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Nutritional quality of salmon products available from major retailers in the UK: content and composition of *n*-3 long-chain PUFA

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Abstract

In the present study, salmon products available from UK retailers were analysed to determine the levels of *n*-3 long-chain PUFA (LC-PUFA), a key determinant of nutritional quality. There was a wide variation in the proportions and absolute contents of EPA and DHA in the products. Relatively high contents of 18 : 1*n*-9, 18 : 2*n*-6 and 18 : 3*n*-3, characteristic of vegetable oils (VO), were found in several farmed salmon products, which also had generally lower proportions of EPA and DHA. In contrast, farmed salmon products with higher levels of 16 : 0 and 22 : 1, characteristic of fish oil (FO), had higher proportions of EPA and DHA. Therefore, there was a clear correlation between the levels of VO and FO in feeds and the proportions of *n*-3 LC-PUFA in products. Although wild salmon products were characterised by higher proportions of *n*-3 LC-PUFA (20–40 %) compared with farmed fish (9–26 %), they contained lower total lipid contents (1–6 % compared with 7–17 % in farmed salmon products). As a result, farmed salmon products invariably had higher levels of *n*-3 LC-PUFA in absolute terms (g/100 g fillet) and, therefore, delivered a higher 'dose' of EPA and DHA per portion. Overall, despite the finite and limiting supply of FO and increasing use of VO, farmed salmon continue to be an excellent source of and delivery system for *n*-3 LC-PUFA to consumers.

Key words: Aquaculture: Farmed salmon products: Wild salmon products: Fish oils: Vegetable oils: EPA: DHA

Global demand for fish and seafood products has increased significantly over the last five decades, and in recent years, with wild fisheries being at, or beyond, their sustainable limits(1), this demand has been increasingly met by aquaculture with almost 50 % of the global market now being farmed(2). As the so-called oily fish, Atlantic salmon (*Salmo salar*) and other salmonids represent not only good sources of protein but also major sources of 'omega-3' or *n*-3 long-chain PUFA (LC-PUFA), principally EPA (20 : 5*n*-3) and DHA (22 : 6*n*-3)(3,4). It is well established that *n*-3 LC-PUFA have several beneficial effects on human health including reduction of coronary vascular disease risk and attenuation of inflammatory diseases and some cancers, as well as promotion of neural development and attenuation of neurological disorders(5–12). The *n*-3 LC-PUFA present in farmed Atlantic salmon are predominantly derived from the feed, specifically fish oils (FO) and fishmeals, traditionally the major ingredients used to supply lipid and protein, respectively(13). Paradoxically, these marine resources are themselves derived from wild fisheries and are finite and limited resources(14). In addition, FO are increasingly being utilised by the nutraceutical industry for direct human consumption in the form of capsules, resulting in further demands on the limited supply(15). As a result, alternatives to FO are increasingly being used and the proportion of FO in aquafeeds is decreasing(16).

Sustainable alternatives to FO have been terrestrial vegetable oils (VO), but in contrast to FO, VO lack LC-PUFA and thus contain no EPA or DHA(17,18). Furthermore, most of the VO are particularly rich in C18, *n*-9 and *n*-6 fatty acids, specifically 18 : 1*n*-9 and 18 : 2*n*-6, while some also have 18 : 3*n*-3 and a few, such as linseed oil, can be very rich in this fatty acid(18). In some species, including salmonids, 18 : 3*n*-3 can be converted to EPA and DHA through a series of desaturation and elongation reactions(19). However, the endogenous production of *n*-3 LC-PUFA is not efficient, even in salmon, and it cannot compensate for a lack of dietary EPA and DHA(20). Therefore, replacement of high amounts of dietary FO with VO reduces the *n*-3 LC-PUFA content of the feeds and, as a consequence, the levels of EPA and DHA in the flesh of all fish including salmon, potentially compromising the nutritional quality of farmed fish products(20). Feeding strategies can minimise the effects of dietary FO replacement. These include limiting the amounts of VO utilised and blending them with FO and feeding this blend at moderate amounts throughout production or, alternatively, feeding high amounts of VO for much of the growth cycle and then utilising a FO-based

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Abbreviations: FAME, fatty acid methyl esters; FO, fish oils; LC-PUFA, long-chain PUFA; VO, vegetable oils.

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'finishing' diet before harvest(21–23). Both strategies can enable more sustainable production of Atlantic salmon while maintaining fish health and minimising the effects on final fatty acid profiles of flesh(21,22,24).

The above-mentioned issues, with the provision of EPA and DHA for aquaculture, reflect a much greater fundamental problem, which is an overall lack of *n*-3 LC-PUFA in the food chain. It has been calculated that the total global supply of EPA and DHA from all sources, primarily fish and seafood, both wild and farmed, is barely sufficient to cover half of the required amount to satisfy the dietary recommendations of 450–500 mg of these essential nutrients per person per d(25). Therefore, despite the improvements that the aquaculture sector has achieved with the development and introduction of more sustainable formulations based on plant meals and VO, a long-term solution is still required. The pressure on existing *n*-3 LC-PUFA feedstocks (essentially only FO) will continue to grow and it will be increasingly difficult to maintain the nutritional quality of farmed products as the aquaculture sector continues to grow rapidly. However, it is important that farmed fish and seafood continue to provide high levels of *n*-3 LC-PUFA as this has become a concern for consumers as the health benefits of '*n*-3' are increasingly being appreciated by the public and become an influential factor in fish consumption.

As the UK is an important producer, importer and consumer of salmon and parts of the UK, namely Scotland, have the highest incidence rates of coronary vascular disease in the world, the above-mentioned issues are particularly pertinent. The aim of the present study was to determine the variation in *n*-3 LC-PUFA levels in salmon products available in the UK. Therefore, a wide range of salmon products were purchased from the major national retailers that supply a large fraction of fish consumed in the UK and their lipid contents and fatty acid compositions were determined. The samples analysed covered several species of wild salmon as well as Atlantic salmon farmed in Scotland, Norway and the Faroe Islands.

Materials and methods

Sampling of retail products

A variety of wild and farmed salmon products were purchased in March 2013 from ten different UK retailers (termed A to J) with individual products being numbered when different products were sourced from a single retailer (e.g. A1, A2, etc.). The sample set included Atlantic salmon farmed in Scotland, Norway and the Faroe Islands as well as a range of wild Pacific salmon, namely chum, coho, pink and sockeye. The majority of the retail products contained two salmon fillets, and each fillet was treated as an individual sample, with the analysis being carried out in duplicate. The product obtained from retailer H and the first product from retailer F (F1) contained only one fillet. In these cases, the products were purchased twice, with each individual fillet being treated as a single replicate. The analysis of the product obtained from retailer I was carried out in quadruplicate as it contained four salmon portions. All samples except one, which was frozen (I), were chilled products and transported on ice from the retailer to the laboratory, where they were immediately processed as described below.

Sample preparation and lipid extraction

All fillets were skinned and deboned as required and homogenised in a commercial food processor. The resultant homogeneous fillet pate was then transferred into plastic tubes and stored at −40°C before analysis. Total lipid was extracted from 0·5 g of the fillet pate by homogenising it in twenty volumes of ice-cold chloroform–methanol (2:1, v/v) containing 0·01 % butylated hydroxytoluene as an antioxidant using an Ultra-Turrax tissue disruptor (Fisher Scientific)(26). After removing non-lipid impurities by washing with 0·88 % (w/v) KCl, the solvent was evaporated using a N_2 evaporator and the remaining lipid was subjected to desiccation *in vacuo* overnight. Lipid weight was then determined gravimetrically. The accepted variance in measured lipid content between sample replicates was ±10 %.

Fatty acid analysis

Fatty acid methyl esters (FAME) of total lipid were prepared by acid-catalysed transmethylation at 50°C for 16 h(27). An internal standard, heptadecanoic acid (17 : 0), was added to total lipid samples to enable the calculation of fatty acid content per g of tissue. FAME were extracted and purified as described previously(28). Purified FAME were separated and quantified by GLC using a Fisons GC-8160 system (Thermo Scientific) equipped with a 30 m × 0·32 mm-inner diameter × 0·25 μm ZB-WAX column (Phenomenex Inc.). The GLC system was equipped with an 'on-column' injector and a flame ionisation detector. H_2 was used as the carrier gas with an initial oven thermal gradient from 50 to 150°C at 40°C/min to a final temperature of 225°C at 2°C/min. Individual FAME were identified by comparison with known standards (Supelco 37-FAME mix; Sigma-Aldrich Limited) and published data(28,29). Chromcard for Windows (version 1.19; Thermoquest Italia S.p.A.) software was used to collect and process the data.

Statistical analyses

The significance of difference between the retail salmon products was determined using one-way ANOVA. All data identified as non-homogeneous using Bartlett's test were transformed using arcsine square root function before applying ANOVA, and differences between individual means were determined using Tukey's test. Differences were considered significant when $P<0·05$. All statistical analyses were carried out using Minitab (version 16.2.4; Minitab Ltd).

Results

The lipid content of the sixteen farmed Atlantic salmon products, collected from different retail outlets in the UK, varied from about 6 % to just over 17 % (Table 1). The proportions of *n*-3 LC-PUFA also varied, with those of EPA and DHA ranging from about 3 and 4 % to over 9 and 12 %,

Table 1. Total lipid content (%) and fatty acid composition (% of total fatty acids) of farmed salmon products*

(Mean values and standard deviations; *n* 2, except for product 'I1' (*n* 4))

Retailers/products…	A1†		A2†		A3†		B1‡		B2†		C1†		C2§		D1†	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total lipid	11·7^{a,b,c,d}	0·7	12·8^{a,b,c,d}	0·6	12·1^{a,b,c,d}	1·0	11·8^{a,b,c,d}	0·3	11·2^{a,b,c,d}	0·7	17·3^{a}	0·8	12·6^{a,b,c,d}	1·3	16·5^{a,b}	4·6
14 : 0	3·6	0·1	6·3	0·0	2·9	0·1	5·8	0·1	5·8	0·1	2·5	0·0	4·8	1·9	2·0	0·5
16 : 0	11·9	0·1	15·2	0·2	11·3	0·3	13·1	0·2	13·8	0·3	10·2	0·0	14·0	2·2	9·4	0·1
18 : 0	3·0	0·1	3·0	0·0	3·0	0·1	2·1	0·0	2·7	0·2	2·6	0·0	3·1	0·1	2·4	0·1
ΣSaturates¶	19·3	0·1	25·3	0·1	17·9	0·3	21·9	0·6	23·0	0·7	16·1	0·2	22·8	4·1	14·7	0·5
16 : 1*n*-7	4·5	0·2	7·3	0·1	3·5	0·0	5·4	0·0	7·3	0·3	2·9	0·1	5·4	1·9	2·7	0·1
18 : 1*n*-9	31·7^{a,b,c,d}	0·7	16·0^{e}	0·2	35·2^{a,b,c}	0·1	17·6^{d,e}	0·7	15·2^{e}	0·5	39·4^{a,b}	0·1	23·8^{b,c,d,e}	12·1	42·4^{a}	1·3
18 : 1*n*-7	3·1	0·1	3·1	0·1	2·8	0·2	2·3	0·0	3·0	0·1	2·9	0·4	2·9	0·2	2·2	1·0
20 : 1*n*-9	3·7^{c,d}	0·1	5·4^{b,c}	0·1	3·5^{c,d}	0·1	12·5^{a}	0·2	7·0^{b}	0·2	2·7^{d,e}	0·1	4·7^{b,c,d}	2·0	3·8^{c,d}	0·0
20 : 1*n*-7	0·2	0·0	0·3	0·0	0·2	0·0	0·3	0·0	0·3	0·0	0·2	0·0	0·3	0·1	0·2	0·0
22 : 1*n*-11	2·3^{d,e,f}	0·1	6·2^{b,c}	0·0	2·1^{d,e,f}	0·1	13·1^{a}	0·2	7·7^{a,b}	0·6	0·9^{e,f}	0·0	4·8^{b,c,d}	3·6	2·0^{d,e,f}	0·3
22 : 1*n*-9	0·5	0·0	0·5	0·0	0·5	0·0	0·7	0·3	0·7	0·0	0·6	0·0	0·6	0·1	0·6	0·0
ΣMonoenes**	46·5	0·4	39·4	0·5	48·4	0·2	52·7	0·2	41·8	1·0	50·2	0·3	43·1	4·5	54·1	0·6
18 : 2*n*-6	11·1^{a,b,c}	0·0	5·2^{b,c,d}	0·1	13·4^{a}	0·1	4·8^{c,d}	0·0	4·9^{c,d}	0·2	14·3^{a}	0·1	7·8^{a,b,c,d}	4·4	14·2^{a}	0·4
20 : 2*n*-6	0·8	0·1	0·4	0·0	0·9	0·0	0·4	0·0	0·4	0·0	1·1	0·1	0·5	0·2	1·1	0·1
20 : 4*n*-6	0·5	0·0	0·8	0·0	0·4	0·0	0·3	0·0	0·7	0·1	0·4	0·0	0·6	0·2	0·3	0·0
Σ*n*-6 PUFA††	12·9	0·2	7·3	0·0	15·2	0·2	5·8	0·0	6·9	0·1	16·1	0·1	9·5	4·3	15·9	0·5
18 : 3*n*-3	4·4^{a,b,c}	0·0	1·8^{d}	0·0	4·5^{a,b,c}	0·0	1·3^{d}	0·0	1·6^{d}	0·1	5·6^{a}	0·1	2·9^{a,b,c,d}	1·9	5·2^{a,b}	0·2
18 : 4*n*-3	0·8	0·1	1·6	0·0	0·7	0·0	1·6	0·1	1·7	0·0	0·6	0·0	1·3	0·5	0·6	0·0
20 : 4*n*-3	0·9	0·0	1·4	0·0	0·8	0·0	1·2	0·0	1·5	0·1	0·7	0·0	1·1	0·3	0·7	0·0
20 : 5*n*-3	5·0^{b,c,d,e,f,g}	0·3	7·8^{a,b,c,d}	0·2	4·0^{e,f,g}	0·2	4·9^{c,d,e,f,g}	0·3	7·8^{a,b,c,d,e}	0·3	3·7^{f,g}	0·1	6·8^{a,b,c,d,e,f}	2·0	2·8^{g}	0·1
22 : 5*n*-3	2·5	0·1	3·2	0·1	1·8	0·1	1·6	0·1	3·1	0·1	1·6	0·0	2·3	0·6	1·2	0·1
22 : 6*n*-3	6·3^{b,c,d,e}	0·1	10·3^{a,b,c}	0·2	5·6^{b,c,d,e}	0·0	8·2^{a,b,c,d,e}	0·2	10·8^{a,b}	0·1	4·2^{e}	0·1	8·6^{a,b,c,d,e}	2·9	3·9^{e}	0·2
Σ*n*-3 LC-PUFA‡‡	15·0^{a,b,c,d,e,f}	0·5	22·9^{a,b,c,d}	0·5	12·5^{d,e,f}	0·3	16·0^{a,b,c,d,e,f}	0·6	23·4^{a,b,c}	0·4	10·6^{e,f}	0·3	19·0^{a,b,c,d,e}	5·7	9·0^{f}	0·4
Σ*n*-3 PUFA§§	20·2	0·5	26·2	0·5	17·7	0·3	18·9	0·7	26·7	0·3	16·8	0·3	23·2	4·3	14·7	0·6
n-3:*n*-6	1·6^{c,d,e}	0·1	3·6^{a,b,c}	0·1	1·2^{e}	0·0	3·3^{a,b,c,d}	0·1	3·9^{a,b}	0·1	1·0^{e}	0·0	2·8^{b,c,d,e}	1·7	0·9^{e}	0·0

Retailers/products…	D2‡		E1†		E2§		F1†		F2†		G1‖		H1§		I1§	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total lipid	8·1^{b,c,d}	1·6	7·4^{c,d}	0·8	5·9^{d}	1·6	7·8^{b,c,d}	1·1	14·4^{a,b,c}	0·4	11·7^{a,b,c,d}	1·9	12·5^{a,b,c,d}	2·8	12·1^{a,b,c,d}	3·6
14 : 0	2·3	0·0	2·9	0·2	3·0	0·2	4·8	0·0	4·6	0·0	6·0	0·4	2·7	0·3	3·4	1·3
16 : 0	10·3	0·2	11·9	0·1	12·3	0·3	15·9	0·0	13·9	0·0	14·9	0·6	11·0	0·1	11·2	2·2
18 : 0	2·6	0·1	3·0	0·1	3·0	0·1	3·8	0·0	3·4	0·0	2·9	0·1	2·9	0·0	2·7	0·3
ΣSaturates¶	15·9	0·0	18·8	0·3	19·2	0·1	25·3	0·1	22·7	0·1	24·5	1	17·5	0·3	18·3	3·9
16 : 1*n*-7	2·9	0·1	3·5	0·3	3·4	0·4	6·2	0·2	6·1	0·0	7·1	0·2	3·3	0·3	4·1	1·7
18 : 1*n*-9	38·4^{a,b}	0·7	35·2^{a,b,c}	1·1	33·3^{a,b,c,d}	0·9	21·2^{c,d,e}	0·0	22·9^{b,c,d,e}	0·1	14·9^{e}	0·1	37·3^{a,b,c}	2·2	33·8^{a,b,c}	7·2
18 : 1*n*-7	3·1	0·1	2·2	0·9	2·9	0·1	3·2	0·1	3·1	0·1	3·3	0·1	3·1	0·1	3·1	0·1
20 : 1*n*-9	3·0^{d,e}	0·1	3·4^{c,d}	0·0	3·4^{c,d}	0·1	1·6^{e}	0·1	1·6^{e}	0·0	6·6^{b}	0·0	3·0^{d,e}	0·7	4·5^{c,d}	0·3
20 : 1*n*-7	0·2	0·0	0·2	0·0	0·2	0·0	0·2	0·0	0·2	0·0	0·4	0·1	0·2	0·0	0·2	0·0
22 : 1*n*-11	1·1^{e,f}	0·2	1·9^{d,e,f}	0·1	2·0^{d,e,f}	0·0	0·9^{f}	0·1	0·8^{f}	0·0	6·7^{b}	0·1	1·5^{d,e,f}	0·9	3·2^{c,d,e}	0·6
22 : 1*n*-9	0·5	0·0	0·6	0·0	0·6	0·0	0·3	0·0	0·3	0·0	0·7	0·0	0·6	0·0	0·6	0·0
ΣMonoenes**	49·6	1·1	47·5	0·3	46·4	1·1	34·1	0·2	35·4	0·2	40·4	0·1	49·4	0·6	50·1	4·7
18 : 2*n*-6	13·4^{a}	0·1	12·4^{a}	0·8	12·1^{a,b}	0·4	9·2^{a,b,c}	0·4	10·5^{a,b,c}	0·1	3·0^{d}	0·1	13·6^{a}	0·1	11·2^{a,b,c}	3·7
20 : 2*n*-6	1·0	0·0	0·9	0·0	0·9	0·0	0·5	0·1	0·5	0·0	0·4	0·0	0·9	0·0	0·8	0·1
20 : 4*n*-6	0·5	0·1	0·5	0·0	0·5	0·0	0·8	0·0	0·8	0·0	0·7	0·1	0·4	0·0	0·4	0·2
Σ*n*-6 PUFA††	15·3	0·1	14·1	0·8	13·9	0·5	11·2	0·4	12·6	0·1	4·8	0·1	15·3	0·0	12·8	3·5
18 : 3*n*-3	5·0^{a,b}	0·0	4·5^{a,b,c}	0·3	4·4^{a,b,c}	0·3	2·2^{c,d}	0·0	2·5^{b,c,d}	0·0	1·1^{d}	0·0	4·9^{a,b}	0·5	4·1^{a,b,c}	1·2
18 : 4*n*-3	0·5	0·0	0·6	0·0	0·6	0·0	1·2	0·1	1·2	0·0	1·7	0·0	0·6	0·2	0·9	0·2
20 : 4*n*-3	0·7	0·0	0·7	0·0	0·8	0·0	1·0	0·0	0·9	0·2	1·8	0·0	0·7	0·1	0·8	0·2
20 : 5*n*-3	3·5^{f,g}	0·3	4·2^{d,e,f,g}	0·1	4·3^{c,d,e,f,g}	0·1	9·1^{a,b}	0·3	9·6^{a}	0·1	8·2^{a,b,c}	0·6	3·7^{f,g}	0·0	4·1^{f,g}	1·7
22 : 5*n*-3	1·9	0·2	1·8	0·0	1·9	0·0	3·2	0·1	3·5	0·0	3·9	0·1	1·6	0·1	1·8	0·8
22 : 6*n*-3	6·5^{a,b,c,d,e}	0·7	6·6^{a,b,c,d,e}	0·1	7·2^{a,b,c,d,e}	0·9	10·6^{a,b}	0·1	9·2^{a,b,c,d}	0·1	12·0^{a}	0·3	5·1^{d,e}	0·6	5·9^{c,d,e}	2·4
Σ*n*-3 LC-PUFA‡‡	13·0^{c,d,e,f}	1·2	13·7^{b,c,d,e,f}	0·0	14·6^{b,c,d,e,f}	0·9	24·0^{a,b}	0·1	23·4^{a,b,c}	0·0	26·1^{a}	1·0	11·4^{e,f}	0·6	12·9^{e,f}	5·0
Σ*n*-3 PUFA§§	18·5	1·1	18·9	0·2	19·7	0·6	27·4	0·1	27·2	0	28·9	1·1	16·9	0·4	18	4·1
n-3:*n*-6	1·2^{e}	0·1	1·3^{d,e}	0·1	1·4^{d,e}	0·0	2·5^{b,c,d,e}	0·1	2·2^{b,c,d,e}	0·0	6·0^{a}	0·1	1·1^{e}	0·0	1·6^{d,e}	0·8

LC-PUFA, long-chain PUFA.

^{a,b,c,d,e,f,g} Mean values within a row with unlike superscript letters were significantly different ($P < 0·05$).

* Each letter (A–I) represents a retailer and the following number (1–4) denotes a specific product.

† Scottish.

‡ Norwegian.

§ Unknown source.

‖ Faroese.

¶ Includes 15 : 0, 20 : 0 and 22 : 0.

** Includes 16 : 1*n*-9, 20 : 1*n*-11, 24 : 1*n*-9.

†† Includes 18 : 3*n*-6, 20 : 3*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

‡‡ Includes 20 : 3*n*-3.

§§ Includes 20 : 3*n*-3.

respectively. Thus, the proportions of total *n*-3 LC-PUFA (sum of 20 : 4*n*-3, EPA, docosapentaenoic acid and DHA) ranged from 9 to 26 % (Table 1). Relatively high contents of 18 : 1*n*-9, 18 : 2*n*-6 and 18 : 3*n*-3, characteristic of VO, were found in several farmed salmon products, which also had lower proportions of EPA and DHA. In contrast, products with higher levels of 16 : 0 and 22 : 1, characteristic of FO, had higher proportions of EPA and DHA (Table 1).

The lipid content of wild salmon products was lower than that of farmed salmon products, ranging from 1·4 to 6·5 %, whereas the proportions of total *n*-3 LC-PUFA were higher, ranging from 20 % to almost 40 %, largely due to a variation in the proportions of DHA (approximately 10 % to over 27 %), while those of EPA were consistent at about 7–8 % (Table 2). However, on expressing fatty acid contents in absolute terms, farmed salmon products were found to provide between 0·7 and 2·9 g of total *n*-3 LC-PUFA/100 g flesh (Table 3), whereas wild salmon products were found to provide between 0·4 and 1·1 g of total *n*-3 LC-PUFA/100 g flesh (Table 4). Therefore, although wild salmon products had higher relative levels of EPA+DHA (Fig. 1), farmed salmon products generally delivered a higher dose of EPA+DHA compared with the wild salmon products due to their higher lipid content (Fig. 2). On taking all the data into account, these differences in the relative proportions and absolute contents of *n*-3 LC-PUFA between farmed and wild salmon products were found to be significant (Fig. 3), as were the levels of markers of VO (18 : 1*n*-9, 18 : 2*n*-6 and 18 : 3*n*-3) and FO (16 : 0 and 22 : 1) intake (Table 5).

When analysing the salmon products by country of origin, no significant differences were found between farmed salmon products originating from Scotland, Norway or the Faroe Islands with regard to total lipid content (Table 6). There was a clear difference in relative fatty acid compositions, with products originating from the Faroe Islands exhibiting lower levels of VO marker fatty acids and higher levels of FO marker fatty acids and, consequently, higher levels of *n*-3 LC-PUFA. These differences were also apparent in absolute terms, with salmon products originating from the Faroe Islands exhibiting higher proportions of *n*-3 LC-PUFA, significantly so in comparison with farmed salmon products originating from Norway (Table 6).

Table 2. Total lipid content (%) and fatty acid composition (% of total fatty acids) of wild salmon products
(Mean values and standard deviations, *n* 2)

Retailers/products...	A4*		B3†		B4‡		C3§		G2§		J1§	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total lipid	4·2^{a,b}	0·6	6·5^{a}	0·7	4·1^{a,b}	2·2	2·3^{b}	0·4	1·4^{b}	0·1	1·4^{b}	0·2
14 : 0	3·4	0·6	3·8	0·2	5·5	0·7	3·1	0·7	3·0	0·5	2·7	0·2
16 : 0	14·3	0·7	15·0	1·1	13·9	0·4	16·9	3·3	17·4	0·7	15·1	0·3
18 : 0	2·5	0·0	1·9	0·2	3·6	0·6	3·2	0·2	3·6	0·4	3·3	0·2
ΣSaturates‖	20·8	1·2	21·4	1·6	24·0	2·1	23·9	4·2	24·8	0·6	21·7	0·3
16 : 1*n*-7	4·5	0·4	5·9	0·4	4·0	0·3	3·5	0·4	3·0	0·1	3·4	0·5
18 : 1*n*-9	15·2	3·1	15·2	1·2	16·9	6·0	15·1	1·0	9·8	1·3	11·9	0·0
18 : 1*n*-7	3·2	0·5	3·5	0·3	1·8	0·2	3·4	1·1	2·3	0·1	2·2	0·4
20 : 1*n*-11	10·1	0·6	10	1·3	4·4	2·3	3·4	0·1	2·8	0·9	5·2	0·7
20 : 1*n*-9	3·6^{a,b}	0·4	4·2^{a}	0·0	2·3^{b,c}	0·0	1·9^{c}	0·5	2·2^{b,c}	0·5	2·1^{c}	0·1
20 : 1*n*-7	0·4	0·0	0·5	0·0	1·6	0·1	0·3	0·0	0·5	0·2	0·2	0·0
22 : 1*n*-11	9·8^{a,b}	0·9	11·2^{a}	0·4	4·6^{b}	1·9	5·1^{a,b}	1·5	5·8^{a,b}	1·7	6·9^{a,b}	0·9
22 : 1*n*-9	1·0	0·0	1·3	0·0	4·6	1·6	0·7	0·2	0·7	0·1	0·8	0·1
ΣMonoenes¶	48·8	3·7	52·8	3·1	40·9	3·6	34·3	1·9	28·1	1·6	33·7	2·6
18 : 2*n*-6	2·2	0·1	1·8	0·1	1·8	0·2	3·4	1·5	1·9	0·3	3·1	0·2
20 : 2*n*-6	0·4	0·0	0·3	0·0	0·5	0·1	0·4	0·1	0·4	0·1	0·3	0·0
20 : 4*n*-6	0·4	0·1	0·3	0·0	0·6	0·1	0·6	0·0	0·7	0·1	0·6	0·0
Σ*n*-6 PUFA**	3·4	0·3	2·7	0·1	3·4	0·2	4·7	1·6	3·4	0·4	4·4	0·1
18 : 3*n*-3	1·0^{a,b}	0·1	0·8^{b}	0·0	1·4^{a,b}	0·3	2·0^{a}	0·3	1·5^{a,b}	0·5	1·7^{a,b}	0·2
18 : 4*n*-3	1·2	0·6	1·4	0·3	1·5	0·1	2·2	0·1	1·8	0·2	1·6	0·1
20 : 4*n*-3	1·0	0·3	1·0	0·1	1·2	0·2	1·3	0·0	1·2	0·0	1·2	0·1
20 : 5*n*-3	7·2	0·9	7·1	0·7	7·6	1·3	7·8	0·8	8·1	0·2	8·1	0·0
22 : 5*n*-3	2·3	0·1	1·6	0·2	2·5	0·8	2·3	0·1	2·6	0·2	2·5	0·1
22 : 6*n*-3	13·6^{c,d}	0·7	10·3^{d}	0·4	15·9^{b,c,d}	5·2	20·5^{a,b,c}	1·5	27·6^{a}	0·3	24·4^{a,b}	2·6
Σ*n*-3 LC-PUFA††	24·3^{b,c}	2·0	20·2^{c}	1·4	27·5^{a,b,c}	7·0	32·1^{a,b,c}	0·7	39·8^{a}	0·3	36·3^{a,b}	2·6
Σ*n*-3 PUFA‡‡	26·6	2·7	22·4	1·6	30·3	6·6	36·3	0·8	43·1	0·6	39·6	2·7
n-3:*n*-6	7·9	1·5	8·2	1·0	8·8	1·5	8·2	2·6	12·6	1·4	9·0	0·3

LC-PUFA, long-chain PUFA.

^{a,b,c,d} Mean values within a row with unlike superscript letters were significantly different ($P<0·05$).

* *Oncorhynchus nerka* or *Oncorhynchus kisutch*.

† *Oncorhynchus keta*.

‡ *Oncorhynchus nerka*.

§ *Oncorhynchus gorbuscha*.

‖ Includes 15 : 0, 20 : 0 and 22 : 0.

¶ Includes 16 : 1*n*-9 and 24 : 1*n*-9.

** Includes 18 : 3*n*-6, 20 : 3*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

†† Includes 20 : 3*n*-3.

‡‡ Includes 20 : 3*n*-3.

Table 3. Fatty acid composition (g total fatty acids/100 g flesh) of farmed products*

(Mean values and standard deviations; *n* 2, except for product ‘I1’ (*n* 4))

Retailers/products. . .	A1†		A2†		A3†		B1‡		B2†		C1†		C2§		D1†	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ΣSaturates¶	2·0^{a,b,c,d,e}	0·1	2·7^{a}	0·1	1·9^{a,b,c,d,e}	0·1	2·2^{a,b,c}	0·1	2·2^{a,b,c,d}	0·1	2·5^{a,b}	0·1	2·4^{a,b}	0·2	2·1^{a,b,c,d}	0·7
ΣMonoenes**	4·7^{a,b}	0·2	4·2^{a,b}	0·0	5·1^{a,b}	0·4	5·4^{a,b}	0·2	4·0^{a,b}	0·4	7·6^{a}	0·3	4·7^{a,b}	0·1	7·8^{a}	2·3
Σ*n*-6 PUFA††	1·3^{a,b,c}	0·1	0·8^{b,c}	0·0	1·6^{a,b,c}	0·1	0·6^{c}	0·0	0·7^{c}	0·1	2·4^{a}	0·1	1·1^{a,b,c}	0·6	2·3^{a,b}	0·6
20 : 5*n*-3	0·5^{c,d,e,f}	0·1	0·8^{a,b}	0·0	0·4^{e,f,g,h}	0·1	0·5^{d,e,f,g}	0·0	0·7^{b,c,d}	0·0	0·6^{b,c,d,e}	0·0	0·7^{b,c,d}	0·1	0·4^{e,f,g,h}	0·1
22 : 6*n*-3	0·6^{c,d,e,f}	0·1	1·1^{a,b}	0·1	0·6^{d,e,f}	0·0	0·8^{a,b,c,d}	0·0	1·0^{a,b,c}	0·1	0·6^{c,d,e,f}	0·0	0·9^{a,b,c,d}	0·2	0·6^{d,e,f}	0·1
Σ*n*-3 LC-PUFA‡‡	1·5^{c,d,e,f}	0·1	2·5^{a,b,c}	0·1	1·3^{d,e,f,g}	0·1	1·6^{b,c,d,e,f}	0·0	2·2^{a,b,c,d}	0·1	1·6^{b,c,d,e,f}	0·1	2·0^{a,b,c,d,e}	0·4	1·3^{e,f,g}	0·3
EPA + DHA (g/150 g)§§	1·65		2·85		1·5		1·95		2·55		1·8		2·4		1·5	
Portions/week‖‖	2·12		1·23		2·33		1·79		1·37		1·94		1·46		2·33	

Retailers/products. . .	D2‡		E1†		E2§		F1†		F2†		G1‖		H1§		I1§	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ΣSaturates¶	1·1^{d,e}	0·2	1·2^{c,d,e}	0·1	1·0^{e}	0·3	1·7^{a,b,c,d,e}	0·2	2·8^{a}	0·1	2·4^{a,b}	0·3	1·9^{a,b,c,d,e}	0·5	1·5^{b,c,d,e}	0·4
ΣMonoenes**	3·5^{a,b}	0·7	3·1^{a,b}	0·3	2·4^{b}	0·7	2·3^{b}	0·3	4·4^{a,b}	0·2	4·1^{a,b}	0·7	5·4^{a,b}	1·2	4·5^{a,b}	2·2
Σ*n*-6 PUFA††	1·1^{a,b,c}	0·2	0·9^{a,b,c}	0·0	0·7^{c}	0·2	0·7^{b,c}	0·1	1·6^{a,b,c}	0·0	0·5^{c}	0·1	1·7^{a,b,c}	0·4	1·2^{a,b,c}	0·7
20 : 5*n*-3	0·2^{h}	0·0	0·3^{g,h}	0·0	0·2^{h}	0·1	0·6^{b,c,d,e}	0·1	1·2^{a}	0·0	0·8^{a,b,c}	0·2	0·4^{e,f,g,h}	0·1	0·3^{f,g,h}	0·0
22 : 6*n*-3	0·5^{e,f}	0·0	0·4^{e,f}	0·0	0·4^{f}	0·1	0·7^{b,c,d,e}	0·1	1·1^{a}	0·0	1·2^{a}	0·2	0·6^{d,e,f}	0·2	0·5^{e,f}	0·0
Σ*n*-3 LC-PUFA‡‡	0·9^{f,g}	0·1	0·9^{f,g}	0·1	0·7^{g}	0·2	1·6^{b,c,d,e,f}	0·2	2·9^{a}	0·1	2·6^{a,b}	0·5	1·3^{e,f,g}	0·4	1·0^{d,e,f}	0·0
EPA + DHA (g/150 g)§§	1·05		1·05		0·9		1·95		3·45		3·0		1·5		1·2	
Portions/week‖‖	3·33		3·33		3·89		1·80		1·01		1·17		2·33		2·92	

LC-PUFA, long-chain PUFA.

^{a,b,c,d,e,f,g,h} Mean values within a row with unlike superscript letters were significantly different ($P < 0·05$).

* Each letter (A–I) represents a retailer and the following number (1–4) indicates a specific product.

† Scottish.

‡ Norwegian.

§ Unknown source.

‖ Faroese.

¶ Includes 14 : 0, 15 : 0, 16 : 0, 18 : 0, 20 : 0 and 22 : 0.

** Includes 16 : 1*n*-9, 16 : 1*n*-7, 18 : 1*n*-9, 18 : 1*n*-7, 20 : 1*n*-11, 20 : 1*n*-9, 20 : 1*n*-7, 22 : 1*n*-11, 22 : 1*n*-9 and 24 : 1*n*-9.

†† Includes 18 : 2*n*-6, 18 : 3*n*-6, 20 : 2*n*-6, 20 : 3*n*-6, 20 : 4*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

‡‡ Includes 20 : 3*n*-3, 20 : 4*n*-3 and 22 : 5*n*-3.

§§ Grams of EPA + DHA in a 150 g portion.

‖‖ Number of 150 g portions required to provide the recommended weekly intake of 3·5 g of EPA + DHA.

Table 4. Fatty acid composition (g total fatty acids/100 g flesh) of wild salmon products
(Mean values and standard deviations, *n* 2)

Retailers/products...	A4*		B3†		B4‡		C3§		G2§		J1§	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ΣSaturates‖	0·7^{a,b}	0·1	1·2^{a}	0·2	0·9^{a,b}	0·5	0·5^{a,b}	0·2	0·3^{a,b}	0·0	0·3^{b}	0·0
ΣMonoenes¶	1·7^{a,b}	0·1	2·9^{a}	0·1	1·4^{a,b,c}	0·9	0·7^{b,c}	0·1	0·3^{c}	0·0	0·4^{c}	0·1
Σ*n*-6 PUFA**	0·1^{a,b}	0·0	0·1^{a}	0·0	0·1^{a,b}	0·1	0·1^{a,b}	0·0	0·0^{b}	0·0	0·1^{b}	0·0
20 : 5*n*-3	0·3^{a,b}	0·1	0·4^{a}	0·1	0·3^{a,b}	0·1	0·2^{b}	0·0	0·1^{b}	0·0	0·1^{b}	0·0
22 : 6*n*-3	0·5^{a,b}	0·1	0·6^{a}	0·1	0·5^{a,b}	0·1	0·4^{a,b}	0·0	0·3^{a,b}	0·0	0·3^{b}	0·0
Σ*n*-3 LC-PUFA††	0·9^{a}	0·2	1·1^{a,b}	0·2	0·9^{a,b}	0·3	0·6^{a,b}	0·1	0·5^{b}	0·0	0·4^{b}	0·0
EPA + DHA (g/150 g)‡‡	1·2		1·5		1·2		0·9		0·6		0·6	
Portions/week§§	2·92		2·33		2·92		3·89		5·83		5·83	

LC-PUFA, long-chain PUFA.
^{a,b,c} Mean values within a row with unlike superscript letters were significantly different ($P < 0·05$).
* *Oncorhynchus nerka* or *Oncorhynchus kisutch*.
† *Oncorhynchus keta*.
‡ *Oncorhynchus nerka*.
§ *Oncorhynchus gorbuscha*.
‖ Includes 14 : 0, 15 : 0, 16 : 0, 18 : 0, 20 : 0 and 22 : 0.
¶ Includes 16 : 1*n*-9, 16 : 1*n*-7, 18 : 1*n*-9, 18 : 1*n*-7, 20 : 1*n*-11, 20 : 1*n*-9, 20 : 1*n*-7, 22 : 1*n*-11, 22 : 1*n*-9 and 24 : 1*n*-9.
** Includes 18 : 2*n*-6, 18 : 3*n*-6, 20 : 2*n*-6, 20 : 3*n*-6, 20 : 4*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.
†† Includes 20 : 3*n*-3, 20 : 4*n*-3 and 22 : 5*n*-3.
‡‡ Grams of EPA + DHA in a 150 g portion.
§§ Number of 150 g portions required to provide the recommended weekly intake of 3·5 g of EPA + DHA.

Variations in lipid and fatty acid compositions within specific products were also determined. Thus, among salmon fillets within a single pack of four, three had similar lipid contents of about 14 %, whereas the other fillet (fillet a) had a lipid content of about 7 % (Table 7). Fillets c and d had similar proportions of EPA and DHA, which were lower than those of fillets a and b, which also had similar proportions of EPA and DHA. In absolute terms, fillets a, c and d had similar proportions of total *n*-3 LC-PUFA compared with fillet b, which had both high lipid contents and high EPA and DHA proportions, with values being double those in the other fillets (Table 7). Variation between two packages of the same retail product is summarised in Table 8. Thus, lipid content was about 8 % in one package and 14 % in the other. The relative fatty acid compositions were similar between the two packs, but the absolute *n*-3 LC-PUFA content was almost twice as high in the pack with the higher lipid content (Table 8). Examination of the fillets before analyses clearly showed that the pack with lower lipid content was a tail fillet while the other pack was a mid-carcass fillet.

Finally, where possible, product label values were compared with the experimentally derived values. The values quoted on the labels of three products (A2, C2 and F2) were generally similar to the analysed values (Table 9). However, for the other four products, where this comparison was possible (i.e. the labels contained lipid and/or fatty acid content data), the analysed values were generally quite different from the values quoted on the labels. Therefore, both lipid and fatty acid contents quoted on the labels could be either higher or lower than the values determined in the present analyses.

Discussion

The primary aims of the present study were to determine the variation in *n*-3 LC-PUFA contents and compositions of salmon products sold in UK retail outlets in 2013 and to evaluate the potential impact of this variation on the health benefits to consumers of the products. To conduct the study, we collected samples of twenty-two different, mostly chilled, salmon products from the ten major retailers responsible for the majority of fish sold in the UK. Of these products, sixteen were farmed Atlantic salmon (*S. salar*), with nine originating from Scotland, two from Norway, one from the Faroe Islands and four of unknown origin (not labelled). The remaining six products were labelled as wild Pacific salmon of four species including *Oncorhynchus gorbuscha*, *Oncorhynchus keta*, *Oncorhynchus kisutch* and *Oncorhynchus nerka*.

Among the sixteen farmed salmon products, there was a significant variation in both lipid and *n*-3 LC-PUFA contents,

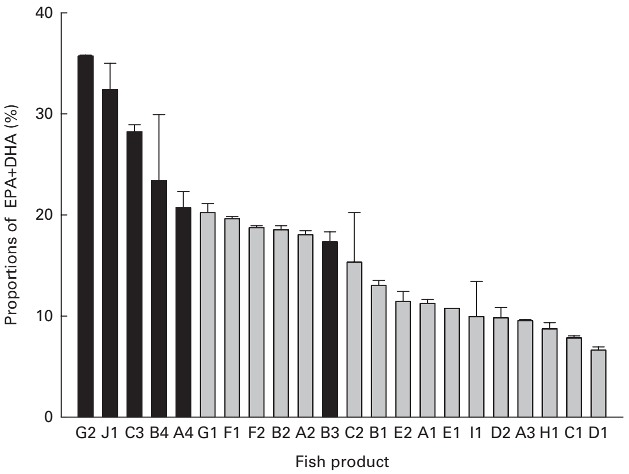

Fig. 1. Relative proportions (% of total fatty acids) of EPA + DHA in farmed (▨; *n* 2, except for product 'I1' (*n* 4)) and wild (■; *n* 2) salmon products obtained from major UK retailers. On the *x*-axis, each letter represents a retailer and the following number denotes a specific product. Values are means, with standard deviations represented by vertical bars.

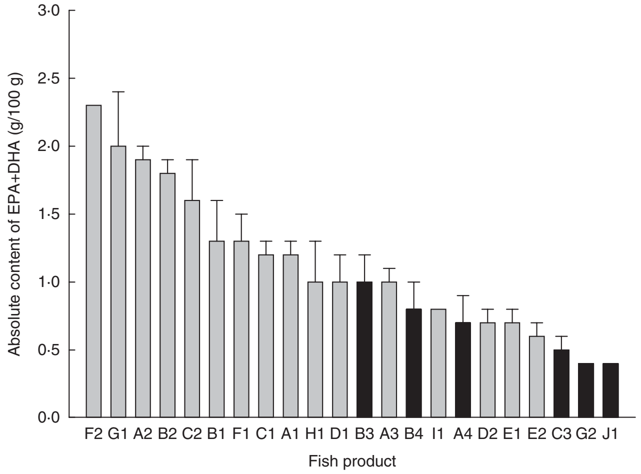

Fig. 2. Absolute contents (g/100 g flesh) of EPA + DHA in farmed (□; *n* 2, except for product 'I1' (*n* 4)) and wild (■; *n* 2) salmon products obtained from major UK retailers. On the *x*-axis, each letter represents a retailer and the following number denotes a specific product. Values are means, with standard deviations represented by vertical bars.

which, in the case of the latter, reflected the differing levels of dietary FO and VO in feeds[16,30]. Thus, the products containing the highest levels of VO fatty acid markers (18 : 1*n*-9, 18 : 2*n*-6 and 18 : 3*n*-3) had the lowest proportions of EPA, DHA and total *n*-3 LC-PUFA, as has been demonstrated in many dietary studies[21,23,24,31–35]. Although the farmed products with the highest lipid contents (C1 and D1) also had the highest levels of 18 : 1*n*-9 and 18 : 2*n*-6 (markers of dietary VO) and the lowest levels of total *n*-3 LC-PUFA, there was no overall correlation between lipid contents and dietary VO levels[17,18]. The variation in lipid contents more probably reflected differences in the lipid contents of the feeds used for different products, data for which are not available, or variations in farming practices that affect this parameter such as the duration of non-feeding period before harvest[36,37]. Among the farmed products, nine contained about 11–12 % of total lipid, but the proportions of *n*-3 LC-PUFA varied between 11 and 26 %. Interestingly, the averaged values obtained for lipid contents and, in general, fatty acid compositions (EPA+DHA) for Scottish farmed salmon in the present study were surprisingly similar to the values recorded for Scottish farmed salmon in 1998[30]. Specifically, average flesh lipid contents were about 10 % and EPA+DHA contents averaged 18 % in farmed Scottish salmon in the study carried out in 1998[30].

The difference in flesh lipid contents between farmed and wild salmon was very clear. First, there was less variation between the wild salmon, which are products of capture fisheries, and the more varied farmed products, which are influenced by and reflect differing feed formulations. Second, the farmed products generally had higher flesh lipid contents than the wild salmon products. The higher lipid content of farmed salmon compared with wild salmon has been reported previously[38–42], and this is often attributed to farming practices and high-energy feeds[31,33,40]. Although this is undoubtedly a contributing factor, it should be appreciated that it is also a result of normal salmon biology. Wild salmon are caught in the middle of their spawning migration after expending substantial energy on migration as well as in gonadogenesis and vitellogenesis[43]. In contrast, farmed fish are harvested before energy reserves are mobilised for

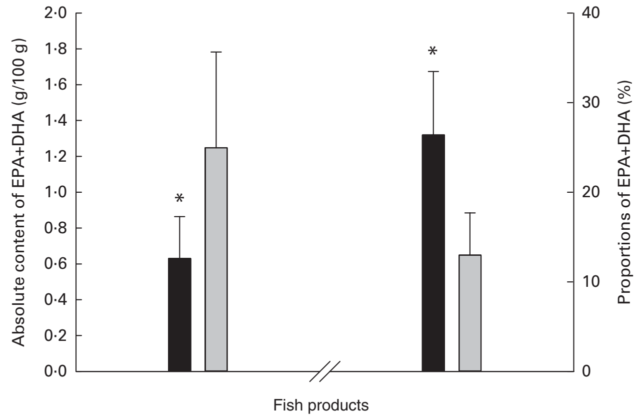

Fig. 3. Consolidated comparison of EPA + DHA levels in farmed (□) and wild (■) salmon products in relative (%) and absolute (g/100 g) terms. Values are means (*n* 34 and *n* 12 for farmed and wild products, respectively), with standard deviations represented by vertical bars. * Mean values were significantly different from that of the farmed salmon products ($P < 0.05$).

Table 5. Comparison of total lipid contents (%) and fatty acid compositions (% of total fatty acids) between farmed and wild salmon products

(Mean values and standard deviations)

Types...	Farmed (*n* 32)		Wild (*n* 12)	
	Mean	SD	Mean	SD
Total lipid	11·7	3·4	3·3*	2·0
14 : 0	3·9	1·5	3·6	1·1
16 : 0	12·4	2·0	15·4*	1·7
18 : 0	2·9	0·4	3·0	0·7
ΣSaturates†	20·1	3·6	22·8*	2·2
16 : 1*n*-7	4·7	1·7	4·0	1·0
18 : 1*n*-9	28·9	9·7	14·0*	3·3
18 : 1*n*-7	2·9	0·4	2·7	0·8
20 : 1*n*-11	0·0	0·0	6·0*	3·2
20 : 1*n*-9	4·4	2·5	2·7*	0·9
20 : 1*n*-7	0·2	0·1	0·6*	0·5
22 : 1*n*-11	3·6	3·3	7·2*	2·7
22 : 1*n*-9	0·5	0·1	1·5*	1·5
ΣMonoenes‡	45·8	6·0	39·8*	9·3
18 : 2*n*-6	10·1	3·9	2·4*	0·8
20 : 2*n*-6	0·7	0·3	0·4*	0·1
20 : 4*n*-6	0·5	0·2	0·5	0·1
Σ*n*-6 PUFA§	11·9	3·9	3·7*	0·9
18 : 3*n*-3	3·6	1·6	1·4*	0·5
18 : 4*n*-3	1·0	0·4	1·6*	0·4
20 : 4*n*-3	1·0	0·3	1·2*	0·2
20 : 5*n*-3	5·5	2·3	7·7*	0·7
22 : 5*n*-3	2·3	0·8	2·3	0·4
22 : 6*n*-3	7·5	2·6	18·7*	6·6
Σ*n*-3 LC-PUFA‖	16·5	5·7	30*	7·5
Σ*n*-3 PUFA¶	21·1	4·7	33·0*	8·0
n-3:*n*-6	2·2	1·4	9·1*	2·0

LC-PUFA, long-chain PUFA.

* Mean values were significantly different from that of the farmed salmon products ($P < 0.05$).

† Includes15 : 0, 20 : 0 and 22 : 0.

‡ Includes 16 : 1*n*-9 and 24 : 1*n*-9.

§ Includes 18 : 3*n*-6, 20 : 3*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

‖ Includes 20 : 3*n*-3.

¶ Includes 20 : 3*n*-3.

Table 6. Comparison of total lipid contents (%) and fatty acid compositions (% and absolute (g/100 g)) between farmed salmon products originating from Scotland, Norway and the Faroe Islands

(Mean values and standard deviations)

Origins...	Scotland (*n* 18)		Norway (*n* 4)		Faroe Islands (*n* 2)		Scotland (*n* 18)		Norway (*n* 4)		Faroe Islands (*n* 2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total lipid	12·4	3·5	10·0	2·3	11·7	0·9						
	%						g/100 g					
14 : 0	3·9	1·5	4·0	2·0	6·0	0·2	0·4	0·2	0·4	0·2	0·6	0·0
16 : 0	12·6	2·2	11·7	1·6	14·9	0·3	1·3	0·3	1·0	0·4	1·5	0·1
18 : 0	3·0^{a}	0·4	2·4^{b}	0·3	2·9^{a,b}	0·1	0·3^{a}	0·1	0·2^{b}	0·0	0·3^{a,b}	0·0
ΣSaturates*	20·4	3·8	18·9	3·4	24·5	0·5	2·1	0·5	1·7	0·6	2·4	0·1
16 : 1*n*-7	4·9	1·8	4·1	1·4	7·1	0·1	0·5	0·2	0·4	0·2	0·7	0·0
18 : 1*n*-9	28·8	9·9	28·0	12·0	14·9	0·1	3·2	1·8	2·3	0·6	1·5	0·1
18 : 1*n*-7	2·8	0·5	2·7	0·5	3·3	0·0	0·3	0·1	0·2	0·0	0·3	0·0
20 : 1*n*-9	3·6^{b}	1·7	7·8^{a}	5·5	6·6^{a,b}	0·0	0·4	0·2	0·7	0·6	0·7	0·1
20 : 1*n*-7	0·2^{b}	0·1	0·2^{a,b}	0·1	0·4^{a}	0·0	0·0	0·0	0·0	0·0	0·0	0·0
22 : 1*n*-11	2·8	2·4	7·1	6·9	6·7	0·0	0·3	0·2	0·7	0·7	0·7	0·1
22 : 1*n*-9	0·5	0·1	0·6	0·2	0·7	0·0	0·1	0·0	0·1	0·0	0·1	0·0
ΣMonoenes†	44·1	6·7	51·1	1·9	40·4	0·1	4·8	1·9	4·4	1·1	4·1	0·4
18 : 2*n*-6	10·6^{a}	3·4	9·1^{a,b}	5·0	3·0^{b}	0·0	1·2	0·6	0·7	0·3	0·3	0·0
20 : 2*n*-6	0·7	0·3	0·7	0·4	0·4	0·0	0·1	0·0	0·1	0·0	0·0	0·0
20 : 4*n*-6	0·6	0·2	0·4	0·1	0·7	0·0	0·1^{a}	0·0	0·0^{b}	0·0	0·1^{a}	0·0
Σ*n*-6 PUFA‡	12·5^{a}	3·3	10·5^{a,b}	5·5	4·8^{b}	0·1	1·4	0·7	0·8	0·3	0·5	0·1
18 : 3*n*-3	3·6	1·5	3·2	2·1	1·1	0·0	0·4	0·3	0·2	0·1	0·1	0·0
18 : 4*n*-3	1·0	0·4	1·1	0·6	1·7	0·0	0·1	0·0	0·1	0·1	0·2	0·0
20 : 4*n*-3	1·0^{b}	0·3	1·0^{b}	0·3	1·8^{a}	0·0	0·1^{a,b}	0·0	0·1^{b}	0·0	0·2^{a}	0·0
20 : 5*n*-3	6·0	2·5	4·2	0·8	8·2	0·3	0·6	0·3	0·4	0·1	0·8	0·1
22 : 5*n*-3	2·4^{a,b}	0·8	1·7^{b}	0·2	3·9^{a}	0·1	0·3^{a,b}	0·1	0·1^{b}	0·0	0·4^{a}	0·0
22 : 6*n*-3	7·5	2·7	7·3	1·1	12·0	0·1	0·8	0·3	0·6	0·2	1·2	0·1
Σ*n*-3 LC-PUFA§	17·2	6·0	14·5	1·9	26·1	0·6	1·8^{a,b}	0·6	1·3^{b}	0·4	2·6^{a}	0·3
Σ*n*-3 PUFA‖	21·8	4·9	18·7	0·8	28·9	0·5	2·3	0·6	1·6	0·4	2·9	0·3
n-3:*n*-6	2·0^{b}	1·1	2·2^{b}	1·2	6·0^{a}	0·0						

LC-PUFA, long-chain PUFA.

[a,b] Mean values within a row with unlike superscript letters were significantly different ($P < 0·05$).

* Includes 15 : 0, 20 : 0 and 22 : 0.

† Includes 16 : 1*n*-9, 20 : 1*n*-11 and 24 : 1*n*-9.

‡ Includes 18 : 3*n*-6, 20 : 3*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

§ Includes 20 : 3*n*-3.

‖ Includes 20 : 3*n*-3.

Table 7. Total lipid content (%) and fatty acid composition (% and absolute (g/100 g)) of four replicate fillets of a single packaged product

Replicates...	a		b		c		d	
Total lipid...	6·64		13·82		13·39		14·41	
	%	g/100 g	%	g/100 g	%	g/100 g	%	g/100 g
14 : 0	4·02	0·23	4·93	0·59	2·40	0·28	2·34	0·30
16 : 0	12·74	0·73	13·54	1·61	9·50	1·12	9·14	1·17
ΣSaturates*	20·51	1·17	22·65	2·70	15·42	1·81	14·71	1·88
18 : 1*n*-9	28·52	1·63	26·53	3·16	40·12	4·71	39·84	5·10
ΣMonoenes†	46·13	2·64	45·97	5·48	54·54	6·40	53·78	6·89
18 : 2*n*-6	8·54	0·49	7·43	0·89	13·87	1·63	14·78	1·89
20 : 1*n*-9	4·63	0·26	4·94	0·59	4·38	0·51	4·19	0·54
22 : 1*n*-11	3·47	0·20	3·90	0·46	2·66	0·31	2·64	0·34
Σ*n*-6 PUFA‡	10·40	0·59	9·16	1·09	15·37	1·80	16·27	2·08
18 : 3*n*-3	3·35	0·19	2·96	0·35	4·99	0·59	5·25	0·67
20 : 5*n*-3	5·43	0·31	5·80	0·69	2·65	0·31	2·61	0·33
22 : 6*n*-3	8·60	0·49	7·22	0·86	3·80	0·45	4·06	0·52
Σ*n*-3 LC-PUFA§	17·64	1·01	16·92	2·02	8·49	1·00	8·72	1·12
Σ*n*-3 PUFA‖	22·00	1·26	21·00	2·50	14·14	1·66	14·69	1·88
n-3:*n*-6	2·10		2·30		0·90		0·90	

LC-PUFA, long-chain PUFA.

* Includes 15 : 0, 18 : 0, 20 : 0 and 22 : 0.

† Includes 16 : 1*n*-9, 16 : 1*n*-7, 18 : 1*n*-7, 20 : 1*n*-11, 20 : 1*n*-9, 20 : 1*n*-7, 22 : 1*n*-11, 22 : 1*n*-9 and 24 : 1*n*-9.

‡ Includes 18 : 3*n*-6, 20 : 2*n*-6, 20 : 3*n*-6, 20 : 4*n*-6, 22 : 4*n*-6 and 22 : 5*n*-6.

§ Includes 20 : 3*n*-3, 20 : 4*n*-3, and 22 : 5*n*-3.

‖ Includes 18 : 4*n*-3, 20 : 3*n*-3, 20 : 4*n*-3 and 22 : 5*n*-3.

Table 8. Total lipid content (%) and fatty acid composition (% and absolute (g/100 g)) of two packages of the same product

(Mean values and standard deviations, *n* 2)

Products…	1				2			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total lipid	7·8		0·6		14·4		0·4	
	%		g/100 g		%		g/100 g	
14:0	4·8	0·0	0·3	0·0	4·6	0·0	0·6	0·0
16:0	15·9	0·0	1·0	0·1	13·9	0·0	1·7	0·0
ΣSaturates*	25·3	0·1	1·7	0·2	22·7	0·1	2·8	0·1
18:1*n*-9	21·2	0·0	1·4	0·2	22·9	0·1	2·8	0·1
ΣMonoenes†	34·1	0·2	2·3	0·3	35·4	0·2	4·4	0·2
18:2*n*-6	9·2	0·4	0·6	0·1	10·5	0·1	1·3	0·0
20:1*n*-9	1·6	0·1	0·1	0·0	1·6	0·0	0·2	0·0
22:1*n*-11	0·9	0·1	0·1	0·0	0·8	0·0	0·1	0·0
Σ*n*-6 PUFA‡	11·2	0·4	0·7	0·1	12·6	0·1	1·6	0·0
18:3*n*-3	2·2	0·0	0·1	0·0	2·5	0·0	0·3	0·0
20:5*n*-3	9·1	0·3	0·6	0·1	9·6	0·1	1·2	0·0
22:6*n*-3	10·6	0·1	0·7	0·1	9·2	0·1	1·1	0·0
Σ*n*-3 LC-PUFA§	24·0	0·1	1·6	0·2	23·4	0·0	2·9	0·1
Σ*n*-3 PUFA‖	27·4	0·1	1·8	0·3	27·2	0·0	3·4	0·1
n-3:*n*-6	2·5	0·1			2·2	0·0		

LC-PUFA, long-chain PUFA.

* Includes 15:0, 18:0, 20:0 and 22:0.

† Includes 16:1*n*-9, 16:1*n*-7, 18:1*n*-7, 20:1*n*-11, 20:1*n*-9, 20:1*n*-7, 22:1*n*-11, 22:1*n*-9 and 24:1*n*-9.

‡ Includes 18:3*n*-6, 20:2*n*-6, 20:3*n*-6, 20:4*n*-6, 22:4*n*-6 and 22:5*n*-6.

§ Includes 20:3*n*-3, 20:4*n*-3, and 22:5*n*-3.

‖ Includes 18:4*n*-3, 20:3*n*-3, 20:4*n*-3 and 22:5*n*-3.

gonadogenesis and energy is not expended on migration and so higher lipid deposits in the flesh are a consequence of normal biological processes.

The fatty acid compositions of wild salmon products, with proportions of *n*-3 LC-PUFA being in the range of 20–40 % of total fatty acids, similar to those in marine FO, simply reflected their marine fish/crustacean diet(44). However, although these values were higher than those of farmed salmon products, the most significant and important finding of the present study was that despite the increasing use of VO in salmon feeds and the variable levels of replacement, farmed salmon still generally provided human consumers with higher doses of EPA and DHA compared with their wild counterparts. Therefore, the generally lower proportions of EPA and DHA in farmed salmon were more than compensated by the higher lipid contents, resulting in twelve of the farmed salmon products delivering ≥1 g EPA+DHA/100 g flesh, whereas only one of the wild salmon products delivering 1 g/100 g. Ranking of all the products in terms of g EPA+DHA/100 g flesh revealed that the eleven products with the highest levels were farmed, with five products delivering >1·5 g/100 g, and the three products with the lowest levels were all wild, delivering <0·5 g EPA+DHA/100 g flesh. These data should be assessed in light of current recommendations for the dietary intake of EPA+DHA in humans, which, for good cardiac health, is a minimum intake of 500 mg/d (International Society for the Study of Fatty Acids and Lipids) or 3·5 g/week(45,46). With a portion size of 150 g(24,35), many of the farmed products could supply approximately 3·5 g/week in two portions. Some of the wild salmon products would have to be consumed five times a week to supply equivalent doses of EPA+DHA.

Another relevant impact arising from the use of dietary VO is the elevation of the levels of *n*-6 PUFA, specifically 18:2*n*-6, in farmed salmon products compared with those in the wild salmon products, with previously reported values being about 10 % for farmed fish and usually under 3 % for wild salmon(47). In the present study, the proportions of 18:2*n*-6 varied between 3 and 14 % (0·3–2·1 g/100 g flesh) in the farmed salmon products and between 2 and 3 % (<0·1 g/100 g flesh) in the wild salmon products. However, some of the increased 18:2*n*-6 content is counterbalanced by increased 18:3*n*-3 content, up to about 5 % (approximately 0·9 g/100 g flesh) in farmed salmon products compared with <2 % (<0·05 g/100 g flesh) in the wild salmon products. The biochemical and molecular mechanisms of LC-PUFA biosynthesis in salmon are well studied and described(20,48,49). Thus, it is known that 18:3*n*-3 and *n*-3 PUFA in general are the preferred substrates for the fatty acyl desaturase and elongase enzymes and so 18:3*n*-3 will effectively compete with 18:2*n*-6 and thereby limit the production of the *n*-6 LC-PUFA, arachidonic acid (20:4*n*-6)(50–52). Indeed, the farmed salmon products had very similar low levels of 20:4*n*-6 compared with the wild salmon products, consistent with biochemical data showing that there was no significant production of 20:4*n*-6 in salmon fed VO(52–54). Thus, we can be confident that 18:2*n*-6 does not have a major impact on the nutritional quality of farmed salmon and certainly does not outweigh the considerable benefits of the high dose of *n*-3 LC-PUFA. It should be stressed that despite potentially

Table 9. Comparison of the experimentally obtained values with the labelled values regarding lipid content (%) and fatty acid composition (g/100 g) of farmed and wild salmon products

(Mean values and standard deviations, *n* 2)

Retailer/products…	A2			B1			C1			C2			F1			F2			J1		
	Analysed			Analysed			Analysed			Analysed			Analysed			Analysed			Analysed		
	Mean	SD	Labelled	Mean	SD	Labelled	Mean	SD	Labelled	Mean	SD	Labelled	Mean	SD	Labelled	Mean	SD	Labelled	Mean	SD	Labelled
Total lipid	12·8	0·6	13·2	11·8	0·3	21·6	17·3	0·8	13·8	12·6	1·3	11·9	7·8	1·1	15·3	14·4	0·4	15·3	1·4	0·2	14·0
ΣSaturates	2·7	0·1	2·9	2·2	0·1	4·5	2·5	0·1	3·1	2·4	0·2	2·8	1·7	0·2	4·2	2·8	0·1	4·2	0·3	0·0	3·9
ΣMonoenes	4·2	0·0	6·2	5·4	0·2	11·2	7·6	0·3	4·6	4·7	1·0	4·5	2·3	0·3	–*	4·4	0·2	–*	0·4	0·1	–*
Σ*n*-6 PUFA	0·8	0·0		0·6	0·0		2·4	0·1		1·1	0·6		0·7	0·1		1·6	0·0		0·1	0·0	
Σ*n*-3 PUFA	2·8	0·1	2·9	1·9	0·0	2·4	2·6	0·2	3·1	2·5	0·2	2·6	1·8	0·3	4·0	3·4	0·1	4·0	0·5	0·1	–*
EPA + DHA	1·9	0·1	2·0	1·3	0·0	–*	1·2	0·1	–*	1·6	0·3	–*	1·3	0·2	3·1	2·3	0·0	3·1	0·4	0·0	–*

* Information was not present on the label.

increased levels of 18 : 2*n*-6, farmed fish still contain much lower levels of *n*-6 PUFA compared with terrestrial animal meat products, which also do not contain high levels of *n*-3 LC-PUFA(4,11).

The most important finding from the analysis of products by country of origin was the apparently fundamentally different feed strategy used in the Faroe Islands in comparison with those used in Scotland and Norway. In the Faroe Islands, the feeds are clearly based largely, if not entirely, on FO and VO inclusion being obviously very low or zero. This resulted in the Faroese products having higher proportions of *n*-3 LC-PUFA, in both relative and absolute terms, than farmed salmon of Scottish or Norwegian origin. This indicates that while the Norwegian and Scottish producers were adopting the use of sustainable feed formulations, the Faroese producers were using a more 'traditional' formulation. This probably reflects the greater access to locally produced FO available in the Faroe Islands. It must be emphasised that the Faroese strategy is only possible for a small industry and cannot be replicated in the much larger Scottish or Norwegian industries. For example, the Faroese salmon industry produced 32 021 tonnes of salmon in 2012 compared with the Scottish salmon industry, which produced 158 018 tonnes. Therefore, Faroese salmon should be regarded as a niche product of a production system that would be totally unsustainable in terms of both supply and cost if attempted on a larger scale.

An interesting finding of the present study was the effect that anatomical origin of specific fillets had on lipid and fatty acid contents. This effect was a consequence of normal salmon physiology as it is well known that the lipid content of salmon muscle varies across the carcass both anteriorly–posteriorly and dorsally–ventrally. Thus, the lipid content of Atlantic salmon fillets varies, with the highest values being found in the dorsal fin region and the lowest values in the tail region(30). This affected the composition of fillets in a single pack such that three fillets in sample I1 had higher lipid contents than the fourth fillet, which was clearly from posterior muscle (tail) and had significantly lower lipid content. Lipid content is largely driven by the amount of neutral lipid (TAG) stores and this could have also affected fatty acid composition with the lower lipid (and lower TAG) content being reflected in higher PUFA contents, but this was not the case(3,19). In contrast, fillets F1 and F2 had similar fatty acid compositions, but the tail fillet had lower absolute levels of *n*-3 LC-PUFA due to the lower lipid content. Therefore, the precise lipid content and fatty acid composition of a particular fillet will vary both due to the above-mentioned aspect of salmon physiology and due to normal biological/genetic variations. There is also some evidence that the flesh lipid storage pattern and composition may vary between Atlantic salmon (*S. salar*) fed FO and those fed VO(55). Flesh lipid content in salmon is well known to be under genetic control and it is a trait that has already been monitored and selected for (i.e. to be maintained within upper and lower limits) in salmon breeding programmes(56). In addition, flesh *n*-3 LC-PUFA content itself has recently been shown to be a highly heritable trait(57).

The final aspect investigated in the present study was the correlation between the analysed lipid and fatty acid contents and the values quoted on the product labels, albeit this was only possible in a limited number of products. Clearly, there were discrepancies between labelled and analysed values in some cases. However, the variation in lipid content and composition with anatomical region, along with normal biological variation in farmed Atlantic salmon populations, which are essentially still wild and not domesticated to the extent that terrestrial animals such as pigs and poultry are domesticated, highlights the difficulty in labelling products. It is obviously difficult to guarantee precise lipid or fatty acid levels in each individual fillet when biological variation is so great. Therefore, taking this into consideration, it is perhaps more surprising that values quoted on the labels quite closely reflected the analysed values for almost half of the products.

In conclusion, the present study demonstrated that the lipid and fatty acid compositions of farmed salmon products reflected the increased application of sustainable feed formulations in the major aquaculture industries in Scotland and Norway. Despite the increased use of VO in feed formulations, the farmed salmon products consistently delivered higher doses of *n*-3 LC-PUFA (EPA+DHA) to human consumers than the wild salmon products. Thus, the study has confirmed that sustainably farmed Atlantic salmon remain a product of high nutritional quality delivering substantial health benefits to human consumers.

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