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Review Article

Physicochemical Characteristics and Nutritional and Biological Properties of Fish Oils in Cameroon: An Overview

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Due to their significant health benefits, fish oils have garnered increasing interest in recent decades. However, Cameroon's fish oil market remains insignificant, and the few available products are imported, despite the country's abundant marine resources. Additionally, research on Cameroonian fish oils is relatively recent and scarce. Therefore, this manuscript provides an overview of research on fish oils in Cameroon, focusing on their physicochemical characteristics, as well as their nutritional and biological properties. As of March 2023, 26 studies on fish oils in Cameroon have been published, with a focus on 23 species collected in the littoral, far-north, and west regions of Cameroon. Filets were the main parts used, and the Bligh Dyer and Soxhlet methods were the primary oil extraction techniques. Depending on the species, tissues, and extraction methods, oil contents ranged from 4.57% to 32.10% dry matter or yielded 0.36% to 66.83% wet weight. These oils generally meet recommended standards for markers of acidity and oxidation. Fatty acid profiles from 16 species showed a total of 48 fatty acids, including those that are beneficial to human health. Oils from eight species were found to significantly reduce weight, hyperlipidemia, hyperglycemia, hepatomegaly, and adipomegaly, while four species showed activity against bacteria responsible for food poisoning. Future work should include all fish species found in Cameroon, with a focus on by-products, and explore the physicochemical, functional, nutritional, and biological properties of these oils.

1. Introduction

Nutraceuticals are raw foods, functional foods, or dietary supplements that contain bioactive molecules and have the ability to provide health benefits beyond their nutritional value. Functional and bioactive compounds from natural sources such as terrestrial and marine plants, animals, or microorganisms have become sustainable solutions that offer new molecules with strong biological activity [1]. Consequently, global public awareness about the health and nutritional benefits of seafood diets is on the rise. Besides supporting human body growth and function, bioactive compounds in seafood also have therapeutic potential that help alleviate and manage disease conditions [2]. Fish occupies a prominent place among marine products and is considered an affordable source of protein and a source of nutraceutical importance [3]. Moreover, fish and other marine species comprise about half of the total biodiversity and are also a valuable source of novel bioactive compounds that improve human health.

Recent critical reviews on bioactive compounds and therapeutics from marine products and fish have been conducted [1–3]. These reviews revealed that fishes and fish products offer numerous nutritional and unique health benefits, which result from their nutrients and bioactive compounds. These compounds confer nutritional importance and therapeutic effects against chronic diseases such as diabetes, obesity, cancer, cardiovascular diseases, infection, inflammatory and oxidative stress-related ailments, hepatic and brain functions, and immune system disorders. Fishes contain protein, essential amino acids, vitamins, minerals, polyunsaturated fatty acids (PUFA), and several other micronutrients and phytonutrients. Fish products are a cheap nutraceutical resource that can help solve nutritional problems, especially for the most vulnerable and low-income earners.

Increased consumption of fish should be encouraged, especially in developing communities where food security is a significant concern. There is also a need to increase awareness of the quality of proteins, omega-3 fatty acids, and other compounds inherent in fish and fish-based food products and nutraceuticals like fish oils. The composition of fish oils, from fatty acids to other compounds, has been reported [1–3]. Fatty acids in fish oils include PUFA (eicosapentaenoic acid/EPA, docosahexaenoic acid/DHA, arachidonic acid, etc.), monounsaturated fatty acids/MUFA (gondoic acid, palmitoleic acid, oleic acid, etc.), and saturated fatty acids/SFA (palmitic acid, stearic acid, etc.). PUFA in fish oils, reflected strongly by bioactive lipids, comprises both EPA and DHA which are known as omega-3 fatty acids. Other compositions include sterols, vitamins, minerals, polyphenols, and pigments such as carotenoids. These compounds also have therapeutic properties. Considering all these benefits of fish oils, substantial efforts must be made to promote them. This requires above all the control of their quality. As with any oil or fat for human or animal consumption, the evaluation of the quality of fish oils is done by determining their physicochemical characteristics which define the behavior and interactions of oils under various conditions. These properties are significant in nutrition and industry [4].

The interest in fish oil has been increasing in recent decades, as evidenced by the projected worldwide fish oil market size of USD 3.60 billion by 2030, growing at a compound annual growth rate (CAGR) of 6% from USD 2,133 million in 2021 [4, 5]. Asia-Pacific has the largest share of the global fish oil market, while Africa has the smallest share [4, 5], with Cameroon's fish oil market being very insignificant. Despite having a large hydrological network and a great diversity of marine products [6, 7], Cameroon relies heavily on foreign fish oils, as local production is estimated at 300,064 tons and fish available for consumption was about 18.10 kg/capita in 2019 [8].

Folack and Emene (unpublished data) have identified 41 target coastal and marine fish species belonging to 20 families in Cameroon, as presented in Table 1. We have in particular the *Ariidae* (1 species), the *Belonidae* (1 species), the *Carangidae* (8 species), the *Clupeidae* (3 species), the *Cynoglossidae* (2 species), the *Dasyatidae* (1 species), the *Drepanidae* (1 species), the *Ephippididae* (1 species), the *Lutjanidae* (5 species), the *Mugilidae* (2 species), the *Ophichthidae* (1 species), the *Polynemidae* (2 species), the *Psettodidae* (1 species), the *Sciaenidae* (5 species), the *Scombridae* (2 species), the *Sparidae* (1 species), the *Sphyraenidae* (1 species), the *Sphrynidae* (1 species), the *Squalidae* (1 species), and the *Trichiuridae* (1 species). The FAO English and French names of species, the local name, and the ecological habitat of these species are also given in Table 1. The species targeted by Folack and Emene represent only a part of the total fish production in Cameroon. In fact, there are many other species as well from the coasts and marine as from the freshwater and aquaculture such as *Arius maculatus* (Spotted catfish), *Arius parkii* (Machoiron), *Cyprinus carpio* (Red carp), *Clarias gariepinus* (African sharptooth catfish/"bapche"), *Clupea harengus* (Herring), *Chrysicthys nigrodigitatus* (Bagrid catfish), *Coptodon camerounensis* (Tilapia), *Ephippion guttifer* (Tétrodon), *Heterotis niloticus* (Kanga), *Hepsetus odoe* (African pike characin), *Pellonula leonensis* (Sardinelles nca), *Pomadasys jubelini* (Dorade grise/Grondeur/Sompat), *Polypterus bichir bichir* (Nile bichir), *Psettias sebae* (Petit disque/dentes/spares nca), *Oreochromis niloticus* (Carp), *Semotilus atromaculatus* (Creek chub), *Silurus glanis* (Wels catfish), *Sphyraena barracuda* (Brochet), *Symphysadon discus* (*disc*), and *Trichius lepterus* (Belt) [7, 9, 10].

Despite the high production and great diversity of local fish, there is a lack of research on fish oils from Cameroon, especially on their physicochemical characteristics and nutritional and biological properties. Substantial efforts should be made to study the oils from fishes caught in Cameroon to explore their potential applications in industry and human nutrition and health. Therefore, this article aims to provide an overview of the studies already conducted on Cameroonian fish oils, as well as to identify the gaps in the current knowledge and suggest areas for future research.

2. Outline of Physicochemical Characteristics and Nutritional and Biological Properties of Fish Oils

2.1. Physicochemical Characteristics. The physicochemical properties of oils refer to the physical and chemical characteristics that define their behavior and interactions under various conditions. These properties are significant in many industrial applications, including the food industry, chemical industry, pharmaceutical industry, and other fields [4].

Physical characteristics include boiling point, flash point, ignition point, melting point, solidification point, viscosity, plasticity, refractive index, specific gravity, solubility, unsaponifiability, emulsion capacity, and plasticity. The boiling point is the temperature at which the vapor pressure of the liquid oil sample equals the pressure surrounding the sample and the sample changes into a vapor. The flash point is defined as the temperature at which an oil sample, when heated under prescribed conditions, will flash when a flame is passed over the surface of the oil, but will not maintain ignition, for the ignition point is the temperature at which an

Table 1: Some target coastal and marine fishes of Cameroon (Folack and Emene, unpublished data).

No.	Families	Species	FAO name		Local name	Habitat
			English	French		
1	*Ariidae*	*Arius heudoloti* (Valeznciennes, 1840)	Smooth mouth sea catfish	*Machoiron banderille*	Machoiron	Coastal marine and brackish waters, estuaries, and rivers mouths
2	*Belonidae*	*Tylosurus crocodilus* (Peron and LeSueur, 1821)	Hound needlefish	*Aiguille crocodile*	Long mouth	Pelagic in near shore surface waters
3	*Carangidae*	*Alectis alexandrinus* (Geoffroy Saint-Hilaire, 1817)	—	*Cordonnier bossu*	—	Adults are demersal within depths of up to 70 cm
4		*Caranx hippos* (Linnaeus, 1766)	Crevalle Jack	*Carangue crevalle*	Motondoh	Pelagic and demersal characteristics within coastal waters, along sandy beaches; also Brackish waters and rivers, Southwest coast
5		*Caranx lugubris* (Poey, 1860)	Black Jack	*Carangue noire*	Bebateh	Coastal waters within 25–65 m depths and even more. Southwest coast
6		*Chloroscombus chrysurus* (Linnaeus, 1776)	Atlantic bumper	*Sapater*	—	Coastal waters, estuaries, within lagoons and mangroves with juveniles far offshore
7		*Selene dorsalis* (Gill, 1863)	African lookdown	*Musso Africain*	—	Coastal waters to 60 cm depth; forms schools; common during the rains
8		*Hemicaranx bicolor* (Giinther, 1860)	Two color Jack	*Carangue*	—	Coastal ecosystems, estuarine waters, demersal
9		*Trichinotus teraia* (Cuvier, 1832)	Terai Pompano	*Pompaneau né-bé*		Coastal ecosystems mostly within estuaries and sometimes in rivers
10		*Trachurus trecae*	Cunene horse mackerel	*Chinchard cunène*		Pelagic ecosystems with depths between 20 and 100 cm
11	*Clupeidae*	*Ethmalosa fimbriata* (Bowddich, 1825)	Bonga shad	*Ethmalose d'Afrique*	Menyanya	Coastal marine waters, estuaries, lagoons, and even rivers. Southwest coast of Cameroon
12		*Ilisha africana* (Bloch, 1795)	West African Ilisha	*Alose rasoir*	—	Coastal waters/ecosystems including estuaries, sometimes benthic
13		*Sardinella maderensis* (lowe, 1839)	Madeiran sardinella	*Grande allache*	Strong kanda	Warm coastal waters from the surface to 50 m depth, sometimes in estuaries and lagoons. Southwest coast of Cameroon
14	*Cynoglossidae*	*Cynoglossus monodi* (*Chabanaud*, 1949)	Guinean tonguesole	*Sole-langue de Guinée*	Sole	Sandy and muddy bottoms from 10 to 25 m depth
15		*Cynoglossus senegal*ensis (Kaup 1858)	Senegalese tonguesole	*Sole-langue de sénégalaise*	Sole	Sandy and muddy bottoms from 10 to 110 m depth
16	*Dasyatidae*	*Fontitrygon margarita* (Gunther, 1870)	Daisy stingray	*Pastenague marguerite*	Coverpot	Shallow coastal waters to 60 cm depth, enters estuaries and lagoons; Southwest coastal
17	*Drepanidae*	*Drepane africana* (Osori, 1892)	African sicklefish	*Forgeron ailé*	—	Sand and muddy bottoms from 20 to 50 m depths
18	*Ephippididae*	*Chaetodipterus goreensis* (Cuvier, 1831)	African spadefish	*Chèvre de mer*	—	Sandy and muddy bottoms of estuaries

Table 1: Continued.

No.	Families	Species	FAO name		Local name	Habitat
			English	French		
19	*Lutjanidae*	*Apsilus fuscus* (Valenciennes, 1830)	African forktale snapper	*Vivaneau pourche d'Afrique*	—	Rocky bottoms with coral reefs between 15 and 100 m
20		*Lutjanus endecacanthus* (Bleeker, 1863)	Guinea Snapper	*Vivaneau de Guinée*	—	Rocky bottoms with coral reefs, sometimes in rivers
21		*Lutjanus agennes*	African red snapper	*Vivaneau brun (Afrique)*	—	Rocky bottom ecosystems and sometimes in estuaries
22		*Lutjanus dentatus* (Duméril, 1860)	African brown snapper	*Vivaneau brun (Afrique)*	—	Rocky bottom ecosystems with corals and sometimes in estuaries
23		*Lutjanus goreensis* (Valenciennes, 1830)	Gorean Snapper	*Vivaneau de Gorée*	—	Hard and rocky bottom ecosystems for adults with juveniles within the estuaries
24	*Mugilidae*	*Liza falcipinnis* (Valenciennes, 1836)	Sicklefin mullet	*Mulet à grande nageoires*	—	Coastal marine and brackish waters
25		*Mugil cephalus* (Linnaeus, 1758)	Flathead grey mullet	*Mulet cabot*	—	Coastal waters/estuaries
26	*Ophichthidae*	*Mystriophis cf. rostellatus* (Richardson, 1844)	African spoon-nose eel	*Serpenton gris*	—	Lagoons and coastal waters up to 40 m depth
27	*Polynemidae*	*Galeodes decadactylus* (Bloch, 1795)	Lesser African threadfin	*Petit capitaine*	—	Sandy and muddy bottoms in shallow coastal waters; also in estuaries
28		*Pentanemus quinquarius* (Linnaeus, 1758)	Royal threadfin	*Capitaine royal*	—	Sandy and muddy bottoms up to 50 m depth
29	*Psettodidae*	*Psettodes belcheri* (Bennett, 1831)	Spottail spiny turbot	*Turbot épineux*	—	Sandy and rocky bottoms up to 150 m depths; also in estuaries
30	*Sciaenidae*	*Pseudotolithus canariensis* (Valenciennes, 1843)	Canary drum	*Ombrine bronze*	Mussobo	In shallow waters, sandy or rocky bottoms between 15 and 75 m depths
31		*Pseudotolithus elongatus* (Bowdich, 1825)	Bobo croaker	*Otolithe bobo*	Mussobo	Brackish waters and estuaries
32		*Pseudotolithus senegalensis*	Cassava croaker	*Otolithe sénégalais*	Mussobo	Sandy or rocky bottom depths of less deeper waters
33		*Pseudotolithus typus* Bleeker, 1863	Longneck croaker	*Otolithe naka*	Mussobo	Muddy and sandy bottoms to about 150 m depth
34		*Pteroscion peli* (Bleeker, 1863)	Boe drum	*Courbine pélin*		Coastal waters to about 200 m depth, but more common between 30 and 60 m
35	*Scombridae*	*Scomberomorus tritor* (Cuvier, 1831)	West African Spanish mackerel	*Thazard blanc*	Nyanga fish	Found in warm waters, sometimes enters estuaries, Southwest coast
36		*Thunnus obsesus* (lowe, 1839)	Bigeye tuna	*Thon Obése*	Fuma-fuma	Frequent deeper coastal waters, also common in artisanal fishing gear
37	*Sparidae*	*Pagrus ariga* (Valenciennes, 1843)	Red banded seabream	*Pagre rayé*	—	Trawlers coastal rocky bottoms with sand up to 170 m depths
38	*Sphyraenidae*	*Sphraena piscatorium*	Barracuda	*Bécune*	Barracuda	In coastal and offshore waters
39	*Sphrynidae*	*Sphyrna couardi* (Cadenat, 1950)	White fin hammerhead	*Requin marteau aile blanche*	Shark	Pelagic in coastal waters
40	*Squalidae*	*Carcharinus* sp	Shark	*Requin*	Shark	Pelagic in warm oceanic waters
41	*Trichiuridae*	*Trichiurus lepturus* (Linnaeus, 1758)	Largehead hairtail	*Poisson sabre commun*	Snakefish	Bentho-pelagic, but also found on muddy bottoms in coastal waters and estuaries

oil sample will continue to burn on its own without the application of additional external heat. The melting point is the temperature at which an oil sample changes state from solid to liquid while the solidification point is the temperature at which the liquid phase of an oil sample is in approximate equilibrium with a relatively small portion of the solid phase. Refractive index which is a numerical expression related to the degree of saturation of the ratio of the speed of light in a vacuum to the speed of light in a test substance is affected by factors such as free fatty acid, oxidation, and heat treatment. Concerning specific gravity, it is the ratio of the weight of a given volume of sample material at a specified temperature to the weight of the same volume of water at a specified temperature, providing a measure of relative density. The unsaponifiable refers to the proportion of oil that cannot be converted into soap using potassium hydroxide lye. This portion typically consists of substances such as sterols, tocopherols, hydrocarbons, and pigments. The emulsifying capacity is the capacity in the water/oil interface allowing the formation of emulsion, while the plasticity is the property that has a body to preserve its shape by resisting a certain pressure [4, 11].

Chemical characterization includes the evaluation of moisture and impurities, acid value (AcV), free fatty acids (FFA), saponification value (SaV), iodine value (IiV), thiobarbituric acid value (TaV), peroxide value (PeV), anisidine value (AnV), total oxidation value (Totox value), color, minerals, and heavy metals content among others [4, 11, 12]. AcV represents the number of milligrams of KOH required to neutralize the organic acids present in 1 gram of fat, and it is a measure of the free fatty acids (FFA) in the fat or oil. An increase in the FFA content of a sample of oil or fat indicates the hydrolysis of triglycerides [13]. SaV represents the weight of KOH required to saponify 1 gram of fat under specified conditions. It is a measure of the average molecular weight (or chain length) of all the fatty acids present in the sample as triglycerides. The higher the SaV, the lower the average length of fatty acids, the lighter the mean molecular weight of triglycerides, and vice versa [14]. IiV is a measure of the unsaturation of oil and fat and is expressed as the mass of iodine consumed by 100 grams of oil or fat. The higher the IiV, the more unsaturation is present in the fat [15]. The thiobarbituric acid reactive substances (TBARS) are formed as a byproduct of lipid peroxidation, which is the degradation of fats and can be detected by the TBARS assay using thiobarbituric acid as a reagent [15]. PeV is defined as the reactive oxygen contents expressed in terms of meq of free iodine per kilogram of fat. It measures the extent to which an oil sample has undergone primary oxidation; the extent of secondary oxidation may be determined from the p-anisidine test. It is particularly useful in food quality testing as it can detect unsaturated aldehydes, which are most likely to generate unacceptable flavors [16]. According to the Codex Alimentarius Commission [17], acceptable values are ≤3 mgKOH/g for AcV, <5% oleic acid for FFA content, 179–200 mgKOH/g for SaV, ≤5 meqO_2/kg for PeV, ≤10 μmol MDA/kg for TaV, and ≤20 for AnV.

2.2. Nutritional and Biological Properties. Fish and fish products are well known to offer numerous/unique nutritional health benefits. These benefits are a result of their nutrients and bioactive compounds which confer nutritional importance and therapeutic effects. Clearly, fishes possess protein alongside several amino acids, dietary vitamins, minerals, PUFA, and several other micronutrients and phytonutrients. More so, fish products remain a cheap nutraceutical resource with the capacity to help solve nutritional problems, especially for the most vulnerable and low-income earners [1–3, 18]. Increased consumption of fish should be encouraged across communities. There is also the need for an increased campaign towards harnessing the potential of the quality nutrients that are inherent in fish, fish-based food products, and nutraceuticals from fish like fish oils. In fact, fish oils have nutritional importance and therapeutic effects against many health problems such as diabetes, obesity, cancer, cardiovascular diseases, infection, inflammatory and oxidative stress-related ailments, hepatic and brain functions, and immune system disorders [19]. These properties are closely linked to the impressive composition of fish oils.

The composition, from fatty acids to other compounds, and subsequently the health benefits of fish oils have been reported. Fatty acids comprised PUFA (eicosapentaenoic acid/EPA, docosahexaenoic acid/DHA, arachidonic acid, etc.), monounsaturated fatty acids/MUFA (gondoic acid, palmitoleic acid, oleic acid, etc.), and saturated fatty acids/SFA (palmitic acid, stearic acid, etc.) [1–3, 18]. Other compositions include sterols, vitamins, minerals, polyphenols, and pigments such as carotenoids [2, 3]. PUFA in fish oils, reflected strongly by bioactive lipids, comprises both EPA and DHA which are known as omega-3 fatty acids [1–3, 18, 19]. They are readily digestible for energy metabolism and several biological activities, including protection against chronic diseases. Alpha-linolenic acid (ALA) is another vital omega-3 fatty acid that is precursory to EPA and DHA. Consumption of EPA and DHA lowers the development of coronary heart diseases via diverse mechanisms. They help protect against coronary heart disease by decreasing serum triglyceride, improving cardiac function, and reducing blood pressure and inflammatory responses. The anti-inflammatory properties of EPA and DHA occur via modulation of prostaglandin synthesis. Fatty acids reduce the amount of platelet buildup in the blood, thus narrowing the blood and reducing the propensity for blood clot formation. Otherwise, omega-3 fatty acids are vital for the growth of children. Particularly, DHA is essential for optimal brain and neurodevelopment in children, whereas EPA is essential for the improvement of overall cardiovascular health. Fatty acids are also involved in osmoregulation, nutrient assimilation, and nutrient transport [1–3, 19]. Besides fatty acids, other compounds of fish oils have therapeutic properties. Thus, sterols can lower the amount of low-density lipoprotein (LDL) cholesterol *in vivo* [2, 3]. Phytosterols and pigments are also significant precursors of a number of vitamins, for example, ergosterol and carotenoids which are precursors of vitamin D2 and vitamin A, respectively. Vitamins produce a wide range of biological effects in the human body. For instance, vitamins A, D, and E are readily bioavailable in some fish oils. Vitamin A sustains normal growth, builds cells, and promotes good eyesight. Additionally, it can influence the biosynthesis of many proteins that regulate cell development/function or determine cell sensitivity to hormones and hormone-like factors, and impact the formation of hormones. Vitamin D, existing in fishes in the form of cholecalciferol, can abate vitamin D deficiency-related conditions, including rickets, osteomalacia, and osteoporosis. A link has also been established between vitamin D deficiency and diabetes, amplified proliferation of cancer cells, and increased incidence of autoimmune and cardiovascular diseases [2, 3, 18]. Some essential minerals found in fish oil like calcium, potassium, iron, sodium, iodine, selenium, magnesium, and zinc provide numerous health benefits, including important biochemical responses [2, 3]. Calcium, magnesium, and phosphorus are involved in teeth and bone formation, whereas sodium and potassium help in nerve impulse transmission and electrolyte balance maintenance. Iron is a component of hemoglobin that transports oxygen around the body. Zinc acts as a cofactor in the activity of many enzymes that are essential for metabolism, DNA and protein synthesis, digestion, nerve function, the development and function of immune cells, cell growth, and division. Iodine is essential in making thyroid hormones that control human growth and development. Otherwise, carotenoids can occur in various forms in fish. Typical examples include beta-carotene, lutein, alpha- and beta-doradexthins, canthaxanthin, and astaxanthin. The most common appears to be astaxanthin, which is able to prevent eye macula (lutein and zeaxanthin) that comes from damaging blue lights and oxidative stress [2, 3].

3. Studies on Fish Oils in Cameroon

The literature search was carried out in the databases of PubMed, Google Scholar, and Web of Science using search terms (keywords) such as Cameroon, fish, fish oil/lipid, physicochemical characteristics, composition, biological properties, and health benefits. Only studies conducted on fish from Cameroon and dealing with at least one aspect of fish oils were included. Overall, it was noted that despite the diversity of fishes in Cameroon, there have been very few recent studies on fish oils. As shown in Table 2, only 26 studies have investigated fish oils in Cameroon as of March 2023.

The first study was conducted by Tenyang et al. who investigated the chemical characteristics and fatty acid profile of oil from *Arius maculatus* collected in the Douala fish market [45]. A year later, Tenyang et al. were also interested in the fatty acid profiles of *A. maculatus, Clupea harengus, Cyprinus carpio, Semotilus atromaculatus, Symphysadon discus,* and *Trichiurus lepturus* collected in Youpowé and Essingué–Douala [44]. In 2016, a total of three studies were published, particularly by Njinkoue et al. who investigated the fatty acid profile of oils from *Pseudotolithus elongatus and Pseudotolithus typus* collected in July 2014 at the Douala fishing port [41]. Tenyang et al. studied the fatty acid profile of oils from *Chrysicthys nigrodigitatus*, *Heterotis niloticus*, *Liza falcipinnis*, and *Oreochromis niloticus* collected in the Maga fish market (Far West region) [42]. Tiwo et al. also investigated the composition of *Clarias gariepinus*, *C. carpio*, *H. niloticus*, and *O. niloticus* collected in Batié (West region). Similarly, in 2017, three studies were published [43]. The first, conducted by Djimbie et al. focused on the fatty acid profile of oils extracted from *O. niloticus* collected in November 2013, March, and July 2014 in the Nkam River–Yabassi [38]; the second study, carried out by Njinkoue et al. explored the hypolipemiant effect of oil from *Pseudotolithus senegalensis* collected in the Douala fishing port [39]. Lastly, Tenyang et al. conducted a study on the chemical characterization and fatty acid profile of oil from *A. maculatus* collected in the Douala fish market [40]. Four studies were conducted in 2018, including Justin et al. who studied the chemical characteristics and fatty acid profile of oil from *C. nigrodigitatus* from the Nkam River [34]; Simplice et al. who investigated the chemical characteristics, fatty acid profile, and antibacterial activity of oils from *C. nigrodigitatus* and *H. odoe* from the Nkam River [35]; Tenyang et al. who studied the chemical characteristics and fatty acid profile of oil from *C. harengus* collected in April 2014 in Youpwe [36]; and Cristelle et al. who investigated the effect of *C. carpio*, *H. niloticus*, *O. niloticus*, and *Silurus glanis* from Batié on the growth of Wistar rats [37]. In 2019, only one study was available, which was conducted by Tenyang et al. on the chemical characteristics and fatty acid profile of oil from *C. carpio* from Youpwe. In 2020 [33], a total of five studies were published: Manz Koule et al. conducted research on the chemical characteristics and anti-hyperlipidemic potential of oil from *Ilisha africana* collected at the Douala fishing port [28]; Nchoutpouen et al. [29] researched the hypolipemiant effect of oil from *Ethmalosa fimbriata* collected at the Douala fishing port; Simo et al. [30] studied the chemical characteristics and antibacterial activity of oil from *Lutjanus dentatus* from Youpwe; and Tenyang et al. conducted two studies on the chemical characteristics and fatty acid profile of oil from *L. falcipinnis* and *O. niloticus* collected at the Maga fish market [31, 32]. In 2021, four studies were conducted: Dama et al. researched the composition of *P. elongatus*, *P. senegalensis*, and *P. typus* from Youpwe [23]; Christophe Manzkoule et al. studied the chemical characteristics of oils from *I. africana* and *Sardinella maderensis* from the Douala fishing port [24]; and Ndômbôl et al. conducted two studies on the chemical characteristics of oils from fish by-products collected at Douala markets [25, 26]; Njiké Ngamga et al. studied the antibacterial activity of oil from of *Chrysichthys nigrodigitatus* [27]. In 2022, two studies were available: Noutsa et al. researched the chemical characteristics, fatty acid profile, and antibacterial activity of oil from *Fontitrygon margarita* collected in Youpwe [21]; and Tenyang et al. conducted research on the chemical characteristics of oil from *Polypterus bichir bichir* collected at the Maga fish market in July

Table 2: Studies on fish oils done in Cameroon.

Studies			Sampling			
Years	Authors	Species	Place of collection	Date	Part of fish	Extraction method
2023	Manz et al. [20]	*Arius parkii* *Cyprinus carpio* *Ethmalosa fimbriata* *Ilisha africana* *Sardinella maderensis*	Douala fishing port	July 2021	Filet	Bligh and Dyer method: Extraction using chloroform/methanol/water1 (1/2/0.8) as solvent
2022	Noutsa et al. [21]	*Fontitrygon margarita*	Youpwe—Douala	April 2020	Liver	Cooking-pressing at 95°C Exudation at 45°C
	Tenyang et al. [22]	*Polypterus bichir bichir*	Maga fish market, far north region	July 2019	Filet	Bligh and Dyer method
2021	Dama et al. [23]	*Pseudotolithus elongatus* *Pseudotolithus senegalensis* *Pseudotolithus typus*	Youpwe—Douala	nd	Filet	Soxhlet using hexane as solvent
	Christophe Manzkoule et al. [24]	*Ilisha africana* *Sardinella maderensis*	Douala fishing port	nd	Filet	Bligh and Dyer method
	Ndômbôl et al. [25]	*Pseudotolithus typus*	Nd	nd	Viscera and gills	Soxhlet using hexane as solvent
	Ndômbôl et al. [26]	*Fishes by-products*	Douala markets	nd	Fishes by-products	Soxhlet using hexane as solvent
	Njiké Ngamga et al. [27]	*Chrysichthys nigrodigitatus*	Youpwe—Douala	nd	Boiled filet	Bligh and Dyer method
2020	Manz Koule et al. [28]	*Ilisha africana*	Douala fishing port	nd	Filet	Soxhlet using hexane as solvent
	Nchoutpouen et al. [29]	*Ethmalosa fimbriata*	Douala fishing port	nd	Filet	Soxhlet using hexane as solvent
	Simo et al. [30]	*Lutjanus dentatus*	Youpwe—Douala	nd	Adipose tissue	Cooking-pressing at 95°C Drying-pressing at 45°C
	Tenyang et al. [31]	*Liza falcipinnis* *Oreochromis niloticus*	Maga fish market	nd	Filet	Bligh and Dyer method
	Tenyang et al. [32]	*Oreochromis niloticus*	Maga fish market	March 2018	Filet	Bligh and Dyer method
2019	Tenyang et al. [33]	*Cyprinus carpio*	Youpwe—Douala	nd	Filet	Bligh and Dyer method
2018	Justin et al. [34]	*Chrysichthys nigrodigitatus*	Nkam River—Yabassi	nd	Filet	Soxhlet using hexane as solvent
	Simplice et al. [35]	*Chrysichthys nigrodigitatus*	Nkam River—Yabassi	nd	Filet	Cooking-pressing at 95°C Maceration
	Tenyang et al. [36]	*Hepsetus odoe* *Clupea harengus*	Youpwe—Douala	April 2017	Filet	Cooking-pressing at 95°C Bligh and Dyer method
	Cristelle Cristelle et al. [37]	*Cyprinus carpio* *Heterotis niloticus* *Oreochromis niloticus* *Silurus glanis*	Batié—west region	nd	Filet	Bligh and Dyer method

Table 2: Continued.

Studies			Sampling			
Years	Authors	Species	Place of collection	Date	Part of fish	Extraction method
2017	Djimbie et al. [38]	*Oreochromis niloticus*	Nkam River—Yabassi	November 2013 March 2014 July 2014	Filet	Bligh and Dyer method
	Njinkoue et al. [39]	*Pseudotolithus senegalensis*	Douala fishing port	nd	Filet	Soxhlet using hexane as solvent
	Tenyang et al. [40]	*Arius maculatus*	Douala fish market	nd	Filet	Bligh and Dyer method
2016	Njinkoue et al. [41]	*Pseudotolithus elongatus* *Pseudotolithus typus*	Douala fishing port	July 2014	Filet	Bligh and Dyer method
	Tenyang et al. [42]	*Chrysichthys nigrodigitatus* *Heterotis niloticus* *Liza falcipinnis* *Oreochromis niloticus*	Maga fish market	nd	Filet	Soxhlet using hexane as solvent
	Tiwo et al. [43]	*Clarias gariepinus* *Cyprinus carpio* *Heterotis niloticus* *Oreochromis niloticus*	Batié—west region	nd	Filet	Bligh and Dyer method
2014	Tenyang et al. [44]	*Arius maculatus* *Cyprinus carpio* *Clupea harengus* *Semotilus atromaculatus* *Symphysadon discus* *Trichius lepterus*	Youpowé and essingué—Douala	nd	Filet	Bligh and Dyer method
2013	Tenyang et al. [45]	*Arius maculatus*	Douala fish market	nd	Filet	Bligh and Dyer method

nd: not determined.

2019 [22]. As of March 2023, only one study done by Manz et al. on chemical characteristics of oil from *Arius parkii*, *C. carpio*, *E. fimbriata*, *I. africana*, and *S. maderensis* was available [20].

To summarize, a total of 23 fish species have been studied to date, with a focus on *Arius maculatus*, *Arius parkii*, *Cyprinus carpio*, *Clarias gariepinus*, *Clupea harengus*, *Chrysicthys nigrodigitatus*, *Ethmalosa fimbriata*, *Fontitrygon margarita*, *Heterotis niloticus*, *Hepsetus odoe*, *Ilisha africana*, *Lutjanus dentatus*, *Liza falcipinnis*, *Oreochromis niloticus*, *Polypterus bichir bichir*, *Pseudotolithus elongatus*, *Pseudotolithus senegalensis*, *Pseudotolithus typus*, *Semotilus atromaculatus*, *Symphysodon discus*, *Silurus glanis*, *Sardinella maderensis*, and *Trichiurus lepturus*. The majority of samples were collected in the Littoral Region, with nine studies conducted at Douala fish markets, seven studies conducted in Youpwe, and three studies conducted in the Nkam River. The other places of sampling were the Maga fish market for four studies and Batié for two studies. Oils were mostly extracted from fish filets (21 studies), with the remaining samples obtained from by-products such as adipose tissue, liver, viscera, and gills. The extraction methods used were the Bligh and Dyer method for 16 studies, Soxhlet using hexane as the solvent for eight studies, cooking-pressing at 95°C for four studies, and drying-pressing at 45°C, exudation at 45°C, and maceration for one study each.

4. Oil Content and Physicochemical Characteristics of Fish Oils Studied in Cameroon

Table 3 summarizes the results obtained from the studies listed above in relation to the oil content/oil extraction yield and physicochemical characteristics of the fish oils obtained. Oil can be extracted from various parts of fish, including the body/flesh/filet, as well as by-products such as livers, viscera, backbones, and heads. Fish body oil accounts for up to 97% of the total marine oil supply, and the oil content and quality vary depending on the part used [12]. Additionally, many other factors can influence the oil content and quality, such as fish species, size, age, season, water temperature, and geographic location [46, 47]. Moreover, the oil extraction yield and quality depend on the extraction method used [12].

Regarding the studies conducted in Cameroon (Table 3), Tenyang et al. found that the filet of *Arius maculatus* had an oil content of 23.02% DM (dry matter) when extracted with the Bligh and Dyer method [40, 44, 45]. Manz Koule et al. obtained an oil extraction yield by the Bligh and Dyer method of 2.55% WW (wet weight) from the filet of *Arius parkii*, while for the filet of *Cyprinus carpio*, an extraction yield of 1.78% WW was obtained by the same method [28]. Furthermore, using the same extraction method, Cristelle et al. obtained an oil content of 15.32% DM and 8.05% DM, respectively, for the filet of *Clarias gariepinus* [37, 43], while Tenyang et al. showed that the filet of *Clupea harengus* had an oil content of 10.20% DM [36, 44]. For the filet of *Chrysicthys nigrodigitatus*, Tenyang et al. [42] and Njiké Ngamga et al. [27] obtained an oil content of 30.34% DM and 32.10% DM, respectively, with the Bligh and Dyer method, while Justin et al. obtained an oil content of 22.06% DM with the Soxhlet method [34], and Mouokeu et al. obtained oil extraction yields of 6.52% WW and 5.80% WW with the cooking-pressing and maceration methods, respectively [35]. For *Ethmalosa fimbriata* filet, Manz Koule et al. noted an oil extraction yield of 2.79% WW, which was obtained using the Bligh and Dyer method [28]. Simo et al. obtained an oil extraction yield of 14.49% WW with cooking-pressing and 16.90% WW with exudation for the liver of *Fontitrygon margarita* [21]. Tenyang et al. obtained an oil content of 5.52% DM from the filet of *Heterotis niloticus* with the Soxhlet method [42], while Cristelle et al. obtained an oil content of 4.20% DM with the Bligh and Dyer method [37, 43]. Simplice et al. obtained an oil extraction yield of 4.31% WW from the filet of *Hepsetus odoe* with the cooking-pressing method [35]. Concerning the *Ilisha africana* filet, Manz Koule et al. found an oil content of 6.41% DM using Soxhlet extraction [28], while the Bligh and Dyer method yielded an oil content of 13.46% DM, with an oil extraction yield of 3.69% WW [24]. Simo et al. worked with *Lutjanus dentatus* adipose tissue and obtained oil extraction yields of 66.83% WW with cooking-pressing and 55.50% WW with drying-pressing [30]. For *Liza falcipinnis* filet, Tenyang et al. reported an oil content of 18.88% DM using Soxhlet extraction [42], while the Bligh and Dyer method yielded an oil content of 19.48% DM in a later study [31]. Njinkoue et al. obtained an oil content of 21.76% DM using Soxhlet extraction for *Oreochromis niloticus* filet [39], while the Bligh and Dyer method yielded an oil content of 4.57% DM according to Tiwo et al. [43], 22.00–23.40% DM according to Djimbie et al. [38], 5.57% DM according to Cristelle et al. [37], 8.71% DM according to Teyang et al. [32], and 20.50% DM according to Tenyang et al. [31]. Tenyang et al. obtained an oil content of 5.74 WW using the Bligh and Dyer method for *Polypterus bichir bichir* filet [22]. Njikoue et al. reported oil contents of 0.36% EP and 0.46% EP for *Pseudotolithus elongatus* and *Pseudotolithus typus* filet, respectively, using Soxhlet extraction [41], while Dama et al. found oil contents of 1.23% EP for *Pseudotolithus elongatus*, 0.43% EP for *Pseudotolithus senegalensis*, and 0.50% EP for *Pseudotolithus typus* using the Bligh and Dyer method [23]. Ndômbôl et al. showed that the viscera and gills of *Pseudotolithus typus* had an oil content of 15.11% DM using Soxhlet extraction [25]. Tenyang et al. reported oil contents of 8.90% DM, 11.35% DM, and 20.89% DM for filet of *Semotilus atromaculatus*, *Symphysadon discus*, and *Trichius lepterus*, respectively [44], while Cristelle et al. found an oil content of 6.11% DM for filet of *Silurus glanis* [37]. Christophe Manzkoule et al. reported an oil content of 13.79% DM using the Bligh and Dyer method for *Sardinella maderensis* filet [24], with an oil extraction yield of 2.72% WW [20]. Ndômbôl et al. found an oil content of 20.30% DM from fish by-products using the Soxhlet method [26].

Regarding the physicochemical properties of fish oils, as indicated in Table 3, only chemical characteristics, particularly markers of acidity (AcV, FFA, and SaV) and oxidation (IiV, TaV, PeV, AnV, and Totox value) are usually analyzed for studies conducted in Cameroon. Tenyang et al.

Table 3: Oil content/extraction yield and quality indexes of Cameroon fish's oils.

Species	Oil content/Extraction yield	AcV (mgKOH/g)	FFA content (%oleic acid)	SaV (mgKOH/g)	IiV (gI_2/100 g)	TaV (μmol MDA/kg)	PeV (meqO_2/kg)	AnV	Totox value	References
Arius maculatus	nd	nd	3.60	nd	nd	nd	7.20	nd	nd	[40]
	23.02% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
	23.02% DM	nd	3.30	nd	nd	nd	7.24	nd	nd	[45]
Arius parkii	2.55% WW	1.14	nd	108.83	116.12	1.26	1.19	0.73	nd	[20]
Cyprinus carpio	1.78% WW	1.45	nd	121.07	105.36	0.87	2.08	0.66	nd	[20]
	nd	nd	1.35	nd	nd	nd	3.77	nd	nd	[33]
	8.05% DM	nd	nd	nd	nd	nd	nd	nd	nd	[37]
	8.05% DM	nd	nd	nd	nd	nd	nd	nd	nd	[43]
	15.32% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
Clarias gariepinus	6.11% DM	nd	nd	nd	nd	nd	nd	nd	nd	[43]
Clupea harengus	10.20% DM	nd	3.73	nd	88.54	nd	2.33	nd	nd	[36]
	10.20% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
Chrysicthys nigrodigitatus	32.10% DM	nd	nd	nd	nd	nd	nd	nd	nd	[27]
	22.06% DM	nd	10.25	nd	56.37	nd	22.02	nd	nd	[34]
	6.52% WW	0.70	nd	nd	96.28	6.72	4.49	9.13	nd	[35]
	5.80% WW	7.33	nd	nd	82.64	7.50	4.49	35.43	nd	
	30.34% DM	nd	nd	nd	nd	nd	nd	nd	nd	[42]
Ethmalosa fimbriata	2.79% WW	1.04	nd	96.04	128.64	1.13	1.28	0.76	nd	[20]
	nd	nd	nd	nd	nd	nd	nd	nd	nd	[29]
Fontitrygon margarita	14.49% WW	2.30	nd	nd	102.42	2.36	3.34	2.85	9.04	[30]
	16.90% WW	2.15	nd	nd	106.65	3.20	3.57	3.32	10.21	
Heterotis niloticus	4.20% DM	nd	nd	nd	nd	nd	nd	nd	nd	[37]
	5.52% DM	nd	nd	nd	nd	nd	nd	nd	nd	[42]
	4.20% DM	nd	nd	nd	nd	nd	nd	nd	nd	[43]
Hepsetus odoe	4.31% WW	0.98	nd	nd	94.85	6.59	6.22	5.05	nd	[35]
Ilisha africana	3.69% WW	1.04	nd	186.82	154.04	0.65	1.48	0.63	3.99	[20]
	13.46% DM	2.15	nd	190.26	162.09	4.67	6.03	3.19	15.07	[24]
	6.41% DM	2.30	nd	nd	171.66	6.67	8.43	nd	nd	[28]
Lutjanus dentatus	66.83% WW	3.24	nd	nd	102.47	2.21	9.76	37.85	nd	[21]
	55.50% WW	3.73	nd	nd	91.55	1.99	6.56	40.94	nd	
Liza falcipinnis	19.48% DM	nd	1.91	nd	95.27	nd	7.82	nd	15.63	[31]
	18.88% DM	nd	nd	nd	nd	nd	nd	nd	nd	[42]
Oreochromis niloticus	20.50% DM	nd	2.53	nd	100.34	nd	4.19	nd	8.39	[31]
	8.71% DM	nd	nd	nd	nd	nd	nd	nd	nd	[32]
	5.57% DM	nd	nd	nd	nd	nd	nd	nd	nd	[37]
	22.00% DM	nd	nd	nd	nd	nd	nd	nd	nd	[38]
	23.34% DM	nd	nd	nd	nd	nd	nd	nd	nd	
	22.00% DM	nd	nd	nd	nd	nd	nd	nd	nd	
	21.76% DM	nd	nd	nd	nd	nd	nd	nd	nd	[42]
	4.57% DM	nd	nd	nd	nd	nd	nd	nd	nd	[43]

TABLE 3: Continued.

Species	Oil content/Extraction yield	AcV (mgKOH/g)	FFA content (%oleic acid)	SaV (mgKOH/g)	IiV (gI_2/100 g)	TaV (μmol MDA/kg)	PeV ($meqO_2$/kg)	AnV	Totox value	References
Polypterus bichir bichir	5.74% WW	0.69	nd	nd	260.00	0.30	2.50	nd	nd	[22]
Pseudotolithus elongatus	1.23% EP	nd	nd	nd	nd	nd	nd	nd	nd	[23]
	0.36% EP	nd	nd	nd	nd	nd	nd	nd	nd	[41]
Pseudotolithus senegalensis	0.43% EP	nd	nd	nd	nd	nd	nd	nd	nd	[23]
	nd	nd	nd	nd	nd	nd	nd	nd	nd	[39]
Pseudotolithus typus	0.50% EP	nd	nd	nd	nd	nd	nd	nd	nd	[23]
	15,11% DM	49.95	nd	nd	122.74	nd	0.52	0.27	1.30	[25]
	0.46% EP	nd	nd	nd	nd	nd	nd	nd	nd	[41]
Semotilus atromaculatus	8.90% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
Symphysadon discus	11.35% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
Silurus glanis	6.11% DM	nd	nd	nd	nd	nd	nd	nd	nd	[37]
Sardinella maderensis	2.72% WW	1.38	nd	194.05	148.73	0.83	1.67	0.68	4.52	[20]
	13.79% DM	1.10	nd	192.12	180.45	5.15	5.96	3.55	15.48	[24]
Trichius lepterus	20.89% DM	nd	nd	nd	nd	nd	nd	nd	nd	[44]
Fishes by-products	20.30% DM	78.95	nd	nd	66.83	nd	0.79	0.52	2.10	[26]

AcV: acid value; FFA: free fatty acids; SaV: saponification value; IiV: iodine value; TaV: thiobarbituric acid value; PeV: peroxide value; AnV: anisidine value; Totox value: total oxidation; DM: dry matter; WW: wet weigh; EP: edible part; nd: not determined.

[40, 44, 45] demonstrated that the oil extracted from the fillet of *Arius maculatus* using the Bligh and Dyer method had an acceptable FFA content (3.30–3.60% oleic acid) and a PeV (7.20–7.24 meqO_2/kg) higher than the standard. For the oil extracted from the fillet of *Arius parkii*, Manz Koule et al. [28] found that the Bligh and Dyer method had an acceptable AcV (1.14 mgKOH/g), TaV (1.26 μmol MDA/kg), PeV (1.19 meqO_2/kg), and AnV (0.73), but a low SaV (108.83 mgKOH/g) compared to acceptable values. The oils obtained by the Bligh and Dyer method from the fillet of *Cyprinus carpio* were acceptable in terms of FFA content (1.35% oleic acid) [33], PeV (2.08–3.77 meqO_2/kg) [29, 41], AcV (1.45 mgKOH/g), TaV (0.87 μmol MDA/kg), and AnV (0.66), but low SaV (121.07 mgKOH/g) [20]. Devi and Khatkar [11, 45] showed that the oil extracted from *Clupea harengus* fillet using the Bligh and Dyer method met the standards for FFA content (3.73% oleic acid) and PeV (2.33 meqO_2/kg). In the case of *Chrysicthys nigrodigitatus* fillet, the oil obtained by Soxhlet [34] had a higher FFA content (10.25% oleic acid) and PeV (22.02 meqO_2/kg) than the standard. Likewise, the oils obtained by cooking-pressing and maceration [35] met the standards for TaV (6.72–7.50 μmol MDA/kg) and PeV (4.49 meqO_2/kg) for both, while AcV (0.70 mgKOH/g) and AnV (9.13) were corrected for the oil obtained by cooking-pressing, but higher than the standards for the oil obtained by maceration (AcV 7.33 mgKOH/g; AnV 35.43). Additionally, the iodine value (IiV) was higher for both oils obtained by cooking-pressing and maceration (82.64–96.28 g I_2/100 g) [35] compared to that obtained by Soxhlet (56.37 gI_2/100 g) [34]. In the study conducted by Manz Koule et al. [28] on *Ethmalosa fimbriata* fillet, the Bligh and Dyer method was used to extract oil, which showed low SaV (96.04 mgKOH/g) compared to standards but respected the standards for AcV (1.04 mgKOG/g), TaV (1.13 μmol MDA/kg), PeV (1.28 meqO_2/kg), and AnV (0.76).

Noutsa et al. [21] extracted oils from *Fontitrygon margarita* liver using cooking-pressing and exudation methods and achieved results that were within the standards for AcV (2.15–2.30 mgKOH/mg), TaV (2.36–3.20 μmol MDA/kg), PeV (3.34–3.57 meqO_2/kg), AnV (2.85–3.32), and Totox value (9.04–10.21) for both methods. The IiV did not significantly vary according to the extraction method (102.42–106.65 g I_2/100 g). In addition, Simplice et al. [35] obtained oil from *Hepsetus odoe* fillet using the cooking-pressing method, which had acceptable levels of AcV (0.98 mgKOH/g), TaV (6.59 μmol MDA/kg), and AnV (5.05), but a high PeV (6.22 meqO_2/kg).

Regarding *Ilisha africana* fillet, Christophe Manzkoule et al. [24, 28] extracted oils using Soxhlet and Bligh and Dyer methods and achieved results that were within the standards for AcV (1.04–2.30 mgKOH/g), SaV (186.82–190.26 mgKOH/g), TaV (0.65–6.67 μmol MDA/kg), AnV (0.63–3.19), and Totox value (3.99–15.07), but had high PeV (6.03–8.43 meqO_2/kg). The oil obtained by Soxhlet seemed to have a higher IiV compared to those obtained by the Bligh and Dyer method.

Simo et al. [30] extracted oils from *Lutjanus dentatus* adipose tissue using cooking-pressing and drying-pressing methods and achieved results that were within the standards for TaV (1.99–2.21 μmol MDA/kg), but had high AcV (3.24–3.73 mgKOH/g), PeV (6.56–9.76 meqO_2/kg), and AnV (37.85–40.94).

Additionally, the IiV of the oil obtained by cooking pressing (102.47 g I_2/100 g) was higher than that obtained by drying-pressing (91.55 gI_2/100 g). In the case of *Liza falcipinnis* filet, the oil obtained by the Bligh and Dyer method [31] had normal FFA content (1.91% oleic acid) and Totox value (15.63) but a high PeV (7.82 meqO_2/kg). For *Oreochromis niloticus* filet, the oil obtained by the Bligh and Dyer method [31] respected standards for FFA content (2.53% oleic acid), PeV (4.19 meqO_2/kg), and Totox value (8.59). Tenyang et al. [22] obtained an oil extract from *Polypterus bichir bichir* using the Bligh and Dyer method that respected standards for AcV (0.69 mgKOH/g), TaV (0.30 μmol MDA/kg), and PeV (2.50 meqO_2/kg). Ndômbôl et al. [25] showed that oil from the viscera and gills of *Pseudotolithus typus* extracted by Soxhlet had high AcV (49.9 mgKOH/g) compared to standards but normal PeV (0.52 meqO_2/kg), AnV (0.27), and Totox value (1.30). Furthermore, oil from *Sardinella maderensis* filet obtained by the noted Bligh and Dyer method [35, 42] respected standards for AcV (1.10–1.38 mgKOH/g), SaV (192.12–194.05 mgKOG/g), TaV (0.83–5.15 μmol MDA/kg), PeV (1.67–5.96 meqO_2/kg), AnV (0.68–3.55), and Totox value (4.52–15.48). The iodine value (148.73–180.45 g I_2/100 g) was higher with the oil obtained by the Soxhlet method compared to that obtained by the Bligh and Dyer method, as noted above with *Ilisha africana*. Also, Ndômbôl et al. [26] obtained oil from fish by-products extracted with the Soxhlet method, which respected standards for PeV (0.79 meqO_2/kg), AnV (0.52), and Totox value (2.10), but had a high AcV (78.95 mgKOH/g).

5. Nutritional Properties of Fish Oils Studied in Cameroon

The nutritional properties of fish oils depend on various factors such as their caloric value, mineral and vitamin content, particularly vitamins A and D, phytochemical compounds, and lipid composition, including lipid classes such as neutral lipids, glycolipids, and phospholipids, as well as fatty acid profiles [12, 48]. In addition, sensory acceptability and toxicity, especially heavy metal content, should also be considered. However, studies on fish oils in Cameroon have focused only on fatty acid profiles, and to the best of our knowledge, other nutritional parameters have not been investigated.

Fatty acid profiles have been established for 16 out of 23 fish species whose oil has been studied in Cameroon, including *Arius maculatus*, *Cyprinus carpio*, *Clupea harengus*, *Chrysicthys nigrodigitatus*, *Fontitrygon margarita*, *Heterotis niloticus*, *Hepsetus odoe*, *Ilisha africana*, *Liza falcipinnis*, *Oreochromis niloticus*, *Pseudotolithus elongatus*, *Pseudotolithus typus*, *Semotilus atromaculatus*, *Symphysadon discus*, *Sardinella maderensis*, and *Trichius lepterus* (see Table 4). In all these species, a total of 48 fatty acids have been identified, including 16 saturated fatty acids (SFA), 15 monounsaturated fatty acids (MUFA), and 17 polyunsaturated fatty acids (PUFA). Pseudotolithus typus has

Table 4: Fatty acid profile of oil of fish in Cameroon (g/100 g lipids/fatty acids).

Species	Saturated fatty acids																References
	C10:0	C11:0	C12:0	C13:0	C14:0	C15:0	C16:0	15-Met C16:0	C17:0	C18:0	C19:0	C20:0	C21:0	C22:0	C23:0	C24:0	
	nd	nd	0.71	nd	3.44	nd	21.90	nd	2.40	12.80	nd	4.57	nd	0.83	nd	nd	[40]
Arius maculatus	nd	nd	0.20	nd	6.41	1.50	26.73	nd	2.43	13.04	nd	2.03	nd	0.31	nd	nd	[44]
	nd	nd	0.71	nd	5.44	nd	21.36	nd	2.40	12.50	nd	3.57	nd	0.83	nd	nd	[45]
Cyprinus carpio	nd	nd	0.18	nd	2.72	nd	23.69	nd	2.11	9.72	nd	nd	nd	nd	nd	nd	[33]
	nd	nd	0.20	nd	2.60	1.00	27.20	nd	1.80	11.80	nd	0.40	nd	0.70	nd	nd	[44]
Clupea harengus	nd	nd	0.20	nd	6.22	nd	28.79	nd	nd	5.08	nd	nd	nd	nd	nd	nd	[36]
	nd	nd	0.10	nd	13.60	0.40	34.00	nd	0.30	5.90	nd	0.30	nd	0.10	nd	nd	[44]
	0.09	0.27	0.66	0.16	2.91	0.70	27.61	nd	1.58	11.29	nd	0.52	0.17	0.42	0.87	0.18	[34]
Chrysichthys	nd	nd	nd	nd	4.58	1.05	27.55	nd	1.58	13.06	nd	1.73	nd	0.38	nd	0.16	[35]
nigrodigitatus	nd	nd	nd	nd	2.86	0.89	34.05	nd	1.34	12.01	nd	0.34	nd	0.21	nd	nd	
	nd	nd	1.03	nd	2.84	1.08	22.75	nd	3.12	9.97	nd	1.96	nd	0.38	0.35	0.04	[42]
Fontitrygon	nd	nd	0.03	nd	2.73	0.00	9.96	nd	0.20	2.40	nd	0.30	nd	0.16	nd	0.08	[21]
margarita	nd	nd	0.12	nd	2.64	0.00	9.94	nd	0.25	2.50	nd	0.40	nd	0.15	nd	0.07	
Heterotis niloticus	nd	nd	nd	nd	2.86	1.92	20.07	nd	3.31	8.92	nd	2.63	nd	0.52	1.15	0.28	[42]
Hepsetus odoe	nd	nd	nd	nd	1.25	0.75	24.25	nd	1.70	8.32	nd	0.76	nd	0.42	nd	0.15	[35]
Ilisha Africana	nd	nd	1.62	nd	7.58	3.28	28.56	0.58	2.58	3.18	nd	nd	nd	nd	nd	nd	[24]
Liza falcipinnis	nd	nd	nd	nd	2.17	1.66	23.01	nd	1.80	5.50	nd	0.73	nd	0.35	0.30	0.22	[31]
	nd	nd	nd	nd	3.37	1.67	22.49	nd	3.04	7.27	nd	0.57	nd	0.25	0.96	0.14	[42]
	nd	nd	nd	nd	3.01	1.65	21.00	nd	2.97	8.12	nd	0.43	nd	0.28	1.01	0.13	[31]
Oreochromis	nd	nd	nd	nd	2.80	1.10	21.55	nd	1.70	4.80	nd	0.60	nd	1.40	nd	0.90	[32]
niloticus	0.03	0.05	0.60	nd	3.20	0.79	26.79	nd	1.80	7.89	nd	0.31	nd	0.30	1.13	0.55	[38]
	nd	nd	nd	nd	2.47	0.96	23.99	nd	1.60	6.37	nd	0.65	nd	0.29	0.27	0.10	[42]
Pseudotolithus elongatus	nd	nd	0.90	1.77	6.07	1.73	13.87	nd	6.80	13.20	1.10	1.13	0.80	1.67	0.37	1.50	[41]
Pseudotolithus typus	nd	nd	nd	1.10	0.57	2.67	6.50	nd	4.50	5.07	2.57	2.00	nd	6.80	nd	2.03	[41]
Semotilus atromaculatus	nd	nd	0.10	nd	11.30	1.80	32.30	nd	0.90	5.40	nd	0.10	nd	nd	nd	nd	[44]
Symphysadon discus	nd	nd	0.10	nd	4.30	0.90	29.30	nd	1.40	10.40	nd	0.60	nd	nd	nd	nd	[44]
Sardinella maderensis	nd	nd	0.50	nd	6.24	2.53	30.54	1.53	2.88	5.28	nd	nd	nd	nd	nd	nd	[24]
Trichius lepterus	nd	nd	0.10	nd	9.20	0.40	29.40	nd	0.40	6.40	nd	0.40	Nd	0.10	nd	nd	[44]

Table 4: Continued.

Species	Monounsaturated fatty acids															References
	C12:1	C14:1	C16: 1ω11	C16: 1ω9	C16: 1ω7	7-Met C16:1ω10	C17:1	C17:1ω7	C18:1ω9	C18: 1ω7	C18: 1ω3	C20:1	C20: 1ω9	C22:1	C24:1	
Arius maculatus	nd	nd	nd	nd	5.81	nd	1.86	nd	14.96	nd	nd	nd	1.05	0.46	nd	[40]
	nd	nd	nd	nd	6.58	nd	0.98	nd	12.18	5.31	nd	nd	1.00	0.63	nd	[44]
	nd	nd	nd	nd	5.80	nd	1.06	nd	14.96	nd	nd	nd	1.05	0.46	nd	[45]
Cyprinus carpio	nd	nd	nd	nd	7.06	nd	1.55	nd	22.91	nd	nd	nd	1.44	nd	nd	[33]
	nd	nd	nd	nd	6.50	nd	1.10	nd	21.80	5.50	nd	nd	1.30	0.10	nd	[44]
Clupea harengus	nd	nd	nd	nd	8.22	nd	nd	nd	27.39	nd	nd	nd	nd	nd	nd	[36]
	nd	nd	nd	nd	13.50	nd	3.70	nd	9.70	3.40	nd	nd	1.10	0.10	nd	[44]
Chrysichthys nigrodigitatus	nd	0.09	nd	nd	5.88	nd	0.41	nd	23.55	nd	nd	nd	0.42	0.07	0.09	[34]
	nd	nd	nd	nd	4.05	nd	1.07	nd	23.98	nd	nd	1.13	nd	0.36	nd	[35]
	nd	nd	nd	nd	4.28	nd	0.78	nd	26.30	nd	nd	2.57	nd	nd	nd	
	nd	nd	nd	nd	7.02	nd	1.15	nd	32.96	nd	nd	1.22	nd	0.18	nd	[42]
Fontitrygon margarita	2.60	nd	nd	nd	3.25	nd	0.17	nd	41.90	nd	nd	4.45	nd	3.25	0.35	[21]
	2.58	nd	nd	nd	2.96	nd	0.34	nd	41.23	nd	nd	4.42	nd	3.50	0.38	
Heterotis niloticus	nd	nd	nd	nd	10.11	nd	0.93	nd	21.42	nd	nd	nd	nd	0.13	nd	[42]
Hepsetus odoe	nd	nd	nd	nd	11.67	nd	0.69	nd	27.28	nd	nd	0.24	nd	0.08	nd	[35]
Ilisha africana	3.76	nd	nd	4.71	19.44	0.99	nd	nd	3.24	nd	3.84	nd	nd	nd	nd	[24]
Liza falcipinnis	nd	nd	nd	nd	7.48	nd	1.14	nd	20.50	nd	nd	0.79	nd	0.27	nd	[31]
	nd	nd	nd	nd	7.41	nd	1.15	nd	24.60	nd	nd	0.54	nd	0.06	nd	[42]
Oreochromis niloticus	nd	nd	nd	nd	7.10	nd	1.23	nd	23.04	nd	nd	nd	nd	0.60	nd	[31]
	nd	nd	nd	0.90	5.65	nd	nd	0.60	22.60	3.85	nd	1.15	1.25	nd	0.10	[32]
	nd	0.70	nd	nd	11.18	nd	0.74	nd	17.72	nd	nd	0.30	nd	nd	nd	[38]
	nd	nd	nd	nd	6.97	nd	1.03	nd	21.10	nd	nd	0.89	nd	0.07	nd	[42]
Pseudotolithus elongatus	nd	nd	nd	nd	2.57	nd	0.33	nd	9.30	4.70	nd	1.30	0.23	nd	0.47	[41]
Pseudotolithus typus	nd	nd	1.10	0.43	6.33	nd	nd	nd	5.53	5.20	10.60	0.39	2.30	0.27	0.27	[41]
Semotilus atromaculatus	nd	nd	nd	nd	15.70	nd	3.10	nd	9.80	2.90	nd	nd	0.20	0.90	nd	[44]
Symphysadon discus	nd	nd	nd	nd	7.00	nd	1.00	nd	20.80	3.50	nd	nd	0.80	nd	nd	[44]
Sardinella maderensis	4.44	nd	nd	5.78	4.63	1.03	nd	nd	4.64	7.96	nd	nd	nd	nd	nd	[24]
Trichius lepterus	nd	nd	nd	nd	15.10	nd	2.30	nd	13.40	5.40	nd	nd	0.60	0.10	nd	[44]

Table 4: Continued.

Species	Polyunsaturated fatty acids C16: 4ω3	C18:2ω6 all trans	C18:2ω6	C18: 3ω3	C18: 3ω6	C18:4ω3	C20: 2ω6	C20:3ω3	C20:3ω6	C20: 4ω3	C20: 4ω6	C20: 5ω3	C22: 2ω6	C22: 4ω6	C22: 5ω3	C22: 5ω6	C22: 6ω3	References
	nd	nd	3.49	0.54	0.71	nd	nd	Nd	nd	nd	3.15	6.55	nd	1.94	3.12	nd	5.91	[40]
Arius maculatus	nd	nd	1.83	1.33	nd	nd	nd	Nd	nd	0.21	2.92	4.60	nd	nd	2.54	1.41	6.05	[44]
	nd	nd	1.49	0.54	0.71	nd	nd	Nd	nd	nd	3.05	6.55	nd	1.64	3.12	nd	5.91	[45]
Cyprinus carpio	nd	nd	5.29	3.53	nd	nd	nd	Nd	nd	nd	3.68	4.06	nd	0.97	1.86	nd	3.02	[33]
	nd	nd	3.90	2.20	nd	nd	nd	Nd	nd	0.30	3.20	3.10	nd	nd	1.80	0.60	3.40	[44]
Clupea harengus	nd	nd	4.89	0.63	0.97	nd	nd	Nd	nd	nd	1.29	5.75	nd	0.67	1.63	nd	4.36	[36]
	nd	nd	1.40	0.90	nd	nd	nd	Nd	nd	0.10	1.90	4.70	nd	nd	4.80	0.60	2.60	[44]
	nd	0.24	6.75	1.32	0.56	nd	0.82	0.65	1.43	nd	4.53	1.41	0.05	nd	nd	nd	4.33	[34]
Chrysichthys	nd	nd	3.28	1.65	nd	nd	0.40	0.57	nd	nd	2.04	4.10	nd	nd	nd	nd	6.36	[35]
nigrodigitatus	nd	nd	3.53	1.53	nd	nd	0.78	3.01	nd	nd	nd	1.29	nd	nd	nd	nd	2.96	
	nd	nd	3.77	1.60	0.18	nd	0.77	Nd	1.26	nd	1.91	1.07	nd	nd	nd	nd	1.06	[42]
Fontitrygon	nd	nd	12.92	4.71	0.15	0.84	nd	Nd	nd	0.30	0.29	3.05	nd	0.13	1.35	0.08	4.35	[21]
margarita	nd	nd	13.07	4.70	0.32	0.82	nd	Nd	nd	0.40	0.29	3.06	nd	0.16	1.30	0.10	4.30	
Heterotis niloticus	nd	nd	8.86	3.26	0.67	nd	0.80	Nd	0.70	nd	4.35	1.66	nd	nd	nd	nd	2.51	[42]
Hepsetus odoe	nd	nd	7.19	3.93	nd	nd	1.06	3.84	nd	nd	0.32	1.45	nd	nd	nd	nd	2.45	[35]
Ilisha africana	nd	nd	0.84	1.68	nd	nd	0.96	Nd	nd	nd	2.67	3.94	nd	nd	nd	nd	5.78	[24]
Liza falcipinnis	nd	nd	11.40	13.10	0.81	nd	0.57	Nd	2.60	nd	1.35	0.70	nd	nd	nd	nd	3.19	[31]
	nd	nd	12.36	4.16	0.55	nd	0.43	Nd	0.97	nd	2.41	1.42	nd	nd	nd	nd	2.13	[42]
	nd	nd	13.13	4.31	0.50	nd	0.39	Nd	1.02	nd	2.05	2.05	nd	nd	nd	nd	2.53	[31]
Oreochromis	nd	nd	10.00	2.55	nd	nd	0.60	1.35	nd	nd	0.60	1.45	0.20	nd	1.15	nd	3.60	[32]
niloticus	nd	nd	9.07	6.27	0.88	nd	0.54	0.89	0.90	nd	3.73	0.75	nd	nd	nd	nd	2.84	[38]
	nd	nd	12.49	11.15	0.72	nd	0.52	Nd	2.37	nd	1.21	0.66	nd	nd	nd	nd	3.29	[42]
Pseudotolithus elongatus	nd	nd	1.37	5.93	nd	nd	3.70	Nd	nd	nd	1.60	9.17	nd	nd	1.60	nd	6.20	[41]
Pseudotolithus typus	nd	nd	0.31	5.30	nd	nd	1.30	Nd	nd	nd	1.83	10.47	nd	1.17	5.57	nd	7.47	[41]
Semotilus atromaculatus	nd	nd	1.30	0.90	nd	nd	nd	Nd	nd	0.30	2.60	4.70	nd	nd	3.30	0.90	2.40	[44]
Symphysadon discus	nd	nd	1.30	0.80	nd	nd	nd	Nd	nd	0.30	2.60	3.90	nd	nd	2.80	1.10	7.20	[44]
Sardinella maderensis	1.97	nd	2.68	1.58	nd	nd	2.23	2.32	nd	nd	1.17	4.28	nd	nd	nd	nd	5.34	[24]
Trichius lepterus	nd	nd	1.70	1.70	nd	nd	nd	Nd	nd	0.30	1.80	3.00	nd	nd	4.80	0.70	2.60	[44]

Table 4: Continued.

Species	Summarizes									References
	NbFA	ΣSFA	ΣMUFA	ΣPUFA	Σω3	Σω6	ΣNiFA	Σω3/Σω6	ΣPUFA/ΣSFA	
	20	46.65	24.14	25.41	16.12	9.29	3.80	1.73	0.55	[40]
Arius maculatus	22	52.63	26.70	20.88	14.73	6.15	—	2.40	0.40	[44]
	20	48.81	23.34	23.01	10.12	6.89	8.64	2.33	0.47	[45]
Cyprinus carpio	16	38.42	32.95	22.41	12.47	9.94	6.22	1.25	0.58	[33]
	22	45.50	36.30	18.50	10.80	7.70	—	1.40	1.40	[44]
Clupea harengus	15	40.29	35.61	20.19	12.37	7.82	4.33	1.58	0.50	[36]
	22	54.90	31.50	13.70	9.80	3.90	—	2.51	0.25	[44]
	32	47.41	30.51	22.08	7.70	14.14	—	0.54	0.47	[34]
Chrysichthys nigrodigitatus	20	50.09	30.59	18.4	12.11	5.32	—	2.27	0.37	[35]
	17	51.72	33.91	12.94	5.62	3.53	—	1.59	0.25	
	23	43.52	42.53	11.62	3.73	7.12	2.30	0.52	0.27	[42]
Fontitrygon margarita	26	15.86	55.97	28.17	14.3	13.87	—	1.03	1.77	[21]
	26	16.07	55.41	28.52	14.18	14.34	—	0.98	1.78	
Heterotis niloticus	21	41.66	32.59	22.81	7.43	14.58	2.94	0.51	0.55	[42]
Hepsetus odoe	20	37.59	39.96	20.24	7.83	7.51	—	1.04	0.54	[35]
Ilisha africana	19	47.38	35.98	15.84	4.44	19.00	—	4.27	0.33	[24]
Liza falcipinnis	22	35.00	30.18	33.72	16.99	14.81	—	1.14	0.95	[31]
	22	39.76	32.61	24.43	7.71	16.29	3.20	0.47	0.61	[42]
	21	38.60	31.97	26.18	8.89	14.65	—	0.60	0.67	[31]
Oreochromis niloticus	25	34.85	36.30	22.30	10.10	12.20	—	0.83	0.64	[32]
	26	43.44	30.68	25.88	10.75	15.13	—	0.71	0.60	[38]
	22	36.70	30.06	32.41	15.10	16.79	0.83	0.90	0.88	[42]
Pseudotolithus elongatus	27	50.93	18.90	29.97	22.90	6.67	0.58	3.44	0.58	[41]
Pseudotolithus typus	28	33.80	32.43	33.41	28.80	4.61	0.36	6.24	0.99	[41]
Semotilus atromaculatus	22	52.00	32.00	16.40	11.60	4.80	—	2.42	0.32	[44]
Symphysadon discus	20	47.00	33.10	20.00	15.00	5.00	—	3.00	0.43	[44]
Sardinella maderensis	21	49.50	28.48	21.57	6.68	27.89	—	4.58	0.44	[24]
Trichius lepterus	22	46.40	36.90	16.60	12.40	4.20	—	2.95	0.36	[44]

nd: not determined or not detected. TaNbFA: number of fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; EPA: eicosapentaenoic acid (C20:5ω3); DHA: docosahexaenoic acid (C22:6ω3); ΣNiFA: unidentified fatty acids.

the highest number of fatty acids (29) among the studied species, and the fatty acid content varies between different species.

Table 4 shows that *Arius maculatus* has a high content of SFA (52.63% total fatty acids) compared to other species. Palmitic acid (16:0) is the main fatty acid, with content varying from 6.50% to 34.05%, where *Pseudotolithus typus* has the lowest content and *Chrysicthys nigrodigitatus* has the highest. Stearic acid follows with a content ranging from 2.40% to 13.20%, where *Pseudotolithus elongatus* is the richest species and *Fontitrygon margarita* is the poorest. Myristic acid (14:0) ranks third and varies from 1.25% to 11.30%, where *Liza falcipinnis* is the richest species and *Pseudotolithus typus* is the poorest. Additionally, we note the presence of fatty acids that are not commonly found in fish oils, such as 15-methyl-hexadecanoic acid (15-methyl-16:0), margaric acid (17:0), arachidic acid (20:0), and lignoceric acid (24:0).

Regarding MUFA (Table 4), *Fontitrygon margarita* (55.97%) and *Arius maculatus* (20.70%) are the richest and poorest species in MUFA, respectively. There are several series of MUFA, namely omega 3 (18:1ω3), omega 7 (16:1ω7, 17:1ω7, 18:1ω7), and omega 9 (16:1ω9, 18:1ω9, 20:1ω9). Oleic acid (18:1ω9) and palmitoleic acid (16:1ω7) are the most abundant. These two acids result from the desaturation of palmitic and stearic acids by delta desaturase 9 [49]. Furthermore, MUFA is produced by the elongation and desaturation of PUFA.

The PUFA are mainly composed of ω3 acids rather than ω6. As shown in Table 4, linoleic acid (18:2ω6) is the main acid among the ω6 series. Pseudotolithus typus has the highest PUFA content (33.41%) among all species studied. *Oreochromis niloticus* is the richest species in ω6 PUFA (16.79%), while *Pseudotolithus typus* has the lowest linoleic acid content (0.31%). Arachidonic acid (20:4ω6) is the second most abundant PUFA in the ω6 series. Among the PUFA of the ω3 series, linolenic acid (18:3ω3), EPA (20:5ω3), and DHA (22:6ω3) are the most prevalent. *Liza falcipinnis* is the richest species in linolenic acid (13.10%), while *Pseudotolithus typus* is the richest species in EPA (10.47%) and DHA (7.47%). The high richness in ω3 could be due to the fact that some species feed on phytoplankton, which is rich in ω3 [49]. Additionally, the ω-3/ω-6 ratio was greater than 1 for all species except for *Oreochromis niloticus*. The highest ratio was noted for *Pseudotolithus typus* (6.24), followed by *Sardinella maderensis* (4.58) and *Ilisha africana* (4.27).

6. Biological Properties of Fish Oils Studied in Cameroon

Fish oil is associated with various outcomes that impact both physical and mental health, particularly inflammation, oxidative stress, obesity, metabolic diseases such as dyslipidemia and diabetes, coronary artery diseases, liver dysfunctions like nonalcoholic fatty liver disease, eye diseases such as age-related macular degeneration, loss of muscle mass and function, osteoarthritis pain, bone diseases, rheumatoid arthritis, brain dysfunctions, mental disorders such as depression and anxiety, autism, cancers, and infectious diseases [20, 30, 32]. These biological properties of fish oils are related to their composition, primarily their fatty acid profiles.

As previously demonstrated, fish oils from Cameroon contain numerous fatty acids, some of which possess biological properties. For instance, stearic acid, a type of saturated fatty acid (SFA), is present in small amounts and has various beneficial effects on the body, such as protecting the cardiovascular system and possessing anticarcinogenic, antitumor, and hypoglycemic properties [50]. Myristic acid, another type of SFA, possesses biological properties such as intracellular signaling and suppressing tumors, oncogenes, and viral proteins [51]. In regards to monounsaturated fatty acids (MUFA), palmitoleic acid has hypoglycemic, hypolipidemic, and anti-inflammatory properties [52]. It also has a role in wound healing by playing an antiseptic role due to being a constituent of sebum [53]. Oleic acid is involved in bile secretions, absorption, and digestion of lipids, as well as regulating blood pressure [54]. As for polyunsaturated fatty acids (PUFA), linoleic and arachidonic acids are precursors of long-chain n-6 PUFA implicated in cardiovascular disorders such as thrombosis and arteriosclerosis. Arachidonic acid is the precursor of series 2 autacoids, aids in the blood clotting process, and binds to endothelial cells during wound healing. Including studied species that are rich in them in the human diet could aid in the wound healing process for consumers [42]. The presence of ω3 suggests beneficial health effects for consumers. Indeed, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have anti-inflammatory properties through their conversion into resolvins, which allow the synthesis of protectins and maresins [55]. Moreover, EPA and DHA have preventive effects on human coronary heart disease, combat type 2 diabetes and fatty liver disease, and possess neuroprotective, antioxidant, and hypotensive properties [56]. EPA preserves carbohydrate homeostasis and inhibits the expansion of adipose tissue [57], while DHA is essential for the development of the fetal brain and ocular retina [58]. Additionally, a ω3/ω6 ratio greater than 1 indicates an oil effective in preventing cardiovascular disease associated with plasma lipid levels [53].

Despite the potential properties of fish oils in Cameroon, few authors have investigated them, and works have mainly focused on metabolic and infectious diseases. Only 11 species have been examined, including *Cyprinus carpio*, *Chrysicthys nigrodigitatus*, *Ethmalosa fimbriata*, *Fontitrygon margarita*, *Heterotis niloticus*, *Hepsetus odoe*, *Ilisha africana*, *Lutjanus dentatus*, *Oreochromis niloticus*, *Pseudotolithus senegalensis*, and *Silurus glanis*.

6.1. Metabolic Diseases.

As shown in Table 5, a total of five studies have been conducted on the activity of fish oil on metabolic diseases in Cameroon, focusing on eight fish species (*Cyprinus carpio*, *Chrysicthys nigrodigitatus*, *Ethmalosa fimbriata*, *Heterotis niloticus*, *Ilisha africana*, *Oreochromis niloticus*, *Pseudotolithus senegalensis*, and *Silurus glanis*). Njinkoue et al. demonstrated that *P. senegalensis* oil

Table 5: Metabolic diseases.

Species	Objective/experiment	Results	References
Cyprinus carpio	Determination of the *in vivo* nutritional value of boiled fish through evaluation of growth parameters of young male and female rats	Feed intake of the experimental diets was similar to those rats under a standard diet Rats fed with experimental diets have a good protein efficiency ratio The serum total cholesterol, HDL-cholesterol, LDL-cholesterol, and (LDL + VLDL)-cholesterol revealed some significant differences, in rats fed with experimental diets compared to rats fed with a standards protein	[37]
Chrysichthys nigrodigitatus	Evaluation of lipids profile of rat-induced *Salmonella typhi* infection fed with diets formulated with fish oils and fish flesh	Formulated diets corrected the anorexia involved in the infection, increased the body weight of infected rats, lowered total cholesterol, LDL-cholesterol, atherogenic index, and increased HDL-cholesterol level	[27]
Ethmalosa fimbriata	Evaluation of the effect of oil on dyslipidemia on female rats after 16 weeks under high-fat diet/HFD (standards laboratory diet/ SLD + cooked egg yolk)	Supplementation with fish oils at 1 g/day/kg bw during 3 weeks after HFD ledto a decrease of blood triglycerides, total cholesterol, LDL-cholesterol, an increase of HDL-cholesterol, and a tendency for disappearance in tissues disorders compared to nonsupplemented rats	[29]
Heterotis niloticus	Determination of the *in vivo* nutritional value of boiled fish through evaluation of growth parameters of young male and female rats	Feed intake of the experimental diets were similar to those rats under a standard diet Rats fed with experimental diets have a good protein efficiency ratio The serum total cholesterol, HDL-cholesterol, LDL-cholesterol and (LDL + VLDL)-cholesterol were similar in rats fed with experimental diets compared to rats fed with a standards protein	[37]
Ilisha africana	Evaluation of antihyperlipidemic potential of oil on rats under HFD (SLD + cooked egg yolk)	Supplementation with fish oils at 1 g/day/kg bw during 21 days leaded to a decrease of blood total cholesterol, LDL-cholesterol, triglyceride, glycemia, proteinemia and an increase of HDL-cholesterol compared to not supplemented rats	[28]
Oreochromis niloticus	Determination of the *in vivo* nutritional value of boiled fish through evaluation of growth parameters of young male and female rats	Feed intake of the experimental diets were similar to those rats under a standard diet Rats fed with experimental diets have good protein efficiency ratio The serum total cholesterol, HDL-cholesterol, LDL-cholesterol, and (LDL + VLDL)-cholesterol were similar in rats fed with experimental diets compared to rats fed with a standards protein	[37]
Pseudotolithus senegalensis	Evaluation of antihyperlipidemic potential of oil on female rats after 4 months under HFD (SLD + cooked egg yolk)	Supplementation with fish oils at 1 g/day/kg bw during 18 days after HFD led to a decrease of blood total cholesterol, LDL-cholesterol and triglycerides, of body mass, fat's deposits, edema and tissue inflammation and an increase of blood cholesterol-HDL compared to nonsupplemented rats	[39]
Silurus glanis	Determination of the *in vivo* nutritional value of boiled fish through evaluation of growth parameters of young male and female rats	Feed intake of the experimental diets was similar to those rats under a standard diet Rats fed with experimental diets have a good protein efficiency ratio The serum total cholesterol, HDL-cholesterol, LDL-cholesterol, and (LDL + VLDL)-cholesterol revealed some significant differences, in rats fed with experimental diets compared to rats fed with a standards protein	[37]

Table 6: Infectious diseases.

Species	Objective/experiment	Results	References
Chrysichthys nigrodigitatus	Evaluation of *In vivo* activity of different diets formulated with boiled fish oils, oil + amoxicillin and boiled fish was evaluated on rat-induced *Salmonella typhi* infection	Diets formulated with fish oils or flesh: (i) Healed the infected rats between the 16^{th} and 18^{th} day (ii) Combined with the antibiotic resulted in a rapid and complete recovery (iii) Normalized the levels of red blood and white blood cells	[27]
	Evaluation by the broth microdilution method of activity of oil against eight bacteria responsible for food poisoning diseases	Oil extracted by cooking-pressing was active on six bacteria of the eight tested while that obtained by maceration was active on only four bacteria	[35]
Fontitrygon margarita	Evaluation by the broth microdilution method of activity of oil and its nanoemulsion against some bacteria responsible for food poisoning; and study of interaction of oil with common antibiotics	(i) Oils exhibited antibacterial against most of the bacterial tested (ii) Oil obtained by exudation was more active than that obtained by cooking-pressing (iii) Nanoemulsion of oils showed better activity compared to oil (iv) Oils potentiated activity of some antibiotics	[21]
Hepsetus odoe	Evaluation by the broth microdilution method of activity of oil against eight bacteria responsible for food poisoning diseases	Oil was active on seven of the eight tested bacteria	[35]
Lutjanus dentatus	Evaluation by the broth microdilution method of activity of oil and its nanoemulsion against some bacteria responsible for food poisoning; and study of interaction of oil with common antibiotics	(i) Oils exhibited antibacterial activity against most of the bacterial tested (ii) Oil obtained by cooking-pressing was more active than that obtained by drying-pressing (iii) Nanoemulsion showed better activity compared to oil (iv) Oils potentiated activity of some antibiotics	[30]

reduced weight and dyslipidemia in obese rats [39]. Tiwo et al. found that young rats fed a standard laboratory diet supplemented with boiled flesh of *S. glanis*, *O. niloticus*, *H. niloticus*, and *C. carpio* had better protein efficiency ratios and lipid profile stabilization compared to rats fed a standard diet [37]. Manz et al. showed that *I. africana* oil prevents hyperlipidemia and hyperglycemia [28], while Nchoutpouen et al. found that *E. fimbriata* oil lowered hyperlipidemia, hyperglycemia, hepatomegaly, and adipomegaly in rats under a high-fat diet [29]. Finally, Njiké Ngamga et al. showed that *C. nigrodigitatus* oil improved the lipid profile of rats infected with Salmonella typhi [27]. These observations could be explained by the presence in oils of significant amounts of PUFA such as DHA and EPA. In fact, studies have demonstrated that EPA and DHA increase lipolysis and reduce and/or inhibit lipogenesis through the modulation of the activity of lipoprotein lipase. Other mechanisms could be involved in this process such as the reduction of the expression of the enzymes responsible for the esterification of glycerol-3 phosphate and/or an elevation of adipose triglyceride lipase which increases insulin sensitivity and reduces circulating lipids [1–3, 39].

6.2. Infectious Diseases. Table 6 shows that only four studies have been conducted on the use of fish oils to combat infectious diseases in Cameroon, involving four fish species (*Chrysicthys nigrodigitatus*, *Fontitrygon margarita*, *Hepsetus odoe*, and *Lutjanus dentatus*). Simplice et al. demonstrated that oils extracted from *H. odoe* and *C. nigrodigitatus* using cooking-pressing and maceration techniques had antibacterial properties against eight bacteria responsible for food poisoning diseases [35]. Similarly, *L. dentatus* oil has also been found to be effective against these bacteria, with cooking-pressed oil exhibiting better antibacterial activity than dried-pressed oil [30]. In addition, rats treated with *C. nigrodigitatus* oil obtained by cooking-pressing showed rapid and complete healing, as well as normalization of red and white blood cell levels after being infected with Salmonella typhi [27]. Simo et al. also found that oil from *F. margarita* liver had activity against bacteria responsible for food-borne illnesses, with exudation-obtained oil being more active than cooking-pressed oil. Furthermore, the nanoemulsion of this oil exhibited better activity than the crude oil [21]. The antimicrobial activity of these oils could be explained by the presence of significant amounts of PUFA including DHA, EPA, linolenic acid, arachidonic acid, palmitoleic acid, and oleic acid [35]. Indeed, the antibacterial activity of fatty acids is accepted nowadays, with their prime target being the cell membrane, where they disrupt the electron transport chain and oxidative phosphorylation. Besides interfering with cellular energy production, fatty acid action may also result from the inhibition of enzyme activity, impairment of nutrient uptake, generation of peroxidation and auto-oxidation degradation products, or direct lysis of bacterial cells [18, 59]. Furthermore, $\omega 3$ and $\omega 6$ PUFA present in these oils are known to have potential antioxidant, anti-inflammatory, and immunomodulatory properties [2, 3, 18, 19].

7. Conclusion

Until March 2023, a total of 26 studies focusing on various aspects of fish oils in Cameroon had been published. These studies examined 23 fish species from three regions: the littoral, far-north, and west. The fish oils were mainly extracted from filets and by-products such as adipose tissue, liver, viscera, and gills using methods such as the Bligh and Dyer method, Soxhlet, and cooking-pressing. The oil content varied between 4.57 and 32.10% DM or oil extraction yields of 0.36 to 66.83% WW, depending on the fish species, tissues, and extraction methods. The species with the highest oil content were *Lutjanus dentatus* adipose tissue (66.83%), *Chrysicthys nigrodigitatus* fillet (32.10% DM), *Oreochromis niloticus* fillet (23.34%), *Arius maculatus* fillet (23.02% DM), *Trichius lepterus* fillet (20.89% DM), and *Fontitrygon margarita* liver (16.90% WW).

The oils studied met the recommended standards regarding markers of acidity and oxidation. Fatty acid profiles were only determined for 16 fish species and showed a total of 48 fatty acids, including 16 saturated fatty acids, 15 monounsaturated fatty acids, and 17 polyunsaturated fatty acids. *Pseudotolithus typus* was found to have the greatest number of fatty acids. Among fatty acids, those of particular interest for human health include palmitic, myristic, palmitoleic, oleic, linoleic, arachidonic, and linolenic acids and especially EPA and DHA. Additionally, 22 of the 23 species had a ω-3/ω-6 ratio greater than 1, indicating that these oils could be effective in preventing cardiovascular disease.

Animal studies have shown that oils from *Cyprinus carpio*, *Chrysicthys nigrodigitatus*, *Ethmalosa fimbriata*, *Heterotis niloticus*, *Ilisha africana*, *Oreochromis niloticus*, *Pseudotolithus senegalensis*, and *Silurus glanis* can reduce weight, hyperlipidemia, hyperglycemia, hepatomegaly, and adipomegaly. Furthermore, oil from *Chrysicthys nigrodigitatus*, *Fontitrygon margarita*, *Hepsetus odoe*, and *Lutjanus dentatus* has been found to be active against bacteria responsible for food poisoning diseases in vivo and in vitro.

8. Direction for Future Research

To advance the understanding and utilization of fish oils in Cameroon, future research should encompass a comprehensive characterization of the nutritional composition of oils derived from all fish species found in the country, broadening the scope beyond the current study of only 23 species. This expanded investigation should include lipid class analysis, in-depth scrutiny of fatty acid profiles, with an emphasis on omega-3 fatty acids such as EPA and DHA, and an exploration of bioactive compounds such as natural antioxidants and vitamins (e.g., tocopherols and carotenoids). This information is vital for evaluating the quality and shelf life of Cameroonian fish oils and optimizing their use as dietary supplements. Furthermore, an examination of the physicochemical properties of these oils, including boiling point, flash point, ignition point, melting point, solidification point, viscosity, plasticity, refractive index, specific gravity, solubility, and emulsion capacity, is necessary to determine their diverse applications. The research should also delve into the biological and functional properties of fish oils, encompassing their emulsification, antimicrobial, antioxidant, anti-inflammatory, and anticancer potential, with a focus on their applications in the food and pharmaceutical sectors. Moreover, an assessment of the toxicity and heavy metal content of Cameroonian fish oils, driven by increasing environmental pollution in coastal and estuarine areas, is imperative to address potential health risks. Clinical studies investigating the benefits of fish oil consumption on human health, particularly its impact on cardiovascular health, metabolic disorders, infections, cancers, inflammation, cognitive function, and relevant health outcomes, should be conducted to provide evidence-based dietary recommendations. Additionally, an evaluation of the ecological impact of fish oil production on the marine ecosystem and the sustainability of fishing practices is essential. Lastly, researchers should assess the feasibility of incorporating fish oils into various industrial sectors, such as food, pharmaceuticals, cosmetics, and dietary supplements, considering their stability, compatibility with different matrices, and potential as functional ingredients in product development. Concurrently, exploring the potential of fish by-products, such as heads, bones, and viscera, for fish oil production would not only add value to Cameroon's marine resources but also contribute to waste reduction.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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