fish oil obtained from these processes can improve brain intelligence, prevent stunting and heart disease, lower cholesterol levels, and boost the immune system. Currently, fish oils are only available in soft capsule or emulsion forms, necessitating product diversification for maximum benefits.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

The authors would like to thank Universitas Gadjah Mada, the Education Financial Service Center, and the Indonesian Education Endowment Fund Agency for granting the Doctoral Education Scholarship Fund under the Indonesian Education Scholarship 2022 scheme run by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia.

References

- Afolabi, H.K., Kholijah, S., Mudalip, A. and Alara, O.R. (2018). Microwave-assisted Extraction and Characterization of Fatty Acid From Eel Fish (*Monopterus albus*). *Beni-Suef University Journal of Basic and Applied Sciences*, 7(4), 465–470. <https://doi.org/10.1016/j.bjbas.2018.04.003>
- Albracht-Schulte, K., Kalupahana, N.S., Ramalingam, L., Wang, S., Rahman, S.M., Robert-McComb, J. and Moustaid-Moussa, N. (2018). Omega-3 fatty acids in obesity and metabolic syndrome: a mechanistic update. *The Journal of Nutritional Biochemistry*, 58, 1–16. <https://doi.org/10.1016/j.jnutbio.2018.02.012>
- Amri, U., Diharmi, A. and Sukmiwati, M. (2021). Characteristics of catfish oil, red palm oil, and shark liver oil as functional foods. *Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan*, 10(2), 151–160. <https://doi.org/10.13170/depik.10.2.19131>
- Anandganesh, E., Nazar, A., Marichamy, G., Gowtham, K. and Shanker, S. (2016). Extraction, Purification, Composition, and Quality Deterioration of Fish Body Oil Extracted From *Sardinella fimbriata* by Traditional Method. *International Journal of Innovative Research in Medical Science*, 1(7), 232–241.
- Athanassiou, I.K., Athanassiou, L. and Athanassiou, P. (2020). The Effect of Omega-3 Fatty Acids on Rheumatoid Arthritis. *Mediterranean Journal of Rheumatology*, 31(2), 190–194. <https://doi.org/10.31138/mjr.31.2.190>
- Ayu, B.I.G., Soni, H. and Gofar, I.E. (2020). Characteristics Of Fish Oil Produced Through Madidihang Fishmeal Industry Waste Treatment (*Thunnus Albacares*) Using Adsorbents. *Journal of Agricultural and Socio-Economic Sciences*, 3(99), 69–76. <https://doi.org/10.18551/rjoas.2020-03.08>
- Bija, S., Suseno, S.H. and Uju. (2017). Purification of Sardine Fish Oil Through Degumming and Neutralization. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 20(1), 143-152. <https://doi.org/10.17844/jphpi.v20i1.16501>
- Bisenius, S., Neuhaus, H., Effkemann, S., Heemken, O.,

- Bartelt, E., Lang, T., Haunhorst, E. and Kehrenberg, C. (2020). Composition of Herring and Cod Fillets from the North and the Baltic Sea Detecting Added Water. *Food Control*, 107, 106766. <https://doi.org/10.1016/j.foodcont.2019.106766>
- Bowen, K.J., Harris, W.S. and Kris-Etherton, P.M. (2016). Omega-3 Fatty Acids and Cardiovascular Disease: Are There Benefits? *Current Treatment Options in Cardiovascular Medicine*, 18(69), 2–16. <https://doi.org/10.1007/s11936-016-0487-1>
- Calder, P.C. (2013). Omega-3 polyunsaturated fatty acids and inflammatory processes: nutrition or pharmacology? *British Journal of Clinical and Pharmacology*, 75(3), 645–662. <https://doi.org/10.1111/j.1365-2125.2012.04374.x>
- Chen, D., Chen, X., Chen, H., Cai, B., Wan, P., Zhu, X., Sun, H., Sun, H. and Jianyu, P. (2016). Identification of Odor Volatile Compounds and Deodorization of. *Oceanic and Coastal Sea Research*, 15(6), 1101–1110. <https://doi.org/10.1007/s11802-016-3166-7>
- Chung, K. and Lee, K. (2009). Removal of trimethylamine by adsorption over zeolite catalysts and deodorization of fish oil. *Journal of Hazardous Materials*, 172(2-3), 922–927. <https://doi.org/10.1016/j.jhazmat.2009.07.081>
- Deepika, D., Ramakrishnan, V., Vasudevan, Pahling, J. and Cheema, S. (2014). Investigation on Oil Extraction Methods and its Influence on Omega-3 Content from Cultured Salmon. *Journal of Food Processing and Technology*, 5, 12.
- Demydova, A.O., Aksonova, O.F., Molchenko, S.M. and Hladkyi, F.F. (2021). Research on A New Approach to Low-Temperature Deodorization and Its Effect on Oxidative Deterioration of Fish Oil. *Journal of Chemistry and Technologies*, 29(4), 639–649. <https://doi.org/10.15421/jchemtech.v29i4.238356>
- Dighriri, I.M., Alsubaie, A.M., Hakami, F.M., Hamithi, D.M., Maryam, M., Khobrani, F.A., Dalak, F.E., Hakami, A.A., Alsueaadi, E.H., Laila, S., Alshammari, S.F., Alqahtani, A.S., Alawi, I.A., Aljuaid, A.A. and Tawhari, M.Q. (2022). Effects of Omega-3 Polyunsaturated Fatty Acids on Brain Functions: A Systematic Review. *Cureus*, 14(10), e30091. <https://doi.org/10.7759/cureus.30091>
- Dulanlebit, Y.H. (2023). Overview of Extraction Methods for Extracting Seaweed and its Applications. *Jurnal Penelitian IPA*, 9(2), 817–824. <https://doi.org/10.29303/jppipa.v9i2.3053>
- Estiasih, T., Ahmadi, K., Kurniawan, F.A. and Maligan, J.M. (2017). Effect of Degumming on the Characteristics of Fish Oil from By-Product of Sardine and Tuna Canning and Meal Processing. *International Journal of ChemTech Research*, 10(6), 101–108.
- Fathony, S.Y., Handajani, F. and Rahayu, I.N. (2022). The Effect of Patin Fish Oil Extract on LDL Cholesterol Levels *Rattus norvegicus* was Induced by Alloxan. *Jurnal Ilmu Kedokteran Wijaya Kusuma*, 11(2), 116-124. <https://doi.org/10.30742/jikw.v11i2.1877>
- Firestone, D. (2011). Official Methods and Recommended Practices of the American Oil Chemists' Society (AOCS). Retrieved from website: <https://bhttps://cir.nii.ac.jp/crid/1130000796797633280>.
- Fonda, G., Pranata, R. and Deka, H. (2016). Role of Omega-3 Fatty Acids in Dyslipidemia and Cardiovascular Diseases. *Journal Kardiologi Indonesia*, 37(4), 213–222. <https://doi.org/10.30701/ijc.v37i4.586>
- Gedi, M.A., Bakar, J. and Mariod, A.A. (2015). Optimization of supercritical carbon dioxide (CO₂) Extraction of Sardine (*Sardinella lemuru* Bleeker) Oil Using Response Surface Methodology (RSM). *Grasas y Aceites*, 66(2), e074. <https://doi.org/10.3989/gya.0824142>
- Gharby, S. (2022). Refining Vegetable Oils: Chemical and Physical Refining. *The Scientific World Journal*, 2022, 6627013. <https://doi.org/10.1155/2022/6627013>
- Greyt, W.D. (2024). Deodorization. Retrieved from American Oil Chemists' Society (AOCS) website: <https://www.aocs.org/resource/deodorization/>
- Guntarti, A., Ahda, M., Kusabandari, A. and Natalie, F. (2020). Analysis of Pork Adulteration In Corned Products Using FTIR Associated With Chemometrics Analysis. *Potravinarstvo Slovak Journal of Food Sciences*, 14(2020), 1042-1046. <https://doi.org/10.5219/1412>
- Gutiérrez, S., Svahn, S.L. and Johansson, M.E. (2019). Effects of omega-3 fatty acids on immune cells. *International Journal of Molecular Sciences*, 20(20), 5028. <https://doi.org/10.3390/ijms20205028>
- Handoko, D.S.P., Ristanti, R.Y. and Handayani, W. (2023). Improvement of the Quality of Fish Oil from Waste Flouring Using Adsorbent Zeolit H5-NZA. *Formosa Journal of Sustainable Research*, 2(5), 1109–1122. <https://doi.org/10.55927/fjsr.v2i5.4083>
- Back, M. and Hansson, G.K. (2019). Omega-3 fatty acids, cardiovascular risk, and the resolution of inflammation. *The FASEB Journal*, 33(2), 1536–1539. <https://doi.org/10.1096/fj.201802445R>
- Harris, W.S., Mozaffarian, D., Rimm, E., Kris-etherton, P., Rudel, L.L., Appel, L.J., Engler, M.M., Engler,

- M.B. and Sacks, F. (2009). Omega-6 Fatty Acids and Risk for Cardiovascular Disease. *AHA Science Advisory*, 119(6), 902–907. <https://doi.org/10.1161/CIRCULATIONAHA.108.191627>
- Hartnett, K.B., Ferguson, B.J., Hecht, P.M., Schuster, L.E., Shenker, J.I., Mehr, D.R., Fritsche, K.L., Belury, M.A., Scharre, D.W., Horwitz, A.J., Kille, B.M., Sutton, B.E., Tatum, P.E. and Greenlief, C.M. (2023). Potential Neuroprotective Effects of Dietary Omega-3 Fatty Acids on Stress in Alzheimer's Disease. *Biomolecules*, 13, 1096. <https://doi.org/10.3390/biom13071096>
- Hastarini, E., Nabilla, M., Permadi, A., Adi, C.P. and Nurbayasari, R. (2021). Characteristic of margarine with ingredients mixed with catfish (*Pangasius* sp.) and vegetable oil. *IOP Conference Series: Earth and Environmental Science.*, 919, 12043. <https://doi.org/10.1088/1755-1315/919/1/012043>
- Hemp, R., Oil, S., Golimowski, W., Teleszko, M. and Zaj, A. (2023). Effect of the Bleaching Process on Changes in the Fatty Acid. *Molecules*, 28(2), 769. <https://doi.org/10.3390/molecules28020769>
- Huang, J. and Sathivel, S. (2010). Purifying salmon oil uses adsorption, neutralization, and combined neutralization and adsorption. *Journal of Food Engineering*, 96(1), 51–58. <https://doi.org/10.1016/j.jfoodeng.2009.06.042>
- Huang, T.H., Wang, P.W., Yang, S.C., Chou, W.L. and Fang, J.Y. (2018). Cosmetic and Therapeutic Applications of Fish Oil's Fatty Acids on the Skin. *Mariene Drug*, 16(8), 256. <https://doi.org/10.3390/md16080256>
- Hurtada, W., Barrion, A.S., Nguyen-Orca, M.F., Orillo, A.T., Magpantay, J.R., Geronimo, G. and Rodriguez, F. (2020). Physicochemical Properties, Nutritional Value, and Sensory Quality of Cassava (*Manihot esculenta* Crantz) Rice-like Grains. *Food Research*, 4(5), 1623–1629. [https://doi.org/10.26656/fr.2017.4\(5\).082](https://doi.org/10.26656/fr.2017.4(5).082)
- Ikhsan, A.N., Irnawati, I., Lestari, L.A., Erwanto, Y. and Rohman, A. (2022). Simultaneous analysis of patin fish oil (*Pangasius micronemus*) and bandeng (*Chanos chanos*) fish oil using FTIR spectroscopy and chemometrics. *Food Research*, 6(3), 262–268. [https://doi.org/10.26656/fr.2017.6\(3\).353](https://doi.org/10.26656/fr.2017.6(3).353)
- Ilza, M. and Sukmiwati, M. (2020). The Use of Jambal Fish (*Pangasius hypophthalmus*) and Grouper (*Cromileptes* sp.) Oils for Infant Biscuit Formulation. *IOP Conference Series: Earth and Environmental Science*, 430, 012009. <https://doi.org/10.1088/1755-1315/430/1/012009>
- Indah, Rohman, A. and Lestari, L.A. (2022). Physicochemical Characterization Refined Patin Fish Oil (*Pangasius micronema*) using Bentonite and Activated Carbon. *Food and Pharmaceutical Sciences*, 10(2), 626–633. <https://doi.org/10.22146/jfps.4682>
- Ivanovs, K. and Blumberga, D. (2017). Extraction of fish oil using green extraction methods: a short review. *Energy Procedia*, 128, 477–483. <https://doi.org/10.1016/j.egypro.2017.09.033>
- Jamali, M., Zarezadeh, M., Jamilian, P. and Ghoreishi, Z. (2024). The effect of n-3 polyunsaturated fatty acids on inflammation status in cancer patients : Updated systematic review and dose- and time-response. *PharmaNutrition*, 27, 100372. <https://doi.org/10.1016/j.phanu.2023.100372>
- Jamshidi, A., Cao, H., Xiao, J. and Simal-Gandara, J. (2020). Advantages of techniques to fortify food products with the benefits of fish oil. *Food Research International*, 137, 109353. <https://doi.org/10.1016/j.foodres.2020.109353>
- Kamini, Suptijah, P., Santoso, J. and Suseno, S.H. (2016). Extraction by Dry Rendering Method and Characterization of Fish Oil of Catfish Viscera Fat by Product of Smoked Fish Processing. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 19(3), 196–205. <https://doi.org/10.17844/jphpi.2016.19.3.196>
- Kokubun, K., Nemoto, K. and Yamakawa, Y. (2020). Fish Intake May Affect Brain Structure and Improve Cognitive Ability in Healthy People. *Frontiers in Aging Neuroscience*, 12, 76. <https://doi.org/10.3389/fnagi.2020.00076>
- Kumar, K., Srivastav, S. and Sharanagat, V.S. (2021). Ultrasound-assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by-products: A review. *Ultrasonics Sonochemistry*, 70, 105325. <https://doi.org/10.1016/j.ultsonch.2020.105325>
- Lestari, L.A., Rohman, A., Prihandiwati, E., Aini, A.R., Irnawati and Khasanah, F. (2022). Analysis of lard, chicken, and beef fat in ternary mixture using FTIR spectroscopy and multivariate calibration for halal authentication. *Food Research*, 6(4), 113–119. [https://doi.org/10.26656/fr.2017.6\(4\).488](https://doi.org/10.26656/fr.2017.6(4).488)
- Li, X., Liu, J., Chen, G., Zhang, J., Wang, C. and Liu, B. (2019). Extraction and purification of eicosapentaenoic acid and docosahexaenoic acid from microalgae: A critical review. *Algal Research*, 43, 101619. <https://doi.org/10.1016/j.algal.2019.101619>
- Lopez-Bascon, M.A. and Luque de Castro, M.D. (2020). Chapter 11 - Soxhlet Extraction. In Poole, C.F. (Ed.) *Liquid-Phase Extraction, Handbooks in Separation*

- Science, p. 327–354, Amsterdam, Netherlands: Elsevier. <https://doi.org/10.1016/B978-0-12-816911-7.00011-6>
- Lubis, H.F., Idrus, E., Fatma, D., Sastradipura, S. and Suseno, S.H. (2024). Characteristics and Nutrition of Fat-Soluble Vitamins from the Patin Fish Oil (*Pangasius hypothalmus*) and Their Potential in Dental Health. *Egyptian Journal of Aquatic Biology and Fisheries*, 28(4), 335–347. <https://doi.org/10.21608/ejabf.2024.368173>
- Nascimento, V.L.V., Bermudes, V.M.S., Oliveira, A.L.L., Kleinberg, M.N., Riberiro, R.T.M., Abreu, R.F.A. and Carioca, J.O.B. (2015). Effects of filtration methods on the neutralization yield of crude marine fish oil. *Food Science and Technology*, 35(1), 83–85. <https://doi.org/10.1590/1678-457X.6477>
- Marton, L.T., Goulart, R.D.A., Cassio, A. and Carvalho, A.De. (2019). Omega Fatty Acids and Inflammatory Bowel Diseases: An Overview. *International Journal of Molecular Sciences*, 20, 4851. <https://doi.org/10.3390/ijms20194851>
- Masrukan, Yanti, R., Setyaningsih, W. and Raharjo, S. (2024). Effect of deodorization method on the physicochemical and nutritional properties of the refined milkfish (*Channos channos*) by-product oil. *Indonesian Journal of Pharmacy*, 35(4), 669–679. <https://doi.org/10.22146/ijp.13730>
- McNamara, R.K. and Almeida, D M. (2020). Omega-3 Polyunsaturated Fatty Acid Deficiency and Progressive Neuropathology in Psychiatric Disorders: A Review of Translational Evidence and Candidate Mechanisms. *Harvard Review of Psychiatry*, 27(2), 94–107. <https://doi.org/10.1097/HRP.000000000000199>
- Mendez, J.R.B. and Concha, J.L.H. (2018). Methods of Extraction, Refining, and Concentration of Fish Oil as a Source of Omega-3 Fatty Acids. *Corpoica Ciencia Tecnologia Agropecuaria*, 19(3), 645–668. https://doi.org/10.21930/rcta.vol19_num2_art:684
- Merkle, S., Giese, E., Rohn, S., Karl, H., Lehmann, I., Wohltmann, A. and Fritsche, J. (2017). Impact of fish species and processing technology on minor fish oil components. *Food Control*, 73, 1379–1387. <https://doi.org/10.1016/j.foodcont.2016.11.003>
- Nadhiro, U., Subekti, S., Tjahjaningsih, W. and Patmawati. (2018). Quality Characteristics of Bali Sardinella (*Sardinella lemuru*) Oil Purified with Bentonite as an Adsorbent. *IOP Conference Series: Earth and Environmental Science*, 137(1), 012012. <https://doi.org/10.1088/1755-1315/137/1/012012>
- Nadine, K., Wittee, V.A., Kertic, L., Grittnerd, U., Philipp, S.J., Hahnf, A. and Floel, A. (2016). Impact of Omega-3 Fatty Acid Supplementation on Memory Functions in Healthy Older Adults. *Journal of Alzheimer's Disease*, 51(16), 713–725. <https://doi.org/10.3233/JAD-150886>
- Ndou, B.A., Guenard, F., Barbier, O. and Vohl, M.C. (2017). A Study of the Differential Effects of Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid. *Nutrients*, 9(5), 7–10. <https://doi.org/10.3390/nu9050424>
- Nengah, N., Kartika, A., Sulchan, M. and Afifah, D.N. (2024). Effects of patin fish oil and turmeric extract on levels of malondialdehyde and superoxide dismutase in Wistar rat metabolic models. *Aceh Nutrition Journal*, 1(2), 307–318. <https://doi.org/10.30867/action.v9i2.1759>
- Ningsih, S.W., Lubis, N.A. and Nasution, G.S. (2024). The Quality of Purified Eel Fish (*Monopterus Albus Zuiewu*) Oil and Mackerel Tuna Fish (*Euthynnus affinis*) Oil. *Health Nations*, 8, 1.
- Pan, J., Jia, H., Shang, M., Li, Q., Xu, C., Wang, Y., Wu, H. and Dong, X. (2018). Effects of deodorization by powdered activated carbon, β -cyclodextrin, and yeast on odor and functional properties of tiger puffer (*Takifugu rubripes*) skin gelatin. *International Journal of Biological Macromolecules*, 118, 116–123. <https://doi.org/10.1016/j.ijbiomac.2018.06.023>
- Panagan, A.T., Yohandini, H. and Wulandari, M. (2012). Analisis Kualitatif dan Kuantitatif Asam Lemak Tak Jenuh Omega-3, Omega-6 dan Karakterisasi Minyak Ikan Patin (*Pangasius pangasius*). *Jurnal Penelitian Sains*, 15(C), 15321-102 - 15321-106. [In Bahasa Indonesia].
- Pandiangan, M. (2021). Penentuan Komposisi Asam Lemak pada Minyak Ikan Patin. *Jurnal Riset Teknologi Pangan Dan Hasil Pertanian*, 1(2), 76–82. <https://doi.org/10.54367/retipa.v1i2.1210> [In Bahasa Indonesia].
- Pasini, F., Gómez-Caravaca, A.M., Blasco, T., Cvejić, J., Caboni, M.F. and Verardo, V. (2022). Assessment of Lipid Quality in Commercial Omega-3 Supplements Sold in the French Market. *Biomolecules*, 12(10), 1361. <https://doi.org/10.3390/biom12101361>
- Perretti, G., Motori, A., Bravi, E., Favati, F., Montanari, L. and Fantozzi, P. (2007). Supercritical carbon dioxide fractionation of fish oil fatty acid ethyl esters. *The Journal of Supercritical Fluids*, 40(3), 349–353. <https://doi.org/10.1016/j.supflu.2006.07.020>
- Ponphaiboon, J., Limmatvapirat, S., Chaidedgumjorn, A. and Limmatvapirat, C. (2018). Physicochemical properties, fatty acid composition, and antioxidant activity of ostrich oils using different rendering methods. *LWT Food Science and Technology*, 93, 45

- 50. <https://doi.org/10.1016/j.lwt.2018.03.024>
- Putri, A.R., Rohman, A. and Riyanto, S. (2019). Comparative Study of Fatty Acid Profiles in Patin (*Pangasius micronemus*) and Gabus (*Channa striata*) Fish Oil and its Authentication Using FTIR Spectroscopy Combined With Chemometrics. *International Journal of Applied Pharmaceutics*, 11 (6), 55–60. <https://doi.org/10.22159/ijap.2019v11i6.34921>
- Putri, A.R., Rohman, A., Riyanto, S. and Setyaningsih, W. (2020). Authentication of Patin Fish Oil (*Pangasius micronemus*) using FTIR Spectroscopy Combined with Chemometrics. *Journal Chemometrics Pharmaceuticals and Analysis*, 1 (1), 22-27. <https://doi.org/10.22146/ijcpa.487>
- Putri, D.N., Manshur, H.A., Setyawan, T. and Harini, N. (2021). Physicochemical and Fatty Acid Profile of Fish Oil From Red Snapper Heads (*Lutjanus malabaricus*) Refined From Various NaOH Concentrations. *Agrointek : Jurnal Teknologi Industri Pertanian*, 15(4), 1026–1037. <https://doi.org/10.21107/agrointek.v15i4.11098>
- Querques, G., Forte, R. and Souied, E.H. (2011). Retina and Omega-3. *Journal of Nutrition and Metabolism*, 2011, 748361. <https://doi.org/10.1155/2011/748361>
- Rahman, N., Hashem, S., Akther, S. and Jothi, J.S. (2023). Impact of various extraction methods on fatty acid profile, physicochemical properties, and nutritional quality index of Pangus fish oil. *Food Science and Nutrition*, 11(8), 4688–4699. <https://doi.org/10.1002/fsn3.3431>
- Rohim, A., Estiasih, T., Susilo, B. and Nisa, F.C. (2024). Extraction of healthy oils from fish viscera by conventional and advanced technologies. *Grasas y Aceites*, 75(2), 1999. <https://doi.org/10.3989/gya.0751231.1999>
- Rohman, A., Putri A.R., Windarsih, A., Nisa, K. and Lestari, L.A. (2021). The Employment of Analytical Techniques and Chemometrics for Authentication of Fish Oils: A review. *Food Control*, 124, 107864. <https://doi.org/10.1016/j.foodcont.2021.107864>
- Sadi, N. and Yoga, G.(2021). Skin characteristics of Pangasius Catfish in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 789, 012026. <https://doi.org/10.1088/1755-1315/789/1/012026>
- Sahena, F., Zaidul, I.S.M., Jinap, S., Yazid, A.M., Khatib, A. and Norulaini, N.A.N. (2010). Fatty Acid Compositions of Fish Oil Extracted from Different Parts of Indian Mackerel (*Rastrelliger kanagurta*) using Various Techniques of Supercritical CO₂ Extraction. *Food Chemistry*, 120(3), 879–885. <https://doi.org/10.1016/j.foodchem.2009.10.055>
- Samsul, E.S., Supomo, Sa'adah, H., Hafsari, P., Bintoro, R.F. A., Yulifitrianto and Sofa, F. (2024). Physicochemical Characterization and Fatty Acid Profile of Patin (*Pangasius micronema*) Fish Oil and Haruan (*Channa striata*) Fish Oil Cultivated in Samarinda. *Rasayan Journal of Chemistry*, 17(1), 267–274. <https://doi.org/10.31788/RJC.2024.1718728>
- Sari, R.N., Utomo, B.S.B., Basmal, J. and Hastarini, E. (2017). Refining of Pangasius Oil from Fish Smoking Products. *Jurnal Pascapanen dan Bioteknologi Kelautan dan Perikanan*, 11(2), 171-182. <https://doi.org/10.15578/jpbkp.v11i2.224>
- Sari, R.N., Utomo, B.S.B., Basmal, J. and Kusumawati, R. (2015). Optimization of Fish Oil Sardinella lemuru from the Canning Industry by Products. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 18(3), 276–286. <https://doi.org/10.17844/jphpi.v18i3.11279>
- Sasongko, H., Nurrochmad, A., Nugroho, A.E. and Rohman, A. (2022). Indonesian freshwater fisheries' oil for health and nutrition applications: a narrative review. *Food Research*, 6(2), 501–511. [https://doi.org/10.26656/fr.2017.6\(2\).362](https://doi.org/10.26656/fr.2017.6(2).362)
- Sembiring, L., Ilza, M. and Diharmi, A. (2018). Karakteristik Minyak Murni dari Lemak Perut Ikan Patin (*Pangasius hypophthalmus*) dan dipurifikasi dengan bentonite. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 21(3), 549-555. [In Bahasa Indonesia].
- Shabanikakroodi, S., Christianus, A., Tan, C.P., Che Man, Y.B. and Ehteshami, F. (2015). Refined oil production from patin catfish (*Pangasianodon hypophthalmus*) by-products. *Iranian Journal of Fisheries Sciences*, 14(2), 457–466.
- Shabanikakroodi, S., Christianus, A., Tan, C.P. and Ehteshami, F. (2019). Effect of various amounts of patin (*Pangasianodon hypophthalmus*) fish oil on physical and chemical properties of moisturizing hand cream. *Iranian Journal of Fisheries Sciences*, 18(2), 215–223. <https://doi.org/10.22092/ijfs.2018.117887>
- Shindou, H., Koso, H., Junko, S., Nakanishi, H., Nakagawa, K.M., Takahashi, Y., Hishikawa, D., Iizuka-Hishikawa, Y., Tokumasu, F. and Noguchi, H. (2017). Docosahexaenoic acid preserves visual function by maintaining correct disc morphology in retinal photoreceptor cells. *Journal Biological Chemistry*, 292(29), 12054–12064. <https://doi.org/10.1074/jbc.M117.790568>
- Song, G., Zhang, M., Peng, X., Yu, X., Dai, Z. and Shen, Q. (2018). Effect of Deodorization Method on The Chemical and Nutritional Properties of Fish Oil During Refining. *Food Science and Technology*, 96

- (149), 560–567. <https://doi.org/10.1016/j.lwt.2018.06.004>
- Su, Y., Xia, W. and Jiang, Q. (2022). Comparison of Effects of Different Deodorization Methods for Deodorizing Sturgeon Fish (*Acipenser Sinensis*). *Probe - Fishery Science and Aquaculture*, 5(1), 1–5. <https://doi.org/10.18686/fsa.v1i2.1315>
- Sukmiwati, M., Syahrul, S., Diharmi, A. and Dewinta, D. (2020). Characteristics of Softgel Capsules Mixture of Patin Oil, Red Palm Oil, and Shark Liver Oil. *IOP Conference Series*, 430, 012008. <https://doi.org/10.1088/1755-1315/430/1/012008>
- Suseno, S.H., Fitriana, N., Jacob, A.M. and Saraswati. (2015). Optimization of sardine oil neutralization process from fish meal industry by-product. *Oriental Journal of Chemistry*, 31(4), 2507–2514. <https://doi.org/10.13005/ojc/310487>
- Suseno, S.H., Jacob, A.M., Nugraha, R. and Salia. (2021). Bleaching optimization of tuna (*Thunnus* sp.) oil using response surface methodology. *Food Research*, 5(6), 92–103. [https://doi.org/10.26656/fr.2017.5\(6\).099](https://doi.org/10.26656/fr.2017.5(6).099)
- Thammapat, P., Raviyan, P. and Siriamornpun, S. (2010). Proximate and fatty acids composition of the muscles and viscera of Asian catfish (*Pangasius bocourti*). *Food Chemistry*, 122(1), 223–227. <https://doi.org/10.1016/j.foodchem.2010.02.065>
- Troesch, B., Eggersdorfer, M., Laviano, A., Rolland, Y., Smith, A.D., Warnke, I., Weimann, A. and Calder, P.C. (2020). Expert Opinion on Benefits of Long-Chain Omega-3 Fatty Acids (DHA and EPA) in Aging and Clinical Nutrition. *Nutrients*, 12(9), 2–25. <https://doi.org/10.3390/nu12092555>
- Usman, I., Hussain, M., Imran, A., Afzaal, M., Saeed, F., Javed, M., Afzal, A., Ashfaq, I., Jbawi, E.A.I. and Saewan, S.A. (2022). Traditional and innovative approaches for the extraction of bioactive compounds. *International Journal of Food Properties*, 25(1), 1215–1233. <https://doi.org/10.1080/10942912.2022.2074030>
- Wafa, R., Agustini, T. and Fahmi, A. (2021). Drying Kinetics and Study of Physical Characteristics Using Image Analysis of Dried Salted Striped Catfish (*Pangasius hypophthalmus*). *IOP Conference Series: Earth and Environmental Science*, 750, 012045. <https://doi.org/10.1088/1755-1315/750/1/012045>
- Wang, H. and Daggy, B.P. (2017). The Role of Fish Oil in Inflammatory Eye Diseases. *Biomed Hub*, 2(1), 1–12. <https://doi.org/10.1159/000455818>
- Wani, A.L., Bhat, S.A. and Ara, A. (2015). Omega-3 fatty acids and the treatment of depression : a review of scientific evidence. *Integrative Medicine Research*, 4(3), 132–141. <https://doi.org/10.1016/j.imr.2015.07.003>
- Zhang, Q.W., Lin, L.G. and Ye, W.C. (2018). Techniques for extraction and isolation of natural products: a comprehensive review. *Chinese Medicine*, 13, 20. <https://doi.org/10.1186/s13020-018-0177-x>