Variation in the nutritional composition of farmed Atlantic salmon (*Salmo salar* L.) fillets with emphasis on EPA and DHA contents

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Abbreviations

n-3 LC-PUFA (omega-3 long-chain polyunsaturated fatty acids); EPA (eicosapentaenoic acid); DHA (docosahexaenoic acid); 18:1n-9 (oleic acid); 18:2n-6 (linoleic acid) 18:3n-3 (α-linolenic acid); AOCS (American Oil Chemist’s Society); EFSA (European Food Safety Authority); ISSFAL (International Society for the Study of Fatty Acids and Lipids); GOED (Global Organization for EPA and DHA Omega-3s); Se (selenium)

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Abstract

The increase in the global popularity and production of farmed Atlantic salmon (*Salmo salar* L.) has led to compositional changes in their feeds that can potentially diminish their nutritive value. Thus, the aim of the study was to compare the lipid, protein, fatty acid (omega-3) and mineral contents of salmon fillet portions available in the UK and estimate their contribution towards consumer dietary intake levels. Twenty pre-packaged fresh salmon fillets, encompassing all ranges (value, standard, premium and organic) and farmed origins (Scotland and Norway) were purchased from 10 main UK-wide retailers and analysed for their nutritional compositions. Lipid contents were between 11.2-16.3% wet weight (ww), except the Retailer 10 value product which was significantly lower due to a high proportion of tail pieces. No difference in protein contents (17.5-20.2% ww) were observed between fillets. However, fatty acid profiles showed marked variations between samples with marker fatty acids 18:1n-9 (24.3-42.0%), 18:2n-6 (8.3-15.1%) and 18:3n-3 (2.6-8.1%) reflecting the differing levels of vegetable oil inclusion and eicosapentaenoic and docosahexaenoic acids (EPA+DHA, 5.6-16.6%) indicating the level of marine oils included within salmon feeds. Consequently, EPA+DHA contents varied from 0.88 to 2.36 g EPA+DHA.130 g^{-1} flesh ww, equivalent to supplying 26 to 67% of the recommended 3.5 g EPA+DHA weekly intake suggested for optimal cardiac health in adults. Similarly, selenium contents differed significantly between samples delivering between 13.9-55.5% and 17.3-69.3% of the 75 and 60 μg.day^{-1} UK intake for males and females, respectively. Additionally, EPA+DHA and selenium contents were both affected by farmed origin, reflecting differences in production strategies of the two salmon producing nations. Overall, the study highlights the contrasting nutritional profiles of farmed salmon fillets available to consumers based on retailer requirements (healthy versus sustainable product) and how this can affect the recommended dietary intakes from a human nutrition perspective.

Keywords: farmed Atlantic salmon; aquaculture, EPA+DHA, selenium; retailer, consumers

1. Introduction

Since the introduction of intensive aquaculture in the 1960’s, Atlantic salmon (*Salmo salar* L.) has grown to become a global commodity. Worldwide production of this high-value species now exceeds 2 million metric tonnes with Norway, Chile, Scotland and Canada the main producers among others (EY, 2018). Accordingly, the increased availability and thus, affordability, of farmed salmon has made it a popular choice among seafood consumers. In the EU, salmon is the most consumed farmed species as well as being the third most consumed fish species overall (EUMOFA, 2018). Global health authorities widely recommend consuming fish on a regular basis as part of a healthy diet due to their rich source of nutrients including protein, minerals and other micronutrients (EFSA, 2005; SACN/COT, 2004; WHO, 2003). Moreover, as an oily fish species, farmed salmon supplies a high level of omega-3 (n-3) long-chain polyunsaturated fatty acids (LC-PUFA), particularly eicosapentaenoic (EPA; 20:5n-3) and docosahexaenoic (DHA; 22:6n-3) acids, compared to many other fish species (Sprague et al., 2016, 2017a). These beneficial n-3 LC-PUFA, and to some extent docosapentaenoic acid (DPA; 22:5n-3), are widely acknowledged as being important for human health and development including neural function and in reducing chronic illnesses such as cardiovascular and inflammatory diseases among others (Calder, 2014; Kaur et al., 2011). However, the continual increase in the global population together with rising demand for seafood, including salmon, has resulted in changes to feed compositions that can negatively affect the final nutritional quality of farmed fish products.

Traditionally, farmed salmon feeds relied upon the inclusion of the finite marine raw materials, fish oil and fishmeal. However, as the aquaculture industry has grown the natural source of these ingredients, i.e. wild capture fisheries, has stagnated resulting in increased substitution by alternatives of terrestrial plant-based origin (Ytrestøyl et al., 2015). Although salmon growth remains largely unaffected due to the nutritional requirements of fish still being met, some of the nutrients delivered by farmed salmon that are important to human health have declined, especially EPA and DHA contents as well as some minerals and other micronutrients (Betancor et al., 2016; Sissener et al., 2013; Sprague et al., 2016), in addition to an associated decrease in some harmful elements such as heavy metals and organic pollutants (Nøstbakken et al., 2015). The UK salmon industry has, nevertheless, adapted to these challenges by creating a distinct market position for itself by supplying a differentiated product largely driven by retailers (Shepherd et al., 2017). Indeed, the UK grocery sector consists of several large retailers/supermarkets that cater for a diverse market ranging from budget/low-cost through to premium/high-end. In addition, some retailers also offer a variety of the same product in an attempt to market themselves towards specific consumer preferences or attitudes such as cost, nutrition, ethics and sustainability. One such product is organically-reared salmon where feed ingredients, and their inclusion levels, as well as rearing standards, may differ to conventionally-reared salmon (Lerfall et al., 2016). However, similar standards can also be applied to conventionally-reared salmon based on specific retailer requirements that could result in a product differing in terms of nutritional content from similar marketed products. As the largest consumers of fresh salmon in Europe, selling four times as much in terms of value and volume compared to salmon's nearest rival, Atlantic cod (*Gadhus morhua*) (EUMOFA, 2018; Seafish, 2018), UK retailers also import additional salmon products to meet consumer demand (Henriques et al., 2014; Seafish, 2018;). Consequently, from a consumer viewpoint the purchasing of fresh salmon products can be a potentially confusing experience due to the many different products and prices ranges available that may, or may not, indicate differences in nutritional quality.

While there has been extensive experimental research over the years on the replacement of marine ingredients with alternatives and their potential implications on flesh quality (Bell et al., 2001, 2004; Betancor et al., 2018; Kousoulaki et al., 2015; Sprague et al., 2015; Torstensen et al., 2004; Turchini et al., 2009, 2011), these studies are not necessarily reflective of current commercial practices. Moreover, the availability, quality and cost of raw ingredients are constantly altering and will ultimately dictate the type and levels of ingredients used in feeds by individual producers as well as determining the final flesh quality. As such, there is a lack of information on the 'actual' levels of nutrients in farmed salmon, which is important with regards to human health since nutritionists and public health bodies rely upon food databases being accurate when establishing and reviewing dietary guidelines to ensure adequate nutrient intakes (De Roos et al., 2017; Elmadfa and Meyer, 2010; Merchant and Dehghan, 2006). Therefore, the present study sought to analyse and compare the nutritional composition, in terms of lipid, protein, fatty acid (EPA+DHA) and mineral contents, of all available farmed salmon fillets (i.e. value, standard, premium and organic ranges) sold within the main UK retailers and assess their contribution in supplying essential nutrients to the human consumer.

2. Materials and Methods

2.1. Sample collection and preparation

Fresh pre-packaged 'own-brand labelled' farmed Atlantic salmon fillet portions were purchased from the refrigerated section of 10 main UK retailers, with exception of one product where the retailer specialised in frozen products only. In addition, a brand-labelled salmon product, available from more than one retailer, was also purchased for comparison. Samples consisted only of raw fillet portions. Value-added products such as breaded or sauce-added products were excluded due to the potential interference of additional ingredients on nutrient profiles. All product ranges (value, standard, premium and organic), as defined by the retail product label, available at the time of study were purchased for analysis (see Table 1). If a retailer stocked only one product range, which was not organic, then this was deemed as their standard product, irrespective of the status of the retailer themselves. Products that shared the same packaging, barcode identifier and nutritional labelling, but differed in farmed origin were treated as separate entities. Three samples per product range were purchased from UK-wide retailers within the Stirling and Clackmannan areas of Central Scotland. To minimise the potential of sampling salmon products from the same batch of fish, i.e. salmon farmed and harvested from the same cage/site, collection of replicate samples occurred over an eight-week period at four week intervals. Individual product packs were analysed as a single pooled sample, regardless of the number of portions contained in the pack (i.e. if a pack contained two portions, these were pooled to provide a single sample for analysis). Fillets were skinned and boned, where required, and homogenised on the day of purchase using a Robot-Coupe Blixer® 4 V.V. blender mixer (Robot-Coupe, Vincennes Cedex, France) before storing at -20^{o}C until analysed. All analyses were performed on a wet weight (ww) basis, and in duplicate minimum, with a relative standard deviation of <5% between technical replicates deemed acceptable.

2.2. Lipid content and fatty acid analysis

Total lipid was extracted from ~0.5 g of homogenised salmon flesh in 20 volumes of ice cold chloroform/methanol (2:1, v/v) according to Folch et al. (1957). Non-lipid impurities were isolated by washing with 0.88% (w/v) KCl and the lipid weight determined gravimetrically following evaporation of solvent under oxygen-free nitrogen and overnight desiccation *in vacuo*.

Fatty acid methyl esters (FAME) were prepared from total lipid extracts by acid-catalysed transmethylation at 50^{o}C for 16 h using 2 mL of a 1% (v/v) solution of sulphuric acid (95%, Aristar®, VWR Chemicals, Poole, UK) in methanol and 1 mL of toluene (Christie, 1993). FAME were extracted and purified according to Tocher and Harvie (1988), based on the American Oil Chemist’s Society (AOCS) methods for marine oils (Ce li-07 and Ce 1b-89; AOCS, 1992, 2007), and separated and quantified by gas-liquid chromatography (GC) using a

Fisons GC-8160 (Thermo Scientific, Milan, Italy) equipped with a 30 m × 0.32 mm i.d. × 0.25 µm ZB-wax column (Phenomenex, Cheshire, UK), 'on column' injection and flame ionisation detection. Hydrogen was used as carrier gas with the initial oven thermal gradient from 50°C to 150°C at 40°C.min^{-1} to a final temperature of 230°C at 2°C.min^{-1}. Individual FAME were identified by comparison to known standards (Restek 20-FAME Marine Oil Standard, Thames Restek UK Ltd., Buckinghamshire, UK) and published data (Tocher and Harvie, 1988). Data were collected and processed using Chromcard for Windows (Version 1.19; Thermoquest Italia S.p.A., Milan, Italy). Fatty acid content per g of tissue was calculated using heptadecanoic acid (17:0) as internal standard (IS), which was included with the sample at a known concentration in order for fatty acid (FA) concentration to be calculated as Conc. FA (mg.g lipid^{-1}) = Peak Area FA x (Conc. IS/Peak Area IS) with the lipid value used to express the result on a ww sample basis (mg.g sample^{-1}).

2.3. Crude protein analysis

Crude protein was determined by weighing out ~0.25 g of sample and adding 5 mL sulphuric acid (analytical reagent grade, Fisher Scientific, Loughborough, UK) together with 2 copper catalyst tablets (Fisher Scientific, Loughborough, UK), before digesting at 400°C for 1 h (Foss Digestor 2040; Foss Analytical AB, Högnäs, Sweden). Total nitrogen levels were measured by Kjeldahl (Foss Kjeltec™ 2300, Foss Analytical AB, Högnäs, Sweden) and the crude protein level calculated as N × 6.25.

2.4. Minerals and trace elements

Total minerals and trace elements (calcium, cobalt, copper, iron, manganese, magnesium, phosphorus, selenium, sodium, vanadium and zinc) were determined using inductively coupled plasma mass spectrometry (ICP-MS) with collision cell technology (Thermo X, Series 2;

Thermo Scientific, Hemel Hempstead, UK) as previously outlined by Betancor et al. (2015). Briefly, 20-30 mg of sample was added to Teflon tubes along with 5 mL of 69% nitric acid (Aristar® analytical grade; VWR Chemicals, Poole, UK) and digested in a microwave digester (MARS Xpress; CEM Microwave Technology Ltd., Buckingham, UK) in three stages consisting of 21-190°C for 10 min at 800 W, then 190°C for 20 min at 800 W followed by a final 30 min cooling period. The digested solution was transferred into 10 mL volumetric flasks and made up to volume with deionised water before 0.4 mL of this solution was transferred to 10 mL centrifuge tubes and made up to volume with deionised water before analysing by ICP-MS. For total selenium determination, 10 μL internal standard (Gallium and Scandium, 10 ppm; BDH Chemicals Ltd., Poole, UK) and 0.2 mL methanol, to ensure sensitivity, was added to 0.4 mL of initial digest solution before making up to 10 mL with deionised water prior to analysis by ICP-MS. The ICP-MS operated in kinetic energy discrimination (KED) mode using 100 % helium as collision gas to correct for any interference. Argon was used as plasma gas. A certified reference material (Fish Muscle ERM-BB42; Institute for Reference Materials and Measurements (IRMM), Geel, Belgium) was included with sample batches to monitor the integrity of the sample procedure.

2.5. Quality assurance

The method of performance of the analytical procedures described above were further assessed through the satisfactory annual performance of interlaboratory proficiency test including: the European Federation for the Science and Technology of Lipids, organised by the German Society for Fat Science (DGF, Frankfurt, Germany), for fatty acid content parameters; Masterlab Analytical Services BV (Boxmeer, Netherlands) for analytical methods routinely used in the feed, oil, fish producing and technology sectors; and AOCS (Illinois, USA) for the fatty acid content of marine oils attaining Approved Chemist status.

2.6. Statistical analyses

Statistical analyses were performed using Minitab® v17.1.0 statistical software package (Minitab Inc., Pennsylvania, USA). Data were analysed for normality with Kolmogorov-Smirnov test and for homogeneity of variances by Bartlett's test together with the examination of residual plots and, where necessary, transformed by arcsine or natural logarithm. Data were compared by a one-way analysis of variance (ANOVA) with multiple comparisons made using Tukey's post hoc test. A significance of $P<0.05$ was applied to all statistical tests performed. Significant differences between data in tables and figures are indicated by different superscript lettering. A principal component analysis (PCA) was used as the ordination method of farmed origin based on the parameters measured in the study in order to distinguish the farmed origin of the unknown sample product from Retailer 4. All data are presented as the mean and standard deviation (mean ± sd).

3. Results and Discussion

3.1. Lipid and protein contents

The lipid and protein contents of the various farmed salmon products are presented in Supplementary Table 1. Lipid levels were generally in the range 11.2-16.3% wet weight (ww), consistent with those reported elsewhere for commercially farmed salmon (Henriques et al., 2014; Jensen et al., 2012; Nichols et al., 2014; Sprague et al., 2016). Only the value-based product from Retailer 10 contained a significantly lower lipid level (6.9 ± 2.4%) than most other salmon fillets. This was related to the high proportion of tail pieces found in this particular product range. Lipid levels are known to vary throughout the flesh fillet, both anteriorly-posteriorly and dorsally-ventrally, with higher contents found around the dorsal fin region and the lowest levels at the tail end (Bell et al., 1998; Katikou et al., 2001). Furthermore, as dietary lipid is a major source of energy, high-energy (lipid) diets are fed to salmon to ensure optimal growth by sparing the more expensive dietary protein for conversion to muscle tissue. However, dietary lipid content also influences lipid deposition (Sargent et al., 2002) and, will therefore contribute to variation in flesh lipid contents. In contrast, protein content of flesh showed less variation between samples with levels ranging from 17.5-20.2% ww.

3.2. Fatty acid composition

The primary concern related to the replacement of marine fish oil in salmon feeds with vegetable oils of terrestrial origin is that these oils are devoid of EPA and DHA, and so their use has a significant impact on the nutritional value of farmed products. Flesh lipid fatty acid profiles, presented as proportions of total fatty acids, of the farmed salmon products surveyed in the present study exhibited a high degree of variation. In particular, oleic (18:1n-9), linoleic (18:2n-6) and α-linolenic (18:3n-3) acids, which are typically characteristic of vegetable oil inclusion (Sargent et al., 2002; Sprague et al., 2016), ranged from a low of 24.3, 8.3 and 2.6%, respectively, in the Retailer 8 Scottish premium product to a high of 42.0, 15.1 and 8.1%, respectively, in the Retailer 2 Norwegian standard product (Figure 1a-c). In contrast, the fatty acids characteristic of marine fish oil inclusion, EPA and DHA, were notably lower in those samples containing higher levels of 18:1n-9, 18:2n-6 and 18:3n-3 and vice versa (Figure 1d). Lipid in commercial aquafeeds is generally comprised of a blend of fish and vegetable oils to meet the nutritional requirements of the fish being farmed, as well as for economic and ecological factors that have arisen from the increased demand for seafood from a growing population. Since the fatty acid composition of fish flesh is primarily determined by diet (Sargent et al., 2002), the present study highlights the many different dietary oils, both source and inclusion level, currently used in feed formulations by the industry to deliver a differentiated supply of salmon products. This may affect consumer choice when purchasing salmon products as the nutrient profiling of foods, such as fat content and fatty acid profiles, can be influential in deciding whether specific nutritional claims (e.g. low in saturated fat, high in omega-3 etc.) can be included on product labels (Lobstein and Davies, 2009). Given the development of farmed animal feeds, particularly salmon, where the type and inclusion level of ingredients are constantly changing according to availability and price (Sissener et al., 2013; Sprague et al. 2016; Ytrestøyl, et al., 2015), the potential impact of the various feed formulations on the final product nutritional quality should be acknowledged and subsequently incorporated into food databases so that they remain up-to-date and minimise errors when assessing dietary human nutrient intake levels (Merchant and Dehghan, 2006).

While there were clear differences between product ranges (e.g. value, standard, premium and organic), the two premium (Retailers 1 and 8), two value (Retailers 8 and 10) and two organic (Brand and Retailer 10) products exhibited similar fatty acid profiles within their respective product ranges, suggesting comparable dietary oil sources and/or inclusions levels employed within the feeds for these ranges. However, a wider range of fatty acid compositions was revealed among the standard range of products. This variation is most likely a reflection of retailer status/values and/or the unique selling point of the product. The UK grocery sector is highly diverse, consisting of high-end premium retailers through to discount chains. In addition, many retailers market themselves on unique selling points relating to specific issues including nutritional quality, ethical and responsible sourcing, and sustainability (Shepherd et al., 2017). Accordingly, many of the standard salmon products would be expected to align with the ethos of the individual retailers. Thus, products sold in retailers promoting health benefits (i.e. omega-3) are expected to have higher levels of EPA+DHA due to increased dietary fish oil inclusion whereas retailers who market sustainable products would most likely have lower levels of these fatty acids due to increased plant oil inclusion (Henriques et al., 2014; Sprague et al., 2016). In the present study, retailers were not ranked on their perceived status owing to the potential ambiguity arising from personal subjectivity. Notwithstanding, the wide variation of fatty acid profiles among retailers observed in the present study was also noted previously (Henriques et al., 2014).

Three of the ten retailers surveyed in the present study, together with the Brand, sold salmon products that encompassed more than one range: Retailer 1, standard and premium; Retailer 8, value, standard and premium; Retailer 10, value standard and organic; Brand, standard and organic. Both the premium products from Retailers 1 and 8 contained a greater EPA+DHA content as a percentage of total lipid, than their standard products (~14 vs. 10%, respectively), although not significant. Similarly, the Brand organic product contained a higher EPA+DHA level than its standard fillet range (10 vs 7%, respectively), whereas levels were similar for the organic and standard products from Retailer 10, around 9.5% of total lipid. Lerfall et al. (2016) found that organically farmed Norwegian salmon contained a higher proportion of EPA+DHA in the flesh than their conventionally-reared counterparts. Conversely, Di Marco et al. (2017) found a higher level of n-3 LC-PUFA in conventionally farmed seabass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) as compared to organic. Organically-reared fish can regularly command higher prices than conventionally farmed salmon (Ankamah-Yeboah et al., 2016; Olesen et al., 2010). However, this isn’t necessarily a reflection of the higher level of high-priced fish oil included in diets, but rather a quality assurance measure ascribed from certified organisations such as the EU’s organic aquaculture standards (Regulation 710/2009) (EU, 2009), relating to a specific specification and/or conditions that differentiate it from comparable products. Similarly, particular specifications are applied to other quality products including *Label Rouge* salmon, where a maximum of 16% lipid is permitted in the flesh and fish must be fed on diets composed exclusively of marine products, vegetable ingredients, vitamin, minerals and carotenoids together with product traceability, maximum stocking densities and other codes of good practice (Label Rouge, 2013). In the UK, it is the retailers which primarily determine the nutritional quality of the farmed salmon, particularly with respect to EPA+DHA contents and thus dietary fish oil inclusion levels (Shepherd et al., 2017). As feed generally represents half of the total production costs, the types and levels of dietary ingredients will typically determine the final cost in supplying the product.

Contrary to what might be expected, the value product from Retailer 10 contained a higher proportion of EPA+DHA (12.0 ± 4.3%) than both the standard and organic products (9.5 ± 3.0% and 9.6 ± 0.8%, respectively), albeit not statistically significant. This could suggest that the value product fish were fed a diet higher in EPA+DHA levels than the organic and standard fish. However, as mentioned above, the value product from retailer 10 contained a high proportion of tail pieces that had a lower lipid content. As such, the tail portions would be expected to contain a lower level of the main storage lipid, triacylglycerol, and a higher level of structural phospholipids than fattier portions. Although fatty acid compositions of both triacylglycerols and phospholipids are affected by dietary oil composition (Ruiz-Lopez et al., 2015), phospholipids generally contain a higher level of EPA and, especially, DHA as these play a crucial role in the structure of membranes (Sargent et al.,2002). Consequently, tail portions will generally have higher relative proportions of EPA and DHA than portions from fattier parts of the fillet. Therefore, while fatty acid profiles can provide an insight into the different feed formulations (dietary oil sources and levels) used, in addition to influencing whether specific health claims can be attached to food products (Lobstein and Davies, 2009), it is important to take into consideration both the lipid content and fatty acid composition when determining the absolute content of fatty acids (i.e. g.100 g flesh^{-1}) available to the human consumer.

3.3. EPA+DHA content and farmed origin

Overall, the average content of EPA+DHA of farmed Atlantic salmon products available on UK retailers' shelves was 1.1 ± 0.4 g.100 g^{-1} flesh ww. However, when separated, based on farmed origin, Scottish salmon were found to contain a significantly ($P<0.05$) higher amount of EPA+DHA (1.3 ± 0.4 g.100 g^{-1} ww) than their Norwegian counterparts (0.8 ± 0.1 g.100 g^{-1} ww) (Figure 2). This compares to 1.36 and 1.15 g EPA+DHA per 100 g^{-1} ww salmon flesh reported in 2015 for Scottish (Sprague et al., 2016) and Norwegian farmed salmon (NIFES, 2016), respectively. This disparity can be explained largely by differences in production strategies. For example, the Norwegian salmon industry is the global powerhouse of farmed salmon production supplying around 1.2 million tonnes in 2016 compared to just 163,000 tonnes in Scotland (EY, 2018; Scottish Government, 2018). Consequently, the Norwegian industry is more reliant upon the use of sustainable feeds as the amount of fish oil used in aquaculture, approximately 800,000 metric tonnes per annum (Shepherd and Bachis, 2014), is spread thinner throughout the growing sector. Indeed, levels of fish oil in Norwegian salmon feeds fell from 24 to 11% between 1990 and 2013 (Ytrestøyl et al., 2015). Although Scottish salmon farmers face the same challenges as their Norwegian colleagues, as evidenced by the decline in EPA+DHA levels in Scottish salmon farmed between 2006 and 2015 (Sprague et al., 2016), the smaller volume of salmon produced in Scotland has enabled the establishment of a niche market for the product. Therefore, inclusion of slightly higher levels of marine ingredients in feeds has resulted in a "quality" product aimed at a premium market (Shepherd et al., 2017). This is clearly illustrated by the data in Figure 1 in which Norwegian farmed salmon are generally clustered together and display higher levels of 18:1n-9, 18:2n-6 and 18:3n-3 as well as lower EPA+DHA levels, indicating a higher inclusion of vegetable oil use, than their Scottish equivalents. Even so, farmed Scottish salmon also presented a wide range of fatty acid profiles that gave varying EPA+DHA levels, providing further evidence that the Scottish sector delivers highly differentiated salmon products based on individual retailer requirements. The importance of obtaining information with respect to the origin of food, and the substances found in food products, has previously been emphasised by many authors as this can greatly affect the usefulness of data from food composition tables when assessing nutrient intake levels (Elmadfa and Meyer, 2010; Merchant and Dehghan, 2006). However, while Norwegian feed formulations are made public (Ytrestøyl et al., 2015), Scottish data remain private either due to the vast amount of bespoke diets produced or more probably due to retailer confidentiality (Shepherd et al., 2017).

3.4. EPA+DHA content and the human consumer

As an oily fish, farmed salmon contributes greatly to the dietary intake of the beneficial EPA+DHA fatty acids by human consumers (Sprague et al., 2016, 2017a). Global health authorities generally recommend consuming at least one portion of oily fish per week as part of a healthy diet (EFSA 2005; SACN/COT, 2004; WHO 2003). Figure 3 shows the amounts of EPA+DHA in the various salmon fillets analysed in the present study based on a portion size of 130 g, as advised by the European Food Safety Authority (EFSA, 2005). Like fatty acid composition, EPA+DHA contents presented a high degree of variation ranging from 2.36 ± 0.85 to 0.88 ± 0.23 g.130 g flesh^{-1} ww in the Retailer 1 premium product and the Retailer 10 value product, respectively. It is important that such variations are acknowledged, particularly by those compiling and using data from food composition tables, as they can affect the ability to provide an accurate basis for assessing dietary nutrient intake and influence whether policy makers need to revise dietary guidelines such as fish consumption (De Roos et al., 2017; Elmadfa and Meyer, 2010).

Significant differences were observed between the Retailer 1 premium product and all Norwegian farmed salmon products together with the standard and value products from Retailer 4 and 10, respectively. Similarly, the Retailer 6 standard product also contained a significantly higher content of EPA+DHA than all Norwegian farmed products, except the Brand product, as well as the standard and value products from Retailers 4 and 10, respectively. Lipid content and fatty acid profiles (reflecting oil sources) of salmon flesh ultimately determine the absolute amounts of EPA and DHA delivered to the human consumer. For example, feeds formulated with an EPA+DHA content of either 5 or 7.5% of lipid would be expected to deliver 0.96 and 1.32 g EPA+DHA.100 g flesh^{-1} ww, respectively, based on a fillet lipid level of 17.5% (Ewos, 2013). Comparing the EPA+DHA contents in the Retailer 9 Norwegian standard product and the Retailer 10 value product (0.8 ± 0.1 and 0.7 ± 0.2 g EPA+DHA.100 g^{-1}, respectively) suggests that fish were fed similar diets. However, the lipid content of the former was twice that of the latter product (15.1 ± 1.2% compared to 6.9 ± 2.4%, respectively). Had they been fed identical formulated diets, the Retailer 9 Norwegian standard product would have given a higher EPA+DHA content. Examination of the fatty acid profiles reveal that EPA+DHA levels, as a proportion of the lipid, were 6.1 and 12.0% (Norwegian standard Retailer 9 and value Retailer 10, respectively), indicating that the value product from Retailer 10 was fed a diet containing a higher level of fish oil, and therefore more EPA+DHA than the Norwegian product from Retailer 9. Thus, the low EPA+DHA content in the value product from Retailer 10 can be explained by the low lipid content due to the high presence of tail pieces. While a similar caveat can be applied to all the samples surveyed in the study, in that it can often be difficult for a purchaser to distinguish where precisely on the fillet a portion is derived with the exception of tail pieces, no other apparent unconformities were noted. As previously highlighted, other than the tail portions from Retailer 10's value product, lipid contents were typically within range for farmed salmon (Henriques et al., 2104; Jensen et al., 2012; Nichols et al., 2014; Sprague et al., 2016). As flesh fatty acid profiles reflect that of the dietary oil (Sargent et al., 2002), diet composition can be considered the main determinant of the EPA+DHA content variation reported in the present study.

Considering salmon products of different ranges available from the same retailer, premium products from Retailer 1 and 8 contained a higher, albeit not significant, amount of EPA+DHA (2.36 ± 0.85 and 1.88 ± 0.28 g EPA+DHA.130 g flesh^{-1} ww, respectively) than their respective non-premium products (1.39 ± 0.11 g.130 g flesh^{-1} ww Retailer 1 standard range, and 1.65 ± 0.23 an 1.59 ± 0.40 g.130 g flesh^{-1} ww for Retailer 8 value and standard ranges, respectively) suggesting differences in feed formulations, and hence fish oil inclusion level, between premium and other 'lower-value' product ranges. In contrast, Retailer 10's standard product had higher EPA+DHA (1.46 ± 0.75 g.130 flesh^{-1} ww) than both organic and value ranges (1.34 ± 0.21 and 0.88 ± 0.23 g.130 flesh^{-1} ww, respectively) whereas, the Brand organic and standard products contained more similar EPA+DHA contents of 1.28 ± 0.19 and 1.19 ± 0.18 g.130 g flesh^{-1} ww, respectively. Interestingly, when EPA+DHA contents were expressed in terms of the amount delivered versus product cost, both the organic products (Retailer 10 and Branded) yielded the lowest amount of EPA+DHA (g) per GBP (£) spent (0.39 ± 0.06 and 0.45 ± 0.07 g EPA+DHA.£$^{-1}$, respectively) (Figure 4). While organically-reared fish can be considered a premium product, the price does not necessarily reflect the inclusion level of fish oil used in the feeds, but takes into account provenance and rearing conditions among other criteria. Consumers are willing to pay up to 15% more for ethically-labelled products such as organic or Freedom Food, a strict animal welfare assurance scheme, than salmon that have been conventionally-reared (Olesen et al., 2010). Certainly, in retailers where more than one product range was available, an increase in the cost per kg was seen as the product range increased, e.g. £11.00, £13.75 and £20.03 per kg for Retailer 8 value, standard and premium ranges, respectively (Table 1). This could indicate that the higher price for premium products reflects enhanced or stricter farming condition. For instance, the value product from Retailer 8 generally gave a higher, although not significant, amount of EPA+DHA per £ (1.15 ± 0.16 g.EPA+DHA.£$^{-1}$) than the standard and premium ranges (0.89 ± 0.22 and 0.69 ± 0.10

g.EPA+DHA.£$^{-1}$, respectively). In contrast, Retailer 1 premium product gave more value (EPA+DHA) for money (1.25 ± 0.45 g.EPA+DHA.£$^{-1}$) than the standard product (1.07 ± 0.09 g.EPA+DHA.£$^{-1}$), suggesting that this retailer included higher priced ingredients (i.e. fish oil) to supply a product with improved health benefits (i.e. EPA+DHA). This is supported by the fact that the premium product from this retailer contained more EPA+DHA per serving than the standard range (see above and Figure 3). For Retailer 10 however, all products gave a similar result (0.39-0.45 g.EPA+DHA.£$^{-1}$) together with being the lowest overall providers of EPA+DHA per £ spent. In order to distinguish themselves from their counterparts, retailers will try to establish a unique selling point by creating a diverse range of salmon products based on certain attributes such as health-benefits, sustainability and/or price (Shepherd et al., 2017). Thus, it is plausible that the ethical principles that Retailer 10 uphold, e.g. lower stocking densities and other welfare/rearing conditions and the use of high-quality ingredients in feeds, either alone or in combination contributed to the higher price of the products.

The reduced use of marine ingredients in aquafeeds and consequent effects on EPA+DHA levels in farmed fish (Sprague et al., 2016; Ytrestøyl et al., 2015), has resulted in questions over whether current dietary guidelines regarding fish intake are sufficient to benefit human health (De Roos et al., 2017). Although at present there is no global consensus on a recommended level for EPA and DHA intake for humans, several advisory bodies have put forward their own recommendations for intakes to promote human health. On average, none of the products sampled in the present study would satisfy the commonly accepted 3.5 g EPA+DHA weekly intake (500 mg.day^{-1}) suggested by the International Society for the Study of Fatty Acids and Lipids (ISSFAL) to support optimal cardiac health in adults and endorsed by the Global Organization for EPA and DHA Omega-3's (GOED, 2019). This is not surprising as Sprague et al. (2016) reported that, on average two servings of farmed salmon in 2015 would be required to supply 3.5 g EPA+DHA owing to the changes in fish oil inclusion in salmon feeds. However, five of the products analysed in the present study would, nevertheless, fulfil the lower recommendation of 1.75 g EPA+DHA per week (250 mg.day^{-1}) advocated by EFSA (2005). Obviously, two portions of these products would therefore satisfy the higher intake levels recommended by ISSFAL and GOED. Notwithstanding, the wide variation in EPA+DHA contents of the farmed salmon fillets sampled in the present study, providing 26 to 67% of the 3.5 g weekly EPA+DHA recommendation, should alert nutritionists to the fact that EPA+DHA levels in farmed salmon can vary so markedly, based on different production strategies, subsequently affecting the amount consumed in order to meet the recommended nutrient requirement.

Irrespective of the disparities in dietary recommendations, farmed salmon has been shown to deliver more EPA+DHA to the consumer than most other seafood products (Sprague et al., 2016; 2017a). Furthermore, both Henriques et al. (2014) and Sprague et al. (2016, 2017a) showed that farmed salmon contained higher EPA+DHA contents than wild Pacific salmon (*Oncorhynchus* sp.), also available in retailers, whereas the EPA+DHA content of wild Atlantic salmon has been reported to vary between 0.8 g (Jensen et al., 2012) to around 1.6 g EPA+DHA.100 g flesh^{-1} ww (Lundebye et al., 2017). While no minimum EPA+DHA level has been officially adopted for salmon feeds, a level of around 1 % of the feed (equivalent to 3 % of dietary oil fraction) has been reported to maintain growth in salmon (Rosenlund et al., 2016; Bou et al., 2017), although fish performance has been shown to be compromised under challenging conditions (Bou et al., 2017). At these low inclusion levels, and taking into account endogenous production, just 0.63 g EPA+DHA.100 g flesh^{-1} ww would be expected (Rosenlund et al., 2016). Novel sources of n-3 LC-PUFA have been trialled in farmed salmon in a bid to halt and reverse the further decline of these beneficial fatty acids, including microalgae (Kousoulaki et al., 2015; Sprague et al., 2015) and transgenic oilseed crops (Betancor et al., 2016b, 2018), with some already being used or nearing commercialisation

(Sprague et al., 2017b; Tocher et al., 2019). However, both availability and price associated with costs in producing these sources will inevitably determine the extent to which they are used. Nevertheless, the nutritional value of farmed salmon products is not served by EPA+DHA alone but also includes other important micronutrients such as minerals and trace elements, especially selenium (Lund, 2013; Tocher, 2015).

3.5. Minerals and trace elements

Fish consumption provides a rich source of minerals and trace elements such as calcium, phosphorous, zinc and selenium to the human consumer. The mineral contents of samples were relatively conserved between the various salmon products, although some significant differences in macro minerals (calcium and sodium) and all trace elements (copper, iron, manganese, selenium, vanadium and zinc) measured were observed (Table 2). Essential minerals are generally supplemented in feeds, particularly given the low cost of inorganic minerals used in premixes, whereas others such as calcium may also be absorbed from seawater (Lall and Dumas, 2015). However, while the nutritional requirements of the farmed fish can be met (NRC, 2011), the levels of some important nutrients from a human consumer viewpoint have fallen due to ingredient changes in farmed fish feeds (Sissener et al., 2013). Indeed, selenium (Se) content was found to vary markedly between the different salmon products, ranging from 0.08 ± 0.03 to 0.32 ± 0.01 mg Se.kg flesh^{-1} ww for the Retailer 8 standard and Brand organic products, respectively. Selenium is a trace element essential for human health, being an important component of the antioxidant enzyme glutathione peroxidase, as well as playing a key role in immune function and thyroid metabolism (BNF, 2001). Current UK recommended daily intakes (RDI) are set at 75 and 60 μg.day^{-1} for males and females, respectively (PHE, 2016). Thus, one 130 g portion of the Brand organic salmon would provide 41.6 μg Se, equivalent to 55.5 and 69.3% of the RDI for males and females, respectively.

Conversely, a 130 g portion of Retailer 4's standard product would give 10.4 μg equating to just 13.9 and 17.3% of the RDI for males and females, respectively. These differences can frequently be overlooked by nutritionists, who often assume farmed salmon to be of equal nutritional value. However, basic understanding of why such differences can occur are crucial to establishing and accurately estimating nutrient intakes.

Fishmeals contain higher levels of available Se than plant-based meals such as soybean or corn gluten (Betancor et al., 2016a; Gabrielsen and Opstvedt, 1980). The levels in plant products are determined by the concentrations and availability of Se in the soil where they are grown. Consequently, Se concentrations vary from country to country and are generally low in the UK and Europe compared to the Se-rich soils in North America (Fordyce, 2005). Therefore, the levels of Se in salmon flesh are dependent upon both the ingredient type and, for plant-based material, where it was grown. Being aware that identical foodstuffs from different origins can differ in their nutrient content is critical when establishing food databases as it can minimise the errors associated with the estimation of human dietary intakes (Elmadfa and Meyer, 2010; Merchant and Dehghan, 2006). There was, however, a significant difference in Se content based on farmed origin with Scottish salmon containing a higher content on average than their Norwegian counterparts (0.17 ± 0.06 versus 0.11 ± 0.03 mg Se.kg^{-1} ww, respectively). These differences are most likely related to the lower use of fishmeal in Norwegian salmon feeds (Ytrestøyl et al., 2015). The replacement of marine ingredients has been linked to the decline in Se and other nutrients such as iodine and vitamin D in Norwegian salmon feeds between 2000 and 2010 (Sissener et al., 2013). Furthermore, Betancor et al. (2016a) demonstrated that, by increasing the substitution of marine ingredients by terrestrial plant-products in salmon feeds, the amount of Se in the flesh available to consumers was reduced.

Highest Se contents were found in the two organic products (0.32 ± 0.01 and 0.23 ± 0.07 mg $Se.kg^{-1}$ ww Brand and Retailer 10, respectively), indicating either higher inclusion of fishmeal or the use of high-quality plant ingredients grown in Se-rich soils such as North American wheat. However, the standard product from Retailer 10 also contained a similar Se content (0.26 ± 0.06 $mg.kg^{-1}$ ww), whereas all other products, including other Scottish farmed salmon, contained less than 0.16 mg $Se.kg^{-1}$ ww. Nevertheless, the range of Se concentrations among Scottish farmed salmon (0.13-0.32 $mg.Se.kg^{-1}$ ww) further reflects the wide range of feed formulations used by the Scottish salmon sector to supply a diverse selection of products (Shepherd et al., 2017).

3.6. Identifying unknown origin and labelling issues

The provenance and traceability of farmed animal products are of increasing importance to producers, retailers and consumers alike. In the present study, the precise origin of the salmon product from Retailer 4 was unknown, being labelled as either “farmed in Scotland or Norway”. The fatty acid composition of this product could suggest that fish were of Norwegian origin as the profile was similar to other Norwegian farmed salmon products (e.g. Retailers 2, 7, 9 and Brand), containing higher 18:1n-9, 18:2n-6 and 18:3n-3 and lower EPA and DHA levels (see Figure 1). However, fatty acid profiles from Retailer 1 and 5 Scottish standard products also exhibited similar profiles to Norwegian fed fish. When PCA was applied, based on farmed origin and all measured parameters (i.e. lipid and protein contents, and fatty acid and mineral compositions), the output for Retailer 4 appeared to align more with salmon of Norwegian farmed origin which were generally tightly clustered, compared to Scottish farmed salmon which were more widely scattered (Figure 5). This further reflects the diverse range of products produced for the UK retail market produced by the smaller Scottish industry ((Shepherd et al., 2017, see Section 3.3). In the present study, individual fillets originating from the same packet were pooled but Henriques et al. (2014) observed marked differences in fatty acid compositions of salmon portions sold within the same packaging, implying that some retail suppliers may utilise fish from various farmed sources to fulfil supply demands.

The differential in feed composition, both within and between salmon producers, can pose problems from a retailers' perspective, particularly with respect to nutritional labelling. This is best illustrated in Figure 6 that compares products that had identical nutritional contents stated on the product label but were of different farmed origins. No significant difference (P>0.05) was observed between Scottish and Norwegian salmon from Retailer 9 (1.04 ± 027.and 0.81 ± 0.07 g EPA+DHA.100 g flesh^{-1} ww, Scotland and Norway, respectively), suggesting that these fish were fed similar formulated feeds. Contrastingly, a significant difference (P<0.05) was observed between the two identically labelled products from Retailer 2 (1.40 ± 0.09 and 0.75 ± 0.15 g EPA+DHA.100g flesh^{-1} ww, Scotland and Norway, respectively), which mirrored the respective average EPA+DHA contents of the two salmon producing nations (see Figure 2). Obviously, this difference in EPA+DHA content between these identically labelled products also resulted in a significant difference in the cost of the EPA+DHA (g delivered per £) (Figure 4). Furthermore, Retailer 2 also sold an additional Norwegian salmon product, containing 3 fillet portions compared to the standard 2 fillet portion packs, which had a different nutritional label attached (see Table 1). The analysed EPA+DHA content of this product (0.80 ± 0.27 g EPA+DHA.100 g flesh^{-1} ww) matched the labelled content of 0.8 g EPA+DHA.100 g flesh $^{-1}$ ww and was comparable to the other (2 fillet) Norwegian product from Retailer 2, indicating that the fish used for these products were likely fed similar diets. Labelling is frequently used to educate consumers and assist them in making healthier choices (Elmadfa and Meyer, 2010). Nevertheless, it is important to appreciate that several factors can affect the nutritional content of salmon flesh throughout the production cycle. In addition to feed composition (i.e. lipid source and level) and where portions are taken on the fillet (Bell et al., 1998; Katikou et al., 2001), fish body size can affect lipid status (Shearer, 1994), although final harvest weights of UK sold salmon generally tend to be within 3-5 kg range. Therefore, changes to production schedules such as early harvest of fish (with lower weight) will also affect the nutritional value of the products to the consumer. Salmon producers routinely monitor several nutritional parameters and, if necessary, alter feed programmes to attain targeted levels. However, the present study represents a true reflection of the nutritional content of salmon portions, encompassing all areas of the fillet.

4. Conclusions

In summary, the results from the current study demonstrate that marked variations occur in the nutritional content of farmed salmon fillets available in the UK, particularly with respect to fatty acid profiles, EPA+DHA and selenium contents. Consequently, these disparities have a knock-on effect on the actual amounts delivered to consumers and will therefore affect an individual’s ability to meet their recommended nutrient intakes. No clear indicators were seen between product ranges (value, standard, premium or organic) or retailers, being most likely due to the combination of the unique selling point of the product range or the retailer themselves (e.g. healthy versus sustainable product). However, EPA+DHA and selenium were affected by farmed origin reflecting differences in production strategies between the two salmon farming nations. Nevertheless, farmed salmon still delivers a high, but variable amount of beneficial nutrients (i.e. n-3 LC-PUFA, selenium) to consumers. Therefore, deviations in the nutritional contents of farmed animal products, as evidenced in the present study with farmed salmon, necessitate further monitoring in order to ensure that nutritional databases remain updated.

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Conflicts of Interest

The authors declare no conflict of interest.

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Figure Legends

Figure 1. Fatty acid compositions (% of total lipid, mean ± SD) of the various salmon products surveyed with respect to a) 18:1n-9, b) 18:2n-6, c) 18:3n-3 and d) EPA+DHA. Samples are of Scottish farmed origin unless otherwise stated. Bars bearing different lettering are significantly different (ANOVA, $P<0.05$) ($n = 3$). *Note, Retailer 2 sold two farmed Norwegian salmon products with different nutritional labelling, differing in the number of fillets per pack, 2 or 3 (Standard and Standard L, respectively).

Figure 2. Content of total EPA+DHA (g.100g flesh^{-1} ww) in farmed salmon products available in the UK and separated based on farmed origin, Scotland and Norway respectively. Mean (···), median (—), interquartile range (box) and 10th and 90th percentiles (whiskers). Boxplots bearing different lettering are significantly different (ANOVA, $P<0.05$). Fish from Retailer 4 was included in overall value but excluded elsewhere due to unknown origin ($n = 60$, 42 and 15, Overall, Scotland and Norway respectively).

Figure 3. Absolute amounts of EPA+DHA in 130 g servings (mean ± SD) of the various farmed salmon products surveyed in the present study. Samples are of Scottish farmed origin unless otherwise stated. Bars bearing different lettering are significantly different (ANOVA, $P<0.05$) ($n = 3$). *Note, Retailer 2 sold two farmed Norwegian salmon products with different nutritional labelling, differing in the number of fillets per pack, 2 or 3 (Standard and Standard L, respectively).

Figure 4. Amount of EPA+DHA (g) per GBP (£) spent of farmed Atlantic salmon products surveyed in the present study. Samples are of Scottish farmed origin unless otherwise stated. Bars bearing different lettering are significantly different (ANOVA, $P<0.05$) ($n = 3$). *Note, Retailer 2 sold two farmed Norwegian salmon products with different nutritional labelling, differing in the number of fillets per pack, 2 or 3 (Standard and Standard L, respectively).

Figure 5. Principal component analysis of the farmed salmon products surveyed in the present study based on farmed origin and measured nutrient variables (lipid and protein content and fatty acid and mineral composition) in farmed Atlantic salmon products of Scottish (●), Norwegian (▲) and unknown (×) farmed origin.

Figure 6. Comparison of the EPA+DHA contents (g.100g flesh^{-1} ww) of salmon products from distinct farmed origins but containing the same nutritional labelling. *Note, Retailer 2 sold two farmed Norwegian salmon products with different nutritional labelling, differing in the number of fillets per pack, 2 or 3 (Standard and Standard L, respectively). Bars from products within the same retailer bearing different lettering are significantly different (ANOVA, $P<0.05$) ($n = 3$).

Table 1. List of the salmon products sampled in the current study with respect to product range (value, standard, premium/organic), farmed origin (Scotland and Norway), price (£ per kg) and nutritional content as stated on product label. Retailers which stocked only one range was deemed as their standard product, irrespective of retailer status.

Retailer	Product Range[a]	Farmed Origin	Pack size (g)[b]	Price (£ per kg)[c]	Nutritional Content (per 100 g)[d]			
					Protein	Fat	Omega-3	EPA+DHA
1	Standard	Scotland	240	9.96	20.0	11.0	-	-
	Premium	Scotland	280	14.54	20.0	11.0	1.4	-
2	Standard	Scotland	240	11.04	23.0	17.0	-	2.7
	Standard	Norway	240	11.04	23.0	17.0	-	2.7
	Standard L[d]	Norway	340*	11.03	23.0	15.0	-	0.8
3	Standard	Scotland	220	18.18	19.0	14.0	3.1	-
4	Standard	Unknown[e]	520*	11.54	24.2	13.1	-	-
5	Standard	Scotland	240	9.96	22.0	19.0	3.6	-
6	Standard	Scotland	230	19.57	20.3	13.4	3.4	2.6
7	Standard	Norway	240	16.67	19.2	15.7	-	-
8	Value	Scotland	343	11.00	23.5	14.9	1.4	0.7
	Standard	Scotland	240	13.75	23.5	14.9	1.9	1.0
	Premium	Scotland	240	20.83	23.6	14.1	2.3	1.2
9	Standard	Scotland	270	11.11	23.6	14.2	2.4	-
	Standard	Norway	270	11.11	23.6	14.2	2.4	-
10	Value	Scotland	600*	15.53	19.1	15.6	1.9	-
	Standard	Scotland	280	24.96	19.1	15.6	1.9	-
	Organic	Scotland	265	26.38	18.8	13.6	1.5	-
Branded	Standard	Norway	240	16.67	23.0	14.7	-	0.8
	Organic	Scotland	252	22.00	23.5	13.9	-	1.8

[a] Product range defined by retail product label; retailers selling only one product range, which was not organic, considered as standard product.

[b] Pack size based on product label and contained two fillet portions, with exception to products marked * which contained a minimum of 3 fillet portions per pack.

[c] Price correct at time of purchase and excludes any promotional offers

[d] According to product label. Values stated based on cooked (grilled, pan-fried, oven cooked) or uncooked conditions.

[e] Retailer 2 contained 2 Norwegian standard products with different nutritional labelling and number of fillets per pack – defined as standard and standard L.

[f] Exact origin unknown, labelled as farmed in Scotland/Norway

Table 2. Mineral compositions of farmed Atlantic salmon products surveyed in the present study. Results are presented on a wet weight (ww) basis.

	Retailer 1		**Retailer 2**			**Retailer 3**	**Retailer 4**	**Retailer 5**	**Retailer 6**	**Retailer 7**
	Standard	Premium	Standard	Standard	Standard L*	Standard	Standard	Standard	Standard	Standard
	Scotland	Scotland	Scotland	Norway	Norway	Scotland	Unknown¶	Scotland	Scotland	Norway
Macro minerals g.kg^{-1} ww										
Sodium	0.31 ± 0.08^{d}	0.36 ± 0.08^{cd}	0.35 ± 0.07^{cd}	0.36 ± 0.02^{cd}	0.32 ± 0.03^{d}	0.33 ± 0.03^{d}	0.35 ± 0.04^{cd}	0.30 ± 0.04^{d}	0.27 ± 0.02^{d}	0.40 ± 0.12^{cd}
Potassium	3.34 ± 0.02	3.34 ± 0.14	3.54 ± 0.17	3.24 ± 0.38	3.58 ± 0.27	3.62 ± 0.27	3.18 ± 0.04	3.18 ± 0.20	3.35 ± 0.17	3.31 ± 0.17
Calcium	$0.22 \pm 0.05^{a-e}$	$0.24 \pm 0.03^{a-d}$	$0.25 \pm 0.07^{a-c}$	0.29 ± 0.04^{a}	$0.27 \pm 0.01^{a-c}$	0.29 ± 0.02^{ab}	$0.19 \pm 0.05^{b-f}$	$0.25 \pm 0.03^{a-c}$	$0.18 \pm 0.04^{c-f}$	$0.14 \pm 0.03^{e-h}$
Magnesium	0.24 ± 0.02	0.22 ± 0.00	0.24 ± 0.02	0.22 ± 0.01	0.23 ± 0.01	0.24 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.22 ± 0.00	0.23 ± 0.02
Phosphorus	2.10 ± 0.05	2.05 ± 0.05	2.14 ± 0.11	1.97 ± 0.19	2.13 ± 0.10	2.18 ± 0.15	1.96 ± 0.05	1.97 ± 0.10	2.08 ± 0.07	2.03 ± 0.15
Trace elements mg.kg^{-1} ww										
Iron	$4.13 \pm 1.23^{a-c}$	$3.69 \pm 0.77^{a-c}$	$2.88 \pm 0.60^{a-c}$	$3.44 \pm 0.83^{a-c}$	4.65 ± 1.03^{a}	$4.01 \pm 0.75^{a-c}$	$2.21 \pm 0.56^{a-c}$	2.01 ± 0.35^{bc}	$2.64 \pm 0.43^{a-c}$	$2.71 \pm 0.19^{a-c}$
Manganese	$0.13 \pm 0.03^{a-d}$	$0.13 \pm 0.01^{a-d}$	0.14 ± 0.00^{ab}	$0.14 \pm 0.00^{a-c}$	$0.14 \pm 0.00^{a-c}$	0.15 ± 0.00^{a}	$0.10 \pm 0.02^{b-f}$	$0.11 \pm 0.01^{a-e}$	$0.10 \pm 0.02^{b-f}$	$0.09 \pm 0.00^{d-f}$
Copper	0.85 ± 0.24^{a}	0.69 ± 0.13^{ab}	0.55 ± 0.03^{ab}	0.64 ± 0.05^{ab}	0.76 ± 0.09^{a}	0.45 ± 0.14^{ab}	0.29 ± 0.05^{b}	0.30 ± 0.06^{b}	0.31 ± 0.07^{b}	0.45 ± 0.32^{ab}
Zinc	6.32 ± 0.76^{ab}	$6.14 \pm 0.55^{a-d}$	6.41 ± 0.80^{ab}	$6.23 \pm 0.52^{a-c}$	$6.02 \pm 0.29^{a-e}$	6.54 ± 0.57^{a}	$5.06 \pm 0.69^{a-f}$	$5.23 \pm 0.78^{a-f}$	$4.98 \pm 0.70^{a-f}$	$4.48 \pm 0.68^{d-f}$
Vanadium	$0.01 \pm 0.00^{b-e}$	0.01 ± 0.00^{de}	$0.01 \pm 0.00^{b-e}$	0.02 ± 0.00^{a}	$0.01 \pm 0.01^{b-e}$	$0.01 \pm 0.00^{c-e}$	0.02 ± 0.01^{ab}	$0.01 \pm 0.00^{b-e}$	0.00 ± 0.00^{de}	$0.01 \pm 0.00^{b-e}$
Selenium	0.17 ± 0.01^{cd}	0.12 ± 0.01^{de}	0.13 ± 0.01^{de}	0.09 ± 0.01^{e}	0.12 ± 0.00^{de}	0.14 ± 0.01^{de}	0.08 ± 0.01^{e}	0.13 ± 0.03^{de}	0.13 ± 0.02^{de}	0.10 ± 0.04^{de}

Table 2 cont.

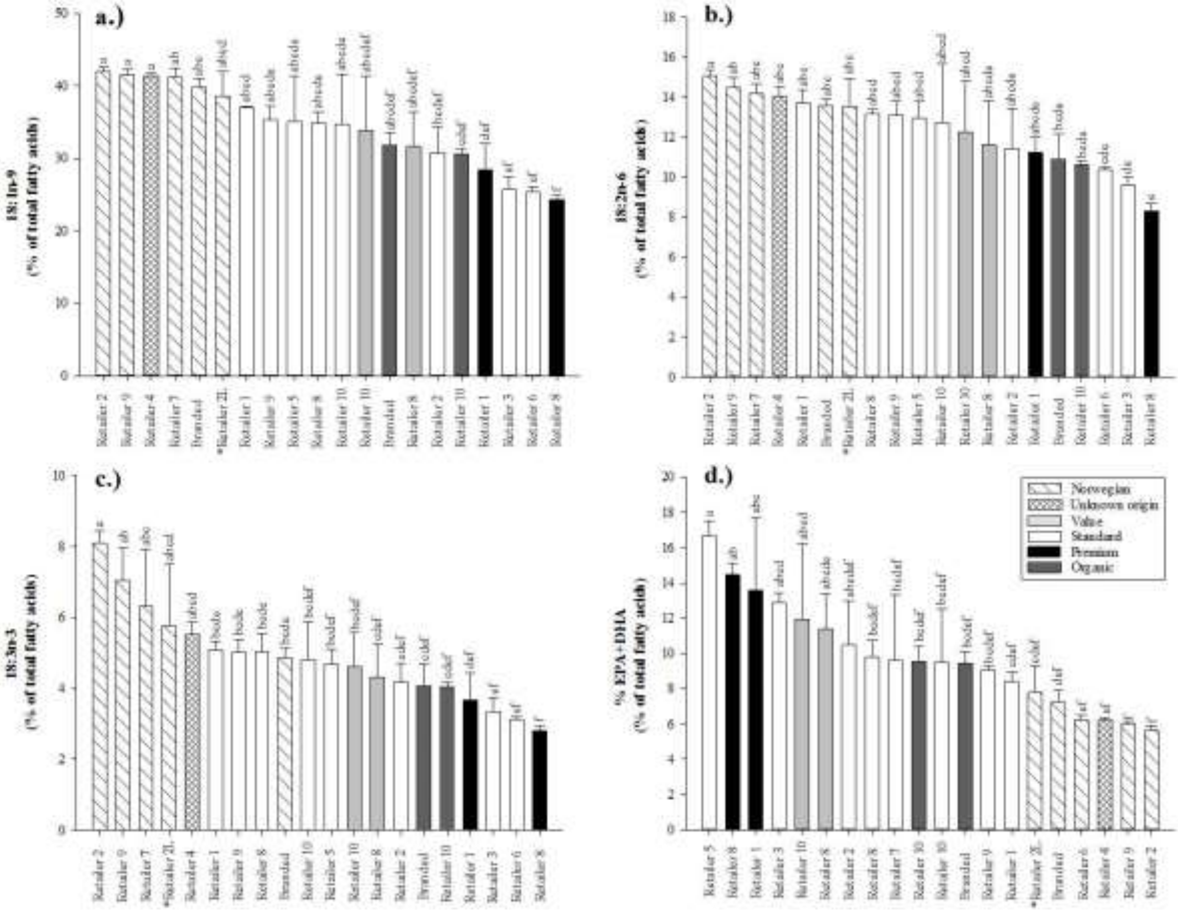
	Retailer 8			**Retailer 9**		**Retailer 10**			**Branded**	
Value Range	Value	Standard	Premium	Standard	Standard	Value	Standard	Organic	Standard	Organic
Farmed Origin	Scotland	Scotland	Scotland	Scotland	Norway	Scotland	Scotland	Scotland	Norway	Scotland
Macro minerals g.kg^{-1} ww										
Sodium	0.60 ± 0.08^{bc}	0.70 ± 0.26^{a}	0.89 ± 0.08^{ab}	0.35 ± 0.08^{cd}	0.36 ± 0.03^{cd}	0.44 ± 0.03^{cd}	0.30 ± 0.06^{d}	0.30 ± 0.03^{d}	0.34 ± 0.04^{d}	0.32 ± 0.02^{d}
Potassium	3.39 ± 0.14	3.25 ± 0.24	3.18 ± 0.20	3.61 ± 0.15	3.46 ± 0.14	3.37 ± 0.07	3.37 ± 0.30	3.58 ± 0.43	3.66 ± 0.21	3.46 ± 0.08
Calcium	$0.15 \pm 0.04^{e-g}$	$0.14 \pm 0.04^{e-h}$	$0.15 \pm 0.06^{d-g}$	$0.09 \pm 0.01^{f-h}$	$0.11 \pm 0.02^{f-h}$	$0.10 \pm 0.02^{f-h}$	0.05 ± 0.02^{h}	0.04 ± 0.02^{h}	0.07 ± 0.02^{gh}	0.07 ± 0.00^{gh}
Magnesium	0.23 ± 0.01	0.23 ± 0.01	0.22 ± 0.01	0.23 ± 0.01	0.24 ± 0.01	0.22 ± 0.01	0.24 ± 0.03	0.23 ± 0.02	0.25 ± 0.04	0.24 ± 0.01
Phosphorus	2.12 ± 0.07	2.11 ± 0.10	2.00 ± 0.09	2.16 ± 0.09	2.15 ± 0.08	2.01 ± 0.05	2.14 ± 0.17	2.14 ± 0.18	2.25 ± 0.19	2.19 ± 0.06
Trace elements mg.kg^{-1} ww										
Iron	$2.84 \pm 1.11^{a-c}$	1.70 ± 0.20^{c}	$2.36 \pm 0.59^{a-c}$	1.92 ± 0.68^{bc}	$2.34 \pm 0.38^{a-c}$	4.38 ± 1.86^{ab}	$2.84 \pm 1.12^{a-c}$	$2.63 \pm 0.37^{a-c}$	$3.43 \pm 0.52^{a-c}$	$3.21 \pm 0.45^{a-c}$
Manganese	$0.09 \pm 0.01^{c-f}$	$0.10 \pm 0.02^{b-f}$	0.07 ± 0.02^{ef}	0.08 ± 0.01^{ef}	0.08 ± 0.02^{ef}	0.07 ± 0.03^{ef}	0.07 ± 0.01^{ef}	0.07 ± 0.00^{ef}	0.06 ± 0.00^{f}	0.06 ± 0.01^{f}
Copper	0.46 ± 0.05^{ab}	0.68 ± 0.21^{ab}	0.59 ± 0.21^{ab}	0.31 ± 0.06^{b}	0.36 ± 0.03^{b}	0.48 ± 0.03^{ab}	0.49 ± 0.11^{ab}	0.48 ± 0.07^{ab}	0.57 ± 0.05^{ab}	0.34 ± 0.01^{b}
Zinc	$4.80 \pm 0.55^{b-f}$	$4.55 \pm 0.56^{c-f}$	4.35 ± 0.62^{ef}	4.27 ± 0.05^{f}	$4.42 \pm 0.09^{d-f}$	$4.55 \pm 0.39^{c-f}$	$4.83 \pm 0.45^{a-f}$	$4.48 \pm 0.46^{d-f}$	4.33 ± 0.34^{ef}	$4.69 \pm 0.54^{b-f}$
Vanadium	$0.01 \pm 0.00^{c-e}$	0.01 ± 0.00^{de}	$0.01 \pm 0.00^{b-d}$	$0.01 \pm 0.00^{b-d}$	$0.01 \pm 0.00^{a-c}$	$0.01 \pm 0.00^{a-d}$	$0.01 \pm 0.00^{b-e}$	0.00 ± 0.00^{e}	0.00 ± 0.00^{de}	0.00 ± 0.00^{de}
Selenium	$0.16 \pm 0.02^{c-e}$	$0.16 \pm 0.05^{c-e}$	$0.15 \pm 0.01^{c-e}$	$0.15 \pm 0.03^{c-e}$	0.10 ± 0.00^{de}	0.13 ± 0.02^{de}	0.26 ± 0.06^{ab}	0.23 ± 0.02^{bc}	0.13 ± 0.04^{de}	0.32 ± 0.00^{a}

Means (± standard deviation) bearing different superscript lettering within the same row are significantly different (ANOVA, $P < 0.05$) ($n = 3$ samples per product)

*Retailer 2 contained 2 Norwegian products with different nutritional labelling and number of fillets per pack – defined as Standard and Standard L (2 and 3 fillet packs, respectively)

¶Exact origin unknown, labelled as farmed in Scotland or No

Figure 1


a.)
18:1n-9
(% of total fatty acids)
0
10
20
30
40
50
Retailer 2
Retailer 9
Retailer 4
Retailer 7
Branded
*Retailer 2L
Retailer 1
Retailer 9
Retailer 5
Retailer 8
Retailer 10
Retailer 10
Branded
Retailer 8
Retailer 2
Retailer 10
Retailer 1
Retailer 3
Retailer 6
Retailer 8
b.)
18:2n-6
(% of total fatty acids)
0
2
4
6
8
10
12
14
16
18
Retailer 2
Retailer 9
Retailer 7
Retailer 4
Retailer 1
Branded
*Retailer 2L
Retailer 8
Retailer 9
Retailer 5
Retailer 10
Retailer 10
Retailer 8
Retailer 2
Retailer 1
Branded
Retailer 10
Retailer 6
Retailer 3
Retailer 8
c.)
18:3n-3
(% of total fatty acids)
0
2
4
6
8
10
Retailer 2
Retailer 9
Retailer 7
*Retailer 2L
Retailer 4
Retailer 1
Retailer 9
Retailer 8
Branded
Retailer 10
Retailer 5
Retailer 10
Retailer 8
Retailer 2
Branded
Retailer 10
Retailer 1
Retailer 3
Retailer 6
Retailer 8
d.)
% EPA+DHA
(% of total fatty acids)
0
2
4
6
8
10
12
14
16
18
20
Retailer 5
Retailer 8
Retailer 1
Retailer 3
Retailer 10
Retailer 8
Retailer 2
Retailer 8
Retailer 7
Retailer 10
Retailer 10
Branded
Retailer 9
Retailer 1
*Retailer 2L
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Retailer 2
Norwegian
Unknown origin
Value
Standard
Premium
Organic

Figure 2

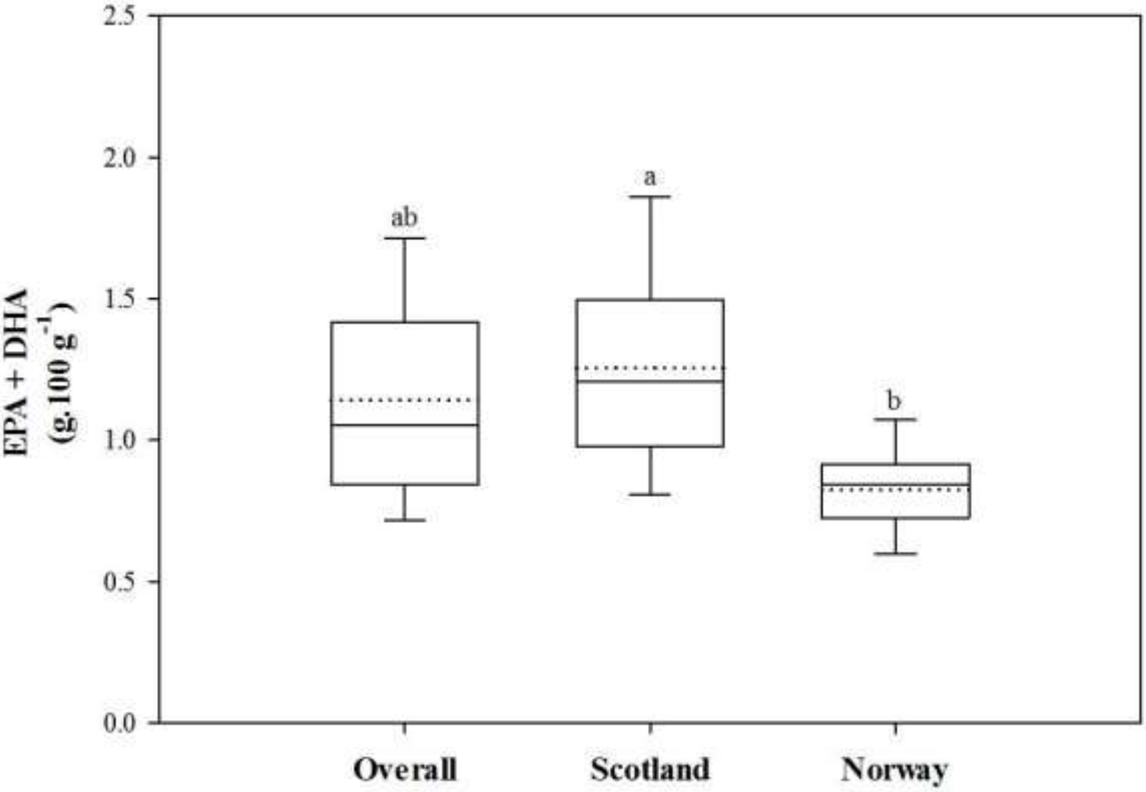


Figure 3

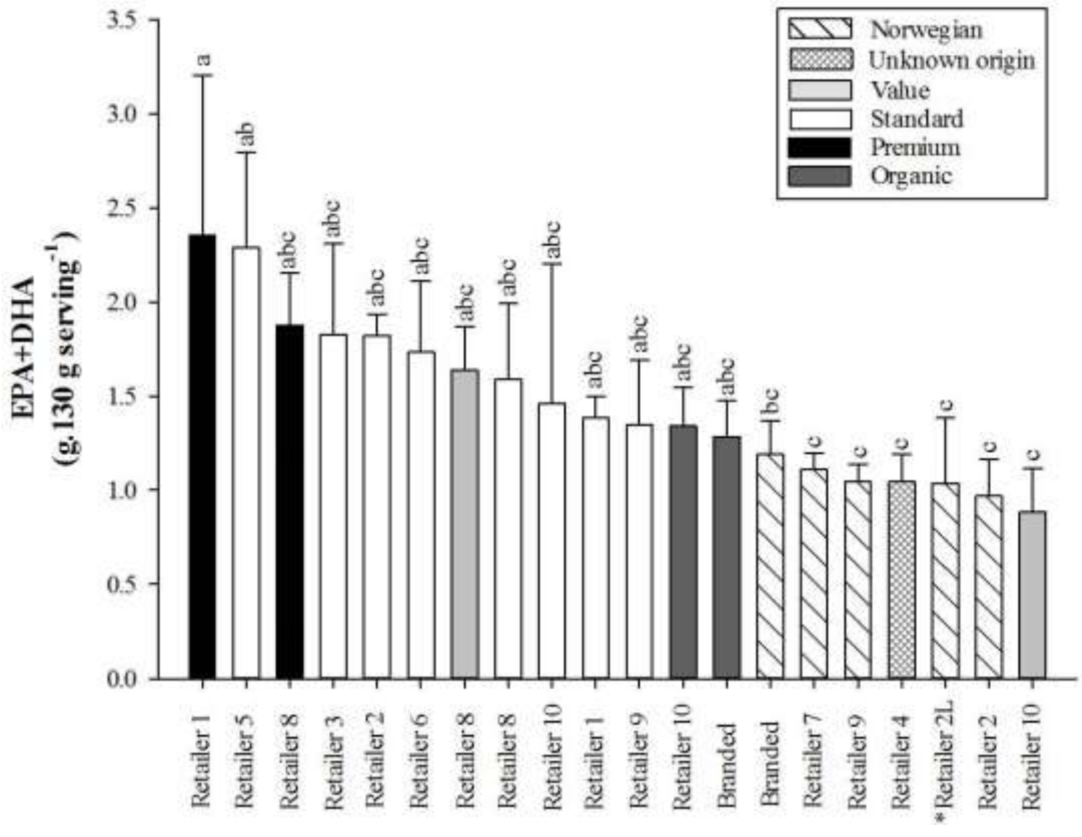

EPA+DHA
(g.130 g serving^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Norwegian
Unknown origin
Value
Standard
Premium
Organic
a
ab
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
bc
c
c
c
c
c
c
Retailer 1
Retailer 5
Retailer 8
Retailer 3
Retailer 2
Retailer 6
Retailer 8
Retailer 8
Retailer 10
Retailer 1
Retailer 9
Retailer 10
Branded
Branded
Retailer 7
Retailer 9
Retailer 4
*Retailer 2L
Retailer 2
Retailer 10

Figure 4

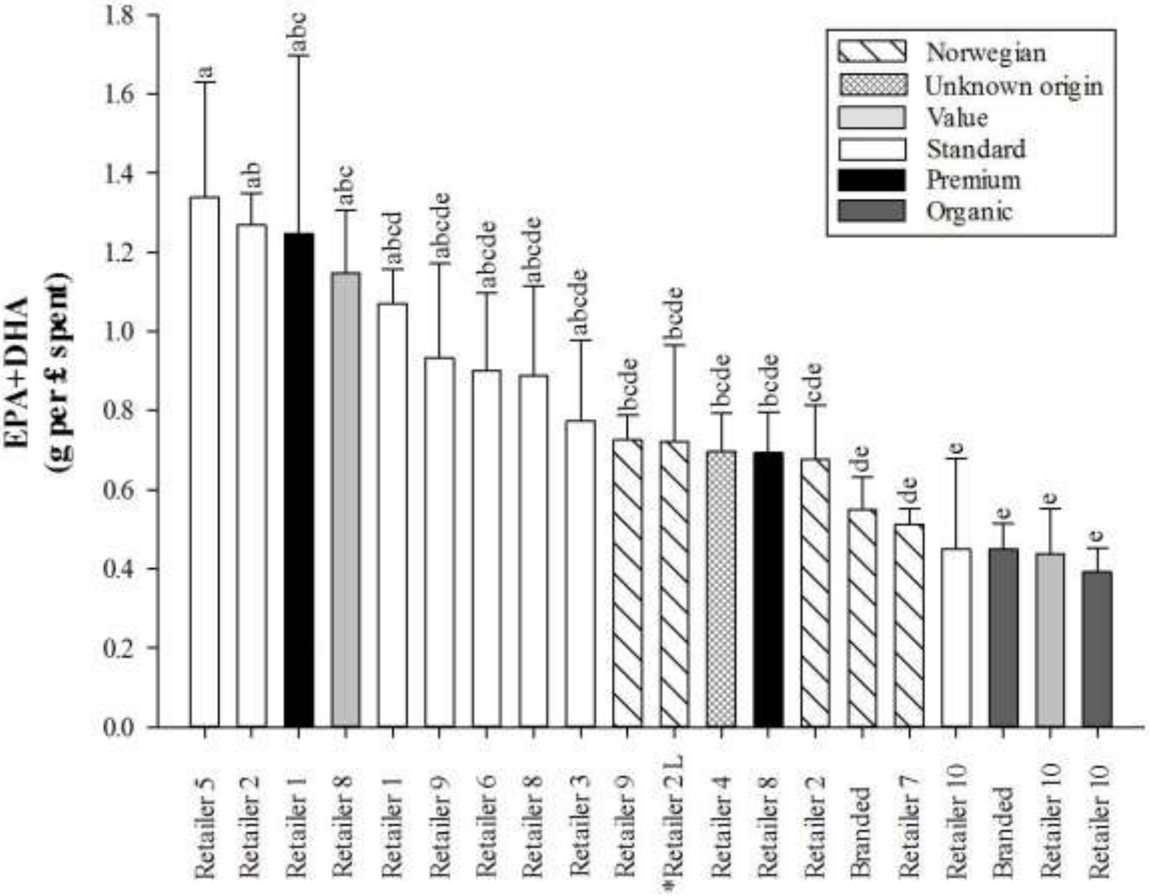
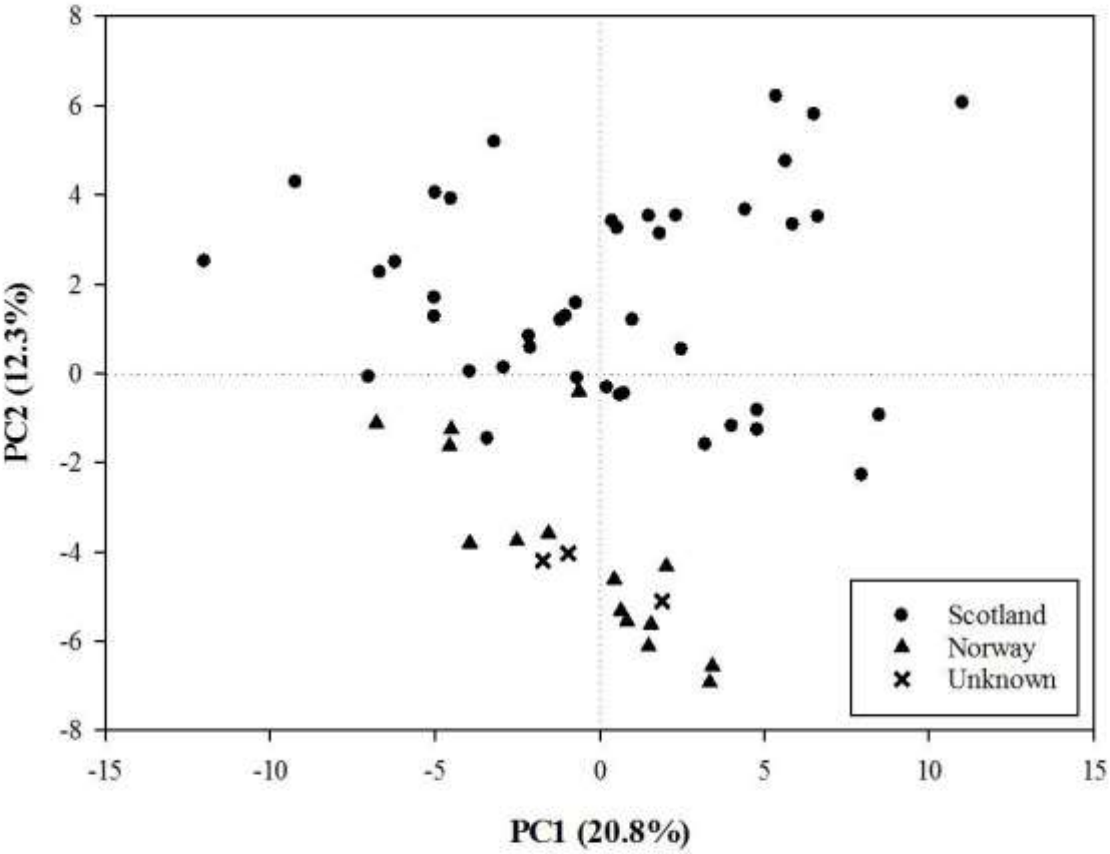
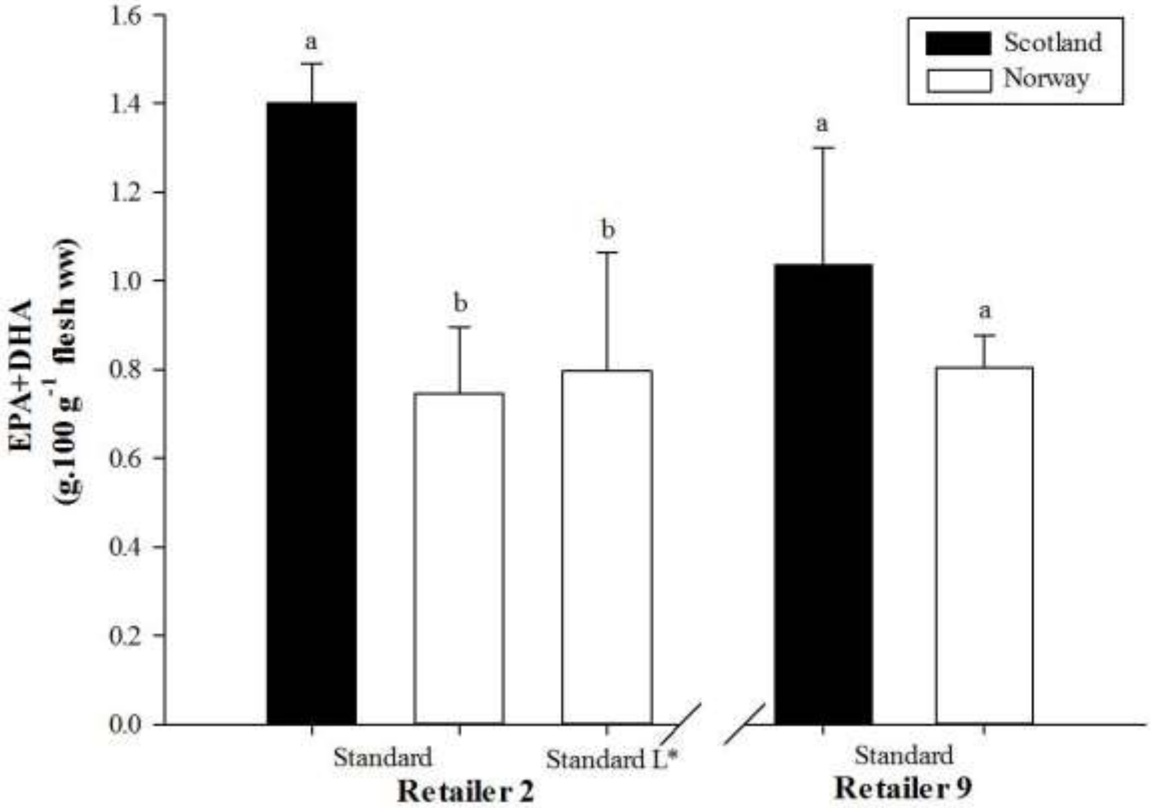

EPA+DHA
(g per £ spent)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Norwegian
Unknown origin
Value
Standard
Premium
Organic
a
ab
abc
abc
abcd
abcde
abcde
abcde
abcde
bcde
bcde
bcde
bcde
cde
de
de
e
e
e
e
Retailer 5
Retailer 2
Retailer 1
Retailer 8
Retailer 1
Retailer 9
Retailer 6
Retailer 8
Retailer 3
Retailer 9
*Retailer 2 L
Retailer 4
Retailer 8
Retailer 2
Branded
Retailer 7
Retailer 10
Branded
Retailer 10
Retailer 10

Figure 5



8
6
4
2
0
-2
-4
-6
-8
-15
-10
-5
0
5
10
15
PC2 (12.3%)
PC1 (20.8%)
● Scotland
▲ Norway
× Unknown

Figure 6


EPA+DHA (g.100 g^{-1} flesh ww)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
a
b
b
a
a
Scotland
Norway
Standard
Standard L*
Retailer 2
Standard
Retailer 9

894