FA Composition of the Oil Extracted from Farmed Atlantic Salmon (*Salmo salar* L.) Viscera

Ting Sun*, Zhimin Xu, and Witoon Prinyawiwatkul

Department of Food Science, Louisiana State University Agricultural Center, Baton Rouge, Louisiana 70803

ABSTRACT: The FA composition of visceral oil extracted from farmed Atlantic salmon (*Salmo salar* L.) viscera was studied. Seventeen FA were identified in the extracted visceral oil, and the major FA were 18:1n9, 16:0, 16:1n7, 20:5n3 (EPA), 14:0, and 22:6n3 (DHA). The percentages of saturated, monounsaturated, and polyunsaturated FA in the total FA were 31.7, 36.0, and 32.2%, respectively. Compared with other fish oils, oil from farmed Atlantic salmon had much higher EPA (1.64 g/100 g) and DHA (1.47 g/100 g) contents. The FA profile of the salmon visceral oil was similar to that of the salmon fillet. Thus, the salmon visceral oil could be a replacement for the oil obtained from edible salmon fillet and used in functional foods or feeds requiring a high level of omega-3 FA. Furthermore, producing visceral oil is also beneficial to salmon fish industry by adding value back to the processing waste.

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KEY WORDS: Fish oil, polyunsaturated fatty acids, salmon, visceral oil.

Fish oil contains long-chain n-3 (omega-3) PUFA, particularly EPA (20:5n-3) and DHA (22:6n-3). Consumption of these PUFA is important in human nutrition, health ,and disease prevention. Many studies have demonstrated that DHA is critical for maintenance of normal brain function in adults, and for growth and functional development of the brain in infants (1). DHA and EPA also lower serum TAG and cholesterol levels, increase membrane fluidity, and reduce thrombosis (1).

DHA and EPA, as well as other PUFA, are synthesized mainly by uni- and multicellular marine phytoplankton and algae. Those PUFA eventually are transferred and incorporated into lipids of aquatic species through the food chain. Therefore, seafood such as marine fish and shellfish are considered as unique sources of n-3 FA (2).

As more consumers become interested in the health benefits of PUFA and as marine fisheries and resources become limited, more potential PUFA sources need to be explored. By-products from salmon processing plants may contain significant quantities of nutritional components. In the North Pacific, fish processing generates tremendous amounts of waste, which in the past were directly discarded into the sea (3). At present, environmental restrictions have limited this practice, and most processing waste from shore-based plants is being used as high-protein fish feeds. However, the economic benefits of producing fish feeds from the wastes may not be that high. As the demand for and use of PUFA in nutraceutical foods increase, fish oil is becoming a more valuable product and has a promising market potential. The value-added oil extracted from fish processing wastes could significantly increase the economics of the fish processing industry and reduce the production cost of nutraceutical foods having a high level of PUFA. In our research, we demonstrate that the visceral oil from farmed Atlantic salmon (*Salmo salar* L.) is a good source of PUFA and that it can be used as supplement or additive in human nutraceutical foods or in the animal feeds industry.

EXPERIMENTAL PROCEDURES

Sample collection and preparation. Farmed Atlantic salmon (*Salmo salar* L.) having an approximate length of 80 cm were starved 7–10 d (to let food in the viscera digest completely) before harvest. The salmon were shipped to a local commercial plant in tanks filled with seawater. They were sacrificed by asphyxiation with CO_2. The salmon viscera were removed by using a vacuum apparatus. The salmon viscera contained 59.4% water and 24.1% lipid.

Production of fish oil from salmon viscera. Approximately 27.0 kg of salmon viscera was homogenized in a blender. Then 13.5 kg of water, mixed with 450 mL of concentrated HCl (12 N) and 5.4 g of TBHQ, was slowly added to the ground viscera. The acid digestion was performed for 12 h at room temperature. The mixture was centrifuged at 700 × *g* for 15 min, and the upper oil layer (about 3.7 kg)was removed and transferred to a plastic bottle. The bottle was then flushed with nitrogen, and the bottle was stored at –20°C before analysis.

FA composition analysis and quantification. The FA composition of salmon visceral oil was analyzed according to the AOCS method Ce 1b-89 (4). Twenty-five milligrams of visceral oil was weighed into a 10-mL culture tube containing 1.0 mg 23:0-methyl ester as internal standard. To the tube was added 1.5 mL of 0.5 N NaOH, and the solution was then heated at 100°C for 7 min in a water bath. Next 2 mL BF_3/methanol reagent was added to the tube and heated at 100°C for 5 min. Iso-octane (1 mL) was added to the tube to extract the FAME. Then, 5 mL of saturated NaCl solution was added to the tube and agitated thoroughly. After the iso-octane layer had been transferred to another tube, the methanol/water phase was extracted again with another 1 mL of iso-octane. The iso-octane extracts were combined. After the solvent had been evaporated, 1 mL of iso-octane was added to redissolve the extract. The FA

*To whom correspondence should be addressed. E-mail: tingsun@lsu.edu

composition of the iso-octane extract was determined by GC. The operating conditions of the gas chromatograph and calculations of the FA concentration were described previously (5).

Statistical analysis. The FA composition was analyzed using ANOVA. If significant differences existed, the data were further compared using a multiple comparison test (Student–Newman–Keuls: SNK) (6). To compare the FA composition (w/w %) of viscera and other sources, a cluster analysis was used to see the similarities among different resources. The Bray–Curtis similarity index was created after data square root transformation (7).

RESULTS AND DISCUSSION

Concentration and composition of FA in the salmon visceral oil. The FA chromatographic profile is given in Figure 1. A total of 17 FA were identified from the visceral oil of farmed Atlantic salmon (*S. salar* L.) (Table 1). These included saturated FA (14:0, 16:0, and 18:0), monounsaturated FA (16:1n-7, 18:1n-9, and 20:1n-9), and PUFA (16:2n-4, 16:3n-4, 18:2n-6, 18:3n-4, 18:3n-3, 18:4n-3, 20:4n-6, 20:4n-3, 20:5n-3, 22:5n-3, and 22:6n-3). Results of the SNK test revealed that 18:1n-9, 16:0, 16:1n-7, 20:5n-3, 14:0, and 22:6n-3 were the major FA, ranging from 6.99 (22:6n-3, 61.20 mg/g visceral oil) to 22.06% (18:1n-9, 194.75 mg/g viscera oil) of the total FA. The concentrations of the other 11 FA were less than 5%, which were between 8.95 (20:4n-6) and 43.65 mg/g (18:0) visceral oil. The saturated, monounsaturated, and PUFA were 31.73, 36.05, and 32.22% of the total FA, respectively. Among the PUFA, DHA and EPA were 6.99 ± 0.15 and 7.91 ± 0.43%, respectively. The ratio of n-3/n-6 FA is an index of the relative nutritional value of FA for different sources of lipids (2). The ratio of n-3/n-6 FA was 4.11 ± 0.07 ($n = 9$) for salmon visceral oil in this study, which was not statistically different ($P > 0.05$) from that of salmon fillet oil (4.51 ± 0.08, $n = 3$) (5).

Comparison of EPA and DHA in the salmon viscera with other sources. Table 2 shows that the concentration of EPA in viscera of farmed salmon (1.64 g/100 g) was highest among the listed data and was about 4.7 times greater than that in its fillet (0.35 g/100 g). For other fish harvested and processed in the United States as listed in Table 2, the concentration of EPA was between 0.01 and 0.71 g/100 g. The lowest EPA concentration was 0.01 g/100 g for vermillion snapper and southern flounder. The highest concentration of DHA was 1.47 g/100 g in the viscera of farmed Atlantic salmon, which was 5.7 times greater than that in its fillet (0.26 g/100 g). The lowest concentration of DHA among the data listed in Table 2 was 0.08 g/100 g for sheephead. Therefore, Atlantic salmon viscera are a good

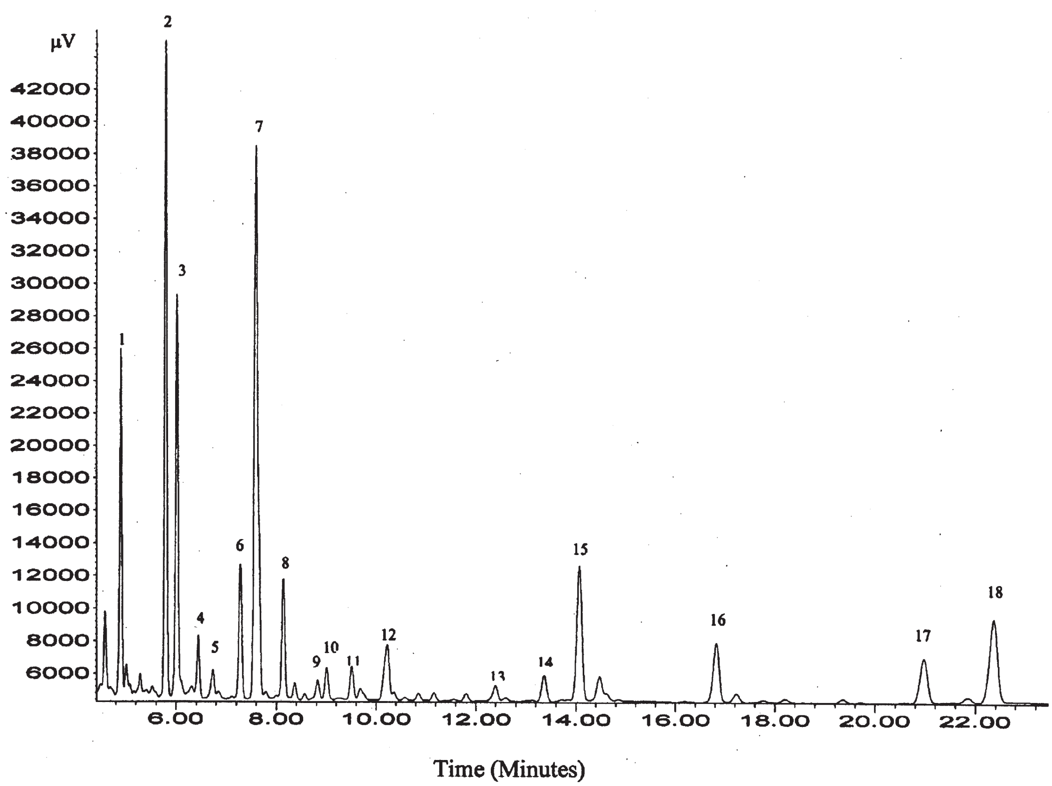

FIG. 1. FA profile of visceral oil of farmed Atlantic salmon (*Salmo salar* L.). Conditions: column SUPELCOWAX-10 (30 m × 0.25 mm, 0.20 μm film; Supelco, Bellefonte, PA) oven 200 to 240°C, 4°C/min, hold 10 min; injector 250°C, detector 270°C. Peak numbers and the correspondent representative FA are: (1) 14:0, (2) 16:0, (3) 16:1n-7, (4) 16:2n-4, (5) 16:3n-4, (6) 18:0, (7) 18:1n-9, (8) 18:2n-6, (9) 18:3n-4, (10) 18:3n-3, (11) 18:4n-3, (12) 20:1n-9, (13) 20:4n-6, (14) 20:4n-3, (15) 20:5n-3, (16) 23:0, (17) 22:5n-3, (18) 22:6n-3.

TABLE 1
FA Concentration[a] and Composition of Fish Oil Extracted from Viscera of Farmed Atlantic Salmon (*Salmo salar* L.)

FA	Concentration[a] (mg per g fish oil)	Composition[b] (%)
14:0	67.55 ± 6.13 d	7.59 ± 0.20
16:0	170.86 ± 14.63 f	19.21 ± 0.47
18:0	43.65 ± 3.24 c	4.93 ± 0.11
Total saturated	282.05	31.73
16:1n-7	100.18 ± 5.57 e	11.49 ± 0.42
18:1n-9	194.75 ± 14.51 g	22.06 ± 0.65
20:1n-9	21.93 ± 1.39 a,b	2.50 ± 0.07
Total monounsaturated	316.85	36.05
16:2n-4	18.48 ± 2.15 a,b	2.05 ± 0.11
16:3n-4	10.91 ± 1.42 a	1.20 ± 0.08
18:2n-6	38.85 ± 2.06 b,c	4.44 ± 0.07
18:3n-4	9.48 ± 1.55 a	1.03 ± 0.11
18:3n-3	10.12 ± 0.81 a	1.14 ± 0.02
18:4n-3	13.02 ± 1.23 a	1.46 ± 0.05
20:4n-6	8.95 ± 0.48 a	1.03 ± 0.05
20:4n-3	12.99 ± 0.59 a	1.49 ± 0.04
20:5n-3	68.02 ± 2.05 d	7.91 ± 0.43
22:5n-3	29.93 ± 0.76 a,b,c	3.48 ± 0.17
22:6n-3	61.20 ± 3.33 d	6.99 ± 0.15
Total polyunsaturated	281.95	32.22

[a]Values are presented as mean ± SE (n = 9). Mean values with the same letters are not significantly different ($P \geq 0.05$).
[b]Values are presented as mean ± SE, n = 9.

source of oil containing higher levels of PUFA, especially EPA and DHA, compared with other sources, even salmon fillet.

Consumption of EPA and DHA (e.g., from salmon visceral oil) may enhance the health benefits of lowering cholesterol in animal biological systems. A 2-wk feeding experiment demonstrated that rats fed with mackerel visceral oil had lower values of TAG, lactate dehydrogenase, glutamic oxaloacetic transaminase, and glutamic pyruvate transaminase in plasma compared with those treated with vegetable oil (8). Therefore, the present study demonstrates that visceral oil from farmed Atlantic salmon is a rich source of EPA and DHA and could be used in health-promoting foods that would potentially lower LDL cholesterol and reduce the risk of heart disease.

Comparison of FA profile of salmon viscera with other sources. The FA composition of Atlantic salmon viscera was compared with that of its fillet (5), some other fishes, and some vegetable oils (Fig. 2). The Bray–Curtis similarity index indicated that the FA composition of salmon viscera was very similar to that of its fillet (97.91%). Subtle differences in diets, animal life stage, or the proportions of TAG and phospholipids of some species result in larger differences in FA composition of fish. Other factors such as handling, processing, storage, and distribution of fish can also influence their FA composition (2). Because of many affecting factors, such as size, maturity, spawning cycle, food intake, and geographical location, FA composition of the same fish species can vary greatly (2). For example, EPA and DHA in catfish are 0.2–2.5 (w/w) and 0.6–6.1% (w/w), respectively (9). From the statistical analysis results shown in Figure 2, the FA composition of farmed Atlantic salmon fillet in this study was different from that obtained in samples from retail stores, probably because the FA

TABLE 2
Comparison of EPA and DHA Concentrations (g per 100 g tissue) in Viscera of Farmed Atlantic Salmon (*Salmo salar* L.) with those of Salmon Fillet and Fish in USA[a]

Source	EPA	DHA
Viscera of farmed Atlantic salmon	1.64	1.47
Fillet of farmed Atlantic salmon	0.35	0.26
Black sea bass	0.03	0.12
Bluefish	0.08	0.17
Gulf butterfish	0.13	0.38
Channel catfish	0.08	0.09
Atlantic croaker	0.12	0.12
Southern flounder	0.01	0.09
Goosefish	0.02	0.09
Gag grouper	0.06	0.28
Yellowedge grouper	0.04	0.21
White grunt	0.03	0.09
Harvest fish	0.05	0.23
Speckled hind	0.09	0.40
Crevalle jack	0.11	0.26
Southern kingfish	0.07	0.17
Ladyfish	0.08	0.25
Chub mackerel	0.24	0.72
King mackerel	0.04	0.13
Striped mullet	0.35	0.13
Red porgy	0.02	0.19
Silver rag	0.16	0.55
Blue runner	0.06	0.31
Rough scad	0.10	0.32
Spotted sea trout	0.11	0.17
American shad	0.51	0.89
Sheephead/sheepshead	0.05	0.08
Red snapper	0.04	0.22
Vermillion snapper	0.01	0.10
Spot	0.35	0.29
Tile fish	0.02	0.15
Blueline tilefish	0.06	0.28
Gray triggerfish	0.02	0.15
Weakfish	0.07	0.23
Snapper	0.05	0.26
Florida pompano	0.18	0.39
Halibut	0.07	0.29
Herring	0.71	0.86
Ocean perch	0.08	0.21
Farmed Atlantic salmon	0.32	0.51
Wild Atlantic salmon	0.24	0.63
Average value of the above	0.17	0.31

[a]These data are taken from different references: viscera from the present study, fillet (3), fish from the southeastern USA (13), farmed Atlantic salmon and wild Atlantic salmon (14), others (15).

composition of the food intake was different. The FA composition of tilapia obtained from Ghana and Seattle was also different (Fig. 2). Wild sea bass had a greater percentage of PUFA and saturated FA, but lower percentage of monoenoic acids than its cultured individuals (10). Overall, the FA profile of salmon viscera oil had a similarity at the level of 52.60% to different fish species (except sockeye salmon, *Oncorhynchus nerka*) and 15.22% to vegetable oil (Fig. 2).

According to their lipid content, fish have been classified into four groups, i.e., lean (<2% fat, such as cod, haddock, and pollock), low (2–4% fat, such as sole, halibut, and redfish), medium (4–8%, such as most wild salmon), and high (8–20%

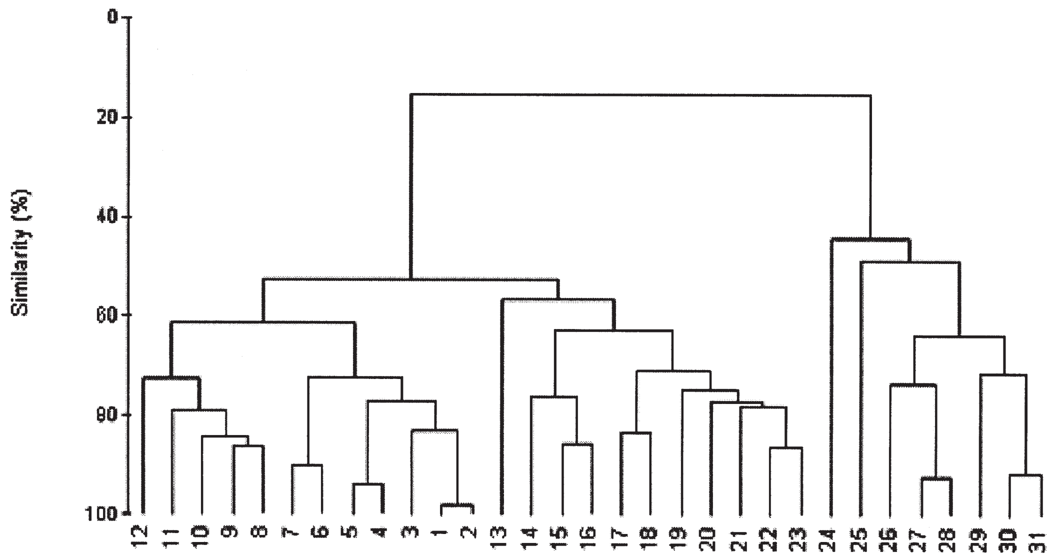

FIG. 2. Bray–Curtis similarity of FA composition (w/w %) among viscera (present experiment, average value); fillet of farmed Atlantic salmon (5); sockeye salmon (16); catfish, carp, tilapia (USA), Atlantic salmon from Seattle local retail stores, chub, whitefish from Lake Superior (17); tilapia (Ghana), sardine, sea bream from Ghana (18); cultured and wild sea bass (10); other fish from Mediterranean area (19). Some plant oils (soy, canola, rapeseed, corn, hemp, linseed, palm, and lupin) are from Higgs and Dong (20). [1. Viscera, 2. fillet, 3. sea bream (Ghana), 4. whitefish, 5. chub, 6. flat sardine, 7. tilapia (Ghana), 8. red mullet, 9. chub mackerel, 10. Bonito, 11. mackerel, 12. catfish, 13. sockeye salmon, 14. carp, 15. tilapia (USA), 16. Atlantic salmon, 17. grey mullet, 18. picarel, 19. sea bream (Mediterranean), 20. salema, 21. anchovy, 22. sea bass (cultured), 23. sea bass (wild), 24. hemp, 25. rapeseed, 26. palm, 27. soy, 28. corn, 29. linseed, 30. canola, 31. lupin].

fat, such as herring, mackerel, and many farmed salmon) (11). Farmed salmon are among the fattest fish. The lipid concentration of viscera is significantly greater than that in fillet, whereas the moisture concentration of viscera is significantly less than that in its fillet ($P < 0.05$) (5). Fish oil produced from fillets has been used in fish feed and is likely to become a limiting commodity in aquaculture industry. Thus, many studies on fish oil replacement have been carried out, such as using vegetable oil as an alternative in the salmon farming industry (12). But there are some problems in using other oil sources as fish oil replacement because dietary oil sources can change the FA content of farmed fish (12). As most vegetable oils have FA profiles that are different from fish oil (Fig. 2), which is particularly rich in n-6 FA, the farmed fish will be lower in n-3 FA and higher in n-6 FA than those fed a diet containing only fish oil as the added lipid source. The result (Fig. 2) of the greater similarity of salmon viscera oil and other fish oil suggests that viscera oil is a better replacement for fish oil in fish feed than vegetable oil.

In conclusion, fish oil prepared from farmed salmon viscera is rich in EPA and DHA. One advantage of fish oil from viscera is that it is much cheaper compared with the traditionally produced fish oil. The higher levels of EPA and DHA in the visceral oil could make it more competitive than any other oils in applications involving health-promoting foods that would potentially lower cholesterol level and prevent heart diseases. Use of viscera as a source of fish oil can also benefit the environment by reducing waste dumping.

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