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Herring vs. anchovy oils in salmon feeding

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Abstract

This study was carried out to investigate the effect of feeding diets containing herring or anchvoy oil, on flesh quality parameters of Atlantic salmon (*Salmo salar*). Two extruded experimental diets with the same basal composition but one coated with herring oil and the other with anchovy oil, were each fed during 24 weeks to salmon with an average initial weight of 1.8 kg. Salmon grew to a final weight of 3.9 kg. Growth, condition factor and biometric parameters were not affected by the dietary treatment. No significant differences were found for intramuscular fat. Monounsaturated fatty acid (MUFA) concentrations were highest in the group fed the diet containing herring oil, in both neutral and polar lipids, while the group fed the diet containing the anchovy oil showed a higher concentration of *n*-3 fatty acids in both fractions of intramuscular lipids. The *n*-3/*n*-6 ratio was higher in the neutral lipid fraction of fish fed the southern hemisphere oil, while no significantly differences were found for the polar lipid fraction. No differences were found on muscle α-tocopherol levels. Muscle homogenates from fish fed the anchovy oil showed the highest thiobarbituric acid reactive substances (TBARS) after 9 days of storage. However no differences were found between groups on the induced oxidation tests. It is concluded that the origin of the fish oil has no effect on growth perfomance, but there is a marked effect on fatty acid composition and susceptibility to lipid oxidation.

Resumen

Aceite de arenque vs. aceite de anchoa en alimentos para salmon. El presente estudio evalúa comparativamente los efectos que produce sobre determinados parámetros de calidad el incluir aceite de arenque ó aceite de anchoa en la alimentación del salmón Atlántico (*Salmo salar*). Para ello se alimentaron salmones de peso inicial medio de 1.8 kg durante 24 semanas con dos piensos extrusionados con la misma composición basal, excepto el tipo de aceite (anchoa ó arenque). Los salmones alcanzaron un peso final de 3.9 kg. No se observaron diferencias en el crecimiento, el factor de condición, los parámetros biométricos, y la grasa intramuscular. Las concentraciones intramusculares de ácidos grasos monoinsaturados (MUFA) fueron superiores, en ambas fracciones lipídicas (lípidos neutros y lípidos polares), en el grupo de animales alimentados con la dieta que contenía aceite de arenque, mientras que en el grupo alimentado con la dieta que contenía aceite de anchoa los ácidos grasos de la serie *n*-3 alcanzaron una concentración más elevada. La relación entre los ácidos grasos *n*-3/*n*-6 resultó ser mayor en los lípidos neutros de los peces alimentados con la dieta que contenía el aceite de anchoa. Sin embargo esta diferencia no se encontró en lípidos polares. No se encontraron diferencias en los niveles musculares de α-tocoferol. Después de 9 días de almacenamiento se encontraron valores superiores del índice de ácido tiobarbitúrico (TBA) en los homogeneizados de músculo de los salmones alimentados con la dieta que contenía aceite de anchoa. Sin embargo no se encontraron diferencias al realizar pruebas de oxidación inducida. En conclusión el crecimiento no se ve afectado por el tipo de aceite de pescado que utilicemos en la alimentación de salmones, pero si existe un efecto marcado en cuanto a composición de ácidos grasos y por lo tanto en la susceptibilidad a la oxidación.

Keywords: Salmon nutrition; Fish oil; Oxidation; Lipids; Fatty acids

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1. Introduction

Oil derived from wild fish has long been used in fish feeding because it provides a good source of energy, essential fatty acids and minerals and it is highly digestible and palatable (NRC, 1993). The current trend in diet formulation for fish is to increase the levels of fat, frequently reaching levels above 35% crude fat in species like the Atlantic salmon. It is estimated that by 2010, 85% of the available fish oil will be used for aquaculture purposes (Bell et al., 2001). Moreover, the marked growth of aquaculture as a commercial activity and the increasing demand of fish oil as a healthy supplement in human nutrition and terrestrial animal feeding, make reasonable to predict that fish oil will soon be an expensive ingredient for fish feed formulation (Bell et al., 2001).

Selection of a fish oil in fish feed formulation is mostly dependent on its price, and little attention is being paid to its fatty acid profile. However, fish oils significantly differ in their fatty acids profile depending on the origin of the fish capture. Available literature indicate that commercial fish oils from the Northern hemisphere such as herring, menhaden or capelin oils (Dosanjh et al., 1998; Roselund et al., 2001; Torstensen et al., 2000), are rich in mono unsaturated fatty acids (MUFA) which represent approximately 50% of the total fatty acids, while the concentration of *n*-3 polyunsaturated fatty acids (PUFA) around 20%. On the other hand, Southern hemisphere fish oils such as anchovy and sardine oil, contain less MUFA (26%) and are richer in *n*-3 PUFA (around 30% of the total fatty acids) (Buzzi et al., 1996; Hvantum et al., 2000). Differences in fish oil composition are likely to produce a marked effect in fish flesh composition and susceptibility to oxidation. This is a matter of interest due to increasing consumer awareness of nutritional characteristics of foods.

The objective of the present work is to compare two commercial fish oils commonly used in aquaculture, one representative from the Northern hemisphere and the other from the Southern hemisphere on the fatty acid composition of salmon muscle and the susceptibility of flesh to lipid oxidation.

2. Materials and methods

2.1. Fish husbandry and feeding

The trial was carried out at Nutreco Aquaculture Research Centre Lerang Research Station, Jørpeland, Norway. Four hundred Atlantic salmon with an average weight of 1.8 kg were randomly distributed into four 5×5 cages, (100 fish per cage) and fed one of the two experimental diets for 24 weeks. The experimental diets were produced at Nutreco Technology Centre (Stavanger, Norway), as extruded, sinking, 9 mm pellets. Their basal composition was the same except for the coated oil (Table 1). Batches of extruded pellets were produced from a common meal mixture. The kernels were coated with herring oil, used in the trial as an example of Northern hemisphere fish oil, or with Anchovy oil, a representative of a Southern hemisphere fish oil (Table 2). The feeds were formulated to reach targeted levels of 37% crude protein and 36% crude fat.

After distribution into the experimental cages, the fish were adapted to their new environment for 3 weeks. During this period the fish received a commercial diet (Compact 2+, Skretting, Norway). All fish were anaesthetised with metacaine (0.05 $g.l^{-1}$) and individually weighed before starting feeding with the experimental diets. Fish were fed to satiation according to routine procedures at Lerang Research Station.

Table 1
Ingredients and analyzed composition of the experimental diets

	Herring	Anchovy
Ingredients (%)		
Fish meal	35.3	35.3
Wheat	11.7	11.7
Extracted soya	10.0	10.0
Corn gluten	10.0	10.0
Carophyll pink	0.1	0.1
Herring oil[1]	31.7	–
Anchovy oil[2]	–	31.7
Vitamin premix	0.3	0.3
Mineral premix	0.3	0.3
Analyzed composition		
Gross energy (10^6J·kg^{-1})	27.1	27.2
Dry matter[3]	93.5	94.6
Protein[3]	42.5	42.2
Crude fat[3]	38.6	38.3
Ash[3]	6.7	6.2

[1] Saint Laurent (Canada).
[2] Denofa (Norway).
[3] Values represents % of dry weight.

Table 2
Fatty acid composition of the experimental diets (g·100 g^{-1} of total fatty acids) containing herring or anchovy fish oil

Fatty acids	Herring	Anchovy
Saturates	18.8	30.2
C20:1(*n*-9)	14.3	1.9
C22:1[1]	21.2	2.2
Monounsaturates[2]	55.0	30.2
C18:2(*n*-6)	2.9	2.9
C20:4(*n*-6)	0.2	0.7
Total (*n*-6)	4.4	5.6
C18:3 (*n*-3)	0.7	0.9
C20:5(*n*-3)	6.4	13.3
C22:6(*n*-3)	5.4	10.0
Total (*n*-3)	15.4	28.9
(*n*-3)/(*n*-6)	3.5	5.1

[1] Includes C22:1(*n*-11) and C22:1(*n*-13).
[2] Includes C16:1(*n*-7), C18:1(*n*-9), C18:1(*n*-7), C20:1(*n*-9) and the sum of C22:1 isomers.

2.2. Sampling

After 24 weeks of experimental feeding, twelve fish per cage were anaesthetised, weighed, measured and immediately bled in chilled sea water. Fish with external signs of sexual maturation were discarded. Fish were kept whole on ice for 120 hours to avoid *rigor mortis*. Then, they were eviscerated and their sex recorded. The weight of viscera, liver and gonads was measured in order to assess the hepato-, viscero-, and gonado-somatic index. Fish with a gonado-somatic index above 0.5 were discarded. The remaining fillets were immediately vacuum-packed and frozen for further analysis.

2.3. Chemical analysis of flesh samples

Intramuscular neutral and polar lipids were extracted by consecutive solvent elution with dichloromethane and dichloromethane/metanol (90/10, vol/vol)) respectively on a glass column containing anhydrous sodium sulfate, celite 545 and dicalcium phosphate (Marmer and Maxwell, 1981). Before the analysis of fatty acids by gas chromatography, all lipid samples were methylated as described elsewhere (López-Bote et al., 1997). Fatty acid methyl esters were then analysed using a Hewlett Packard HP-6890 gas chromatograph equipped with flame ionisation detection and a 30 m × 0.32 mm × 0.25 mm cross linked polyethylene glycol capillary column (HP-Innowax). Analyses were performed with a temperature program from 170 to 240 °C at a rate of 1 °C.min^{-1}. Injector and FID detector were maintained at 250 °C. Carrier gas was helium at a flow rate of 3 ml.min^{-1}. Results were expressed as the percentage of each fatty acid with respect to the total fatty acids.

To determine the effects of experimental diets on lipid oxidation, representative cutlets taken from the same place of each fillet were placed on polystyrene trays, wrapped in an oxygen permeable PVC stretch overwrap and kept at 4 °C under fluorescent light. Lipid oxidation was determined at 0, 72, 144, and 216 hours of storage using the 2-thiobarbituric acid method of Salih et al. (1987), thiobarbituric acid reactive substances (TBARS) were expressed as µmol malondialdehyde (MDA)·kg^{-1} wet tissue. Also stimutated lipid peroxidation analyses were performed by a modification of the method of Kornbrush and Mavis (1980). Muscle homogenates (approximately 0.1 g·ml^{-1} KCl 1.15%) were incubated at 37 °C in a solution containing 40 mM Tris-maleate buffer (pH 7.4) and 0.4 mM ascorbic acid. At fixed intervals (0, 10, 20, 30, 45, 60, 90 and 120 min), 0.4 ml aliquots were removed for measurements of TBARS. TBARS were expressed as nmol malondialdehyde (MDA)·mg^{-1} soluble protein.

Alpha-tocopherol was extracted from fillets as described by Sheehy et al., (1994). Quantification was performed by high perfomance liquid chromatography (Waters, Machey-Nagel Nucleosil C18 column, Waters 486 UV detector, Germany). The eluting solvent was methanol : water (97 : 3) at a flow rate of 2 ml·min^{-1}.

2.4. Calculations

Condition factor (CF) was calculated as 100 × (BW, g) × (fork length, cm)$^{-3}$. The hepato-somatic index (HSI) was calculated as 100 × liver weight × BW^{-1}. The viscero-somatic index (VSI) was calculated as 100 × carcass weight × BW^{-1}. The gonado-somatic index (GSI) was calculated as 100 × gonad weight × BW^{-1}.

2.5. Statistical analysis

The results were analysed by the General Linear Model procedure contained in the SAS computer software (SAS, 1996). Percentage of fatty acids were arcsin transformed before statistically analysed to fulfil the population normality and homogeneity assumptions. Two sets of results are presented as recommended by Mead et al. (1993), first the means calculated on the untransformed scale, and alongside these means the corresponding set of means on the transformed scale with standard deviations. A repeated measures mean test was used to compare differences in oxidation rates between groups during refrigerated storage and stimulated lipid peroxidation.

3. Results

No significant differences were observed in growth, condition factor, hepato-somatic index, viscero-somatic index and gonado-somatic index (Table 3). The fatty acid types of neutral and polar lipids from the dorsal muscle are shown in Tables 4 and 5 respectively. Fish fed the diet containing the anchovy oil showed significantly higher concentration ($p < 0.0001$) in both saturated fatty acids (SAFA) and PUFA in neutral lipids, while fish fed the herring oil showed more MUFA concentration ($p < 0.0001$), clearly reflecting the composition of the dietary fat into the neutral lipid fraction. Levels of EPA, DHA and arachidonic acid (AA, 20:4*n*-6) in this fraction were higher in fish fed the anchovy oil than in the fish fed the herring oil ($p < 0.0001$) (Table 4).

A similar effect was observed in the fatty acid profile of polar lipids (Table 5). SAFA ($p < 0.005$) and PUFA ($p < 0.0001$) concentrations were higher in fish fed the anchovy oil, and MUFA concentration ($p < 0.001$) was higher in fish fed the herring oil. Again AA ($p < 0.0001$), EPA ($p < 0.001$) and DHA (0.001) were higher in fish fed the diet containing the southern hemisphere fish oil, while no significant differences were found for the *n*-3/*n*-6 ratio of the polar lipid fraction.

No differences were found in muscular levels of α-tocopherol and intramuscular lipids content (Table 6) in fish fed either the diet containing the northern or the

Table 3
Variations in body weight and effect of dietary fat type (herring or anchovy fish oil) on hepato-, visceral and gonado-somatic index[1]

	Herring	Anchovy
Initial weight (g)	1 897 ± 18	1 942 ± 52
Intermediate weight[2] (g)	2 774 ± 41	2 753 ± 64
Final weight[3] (g)	3 825 ± 86	3 960 ± 248
CF[4] g.cm^{-3}	1.25 ± 0.04	1.27 ± 0.05
HSI[5] (%)	0.78 ± 0.03	0.78 ± 0.01
VSI[6] (%)	8.21 ± 0.30	7.85 ± 0.56
GSI[7] (%)	0.16 ± 0.02	0.16 ± 0.01

[1] Means ± standard deviation (n = 12).
[2] intermediate (week 12).
[3] final (week 24).
[4] condition factor (CF =100 × (BW,g) × (fork length,cm)$^{-3}$).
[5] hepato-somatic index (HSI = 100 × liver weight × BW^{-1}).
[6] viscero-somatic index (VSI = 100 × carcass weight × BW^{-1}).
[7] gonado-somatic index (GSI = 100 × gonad weight × BW^{-1}).

southern hemisphere fish oil. The effects of the experimental diets on the susceptibility of fish tissues to oxidation were evaluated throughout the refrigerated storage of muscle samples (Fig. 1) and the induced oxidation of muscle homogenates (Fig. 2). A significant effect of time ($p < 0.0001$) was observed on TBARS concentration on fish samples along storage in both lipid oxidation studies. A significant interaction time x dietary treatment ($p < 0.01$) was observed in TBARS development, the samples from salmon fed the diet containing anchovy oil showing higher susceptibility to oxidation. On the other hand no significant interaction time x dietary treatment was observed on the induced oxidation study (Fig. 2).

4. Discussion

When comparing with fresh-water fish oils and lipids, the marine fish oils are characterised by containing low levels of both linoleic acid (18:2 *n*-6) and linolenic acid (18:3 *n*-3) as well as high levels of *n*-3 highly unsaturated fatty acids (HUFA), more than three unsaturations per fatty acid residue, mainly EPA and DHA (Steffens, 1997). They are also characterized by a high ratio of total *n*-3 to *n*-6 fatty acids, varying between about 5 and more than 10 (Steffens, 1997). In addition fish oil fatty acids profiles vary according to fish species and the location of the catch. Traditionally fish oils used for aquaculture purposes are of industrial fisheries origin. The biggest fisheries occur over the continental shelf (less than 200-m depth) where nutrient turnover occurs on winter, or in areas of upwelling of deep water as on the coast of Peru and Chile. In terms of weight, the most productive group of fish are the clupeoids (anchovy, herring, menhaden, sardine and sprat) which feed mainly near the base of the food chain of zooplankton or phytoplankton, often by filter-feeding (Bone et al., 1995).

The fish choose a natural prey depending on the abundance and its filter-feeding capacity. In the North Sea the dominant phytophankton (diatoms and dinoflagellates rich in PUFA) is consumed by crustacean zooplankton, espe-

Table 4
Effect of dietary herring or anchovy oil on selected fatty acid (FA) composition of neutral intramuscular lipids from Atlantic salmon[1]

	Herring		Anchovy		
	g·100 g^{-1} FA	arcsin	g·100 g^{-1} FA	arcsin	p
Saturates	20.7	78.04 ± 0.67	26.4	74.95 ± 1.04	0.0001
C20:1(*n*-9)	12.6	82.72 ± 0.45	3.8	87.78 ± 0.19	0.0001
C22:1(*n*-11)	13.9	82.01 ± 0.55	3.7	87.87 ± 0.27	0.0001
Monounsaturates[2]	53.7	57.53 ± 0.88	35.4	69.43 ± 0.75	0.0001
C18:2(*n*-6)	3.9	87.74 ± 0.17	4.3	87.54 ± 0.10	NS[3]
C20:4(*n*-6)	0.4	89.75 ± 0.01	0.8	89.53 ± 0.01	0.0001
Total (*n*-6)	5.3	86.95 ± 0.15	5.7	86.78 ± 0.15	NS
C18:3 (*n*-3)	0.8	89.53 ± 0.02	1.0	89.41 ± 0.03	0.0001
C20:5(*n*-3)	5.8	86.65 ± 0.16	10.0	84.26 ± 0.31	0.0001
C22:6(*n*-3)	8.8	84.96 ± 0.35	13.5	82.22 ± 0.26	0.0001
Total (*n*-3)	20.2	78.33 ± 0.54	32.1	71.29 ± 0.68	0.0001
(*n*-3)/(*n*-6)	3.8	87.81 ± 0.18	5.7	86.71 ± 0.21	0.0001

[1] Means of untransformed and arcsin transformed (± standard deviation) (n = 12).
[2] Includes C16:1(*n*-7), C18:1(*n*-9), C18:1(*n*-7), C20:1(*n*-9) and the sum of C22:1 isomers.
[3] NS = $p > 0.05$.

Table 5
Effect of dietary herring or anchovy oil on selected fatty acid (FA) composition of polar intramuscular lipids from Atlantic salmon[1]

	Herring		Anchovy		
	g·100 g^{-1} FA	arcsin	g·100 g^{-1} FA	arcsin	*p*
Saturates	28.6	73.40 ± 0.80	30.2	72.44 ± 0.47	0.0020
C20:1(*n*-9)	4.4	87.69 ± 0.70	1.0	89.42 ± 0.08	0.0001
C22:1(*n*-11)	3.6	87.93 ± 0.81	0.9	89.49 ± 0.07	0.0001
Monounsaturates[2]	19.4	78.71 ± 2.20	14.5	81.64 ± 0.43	0.0002
C18:2(*n*-6)	1.7	89.02 ± 0.06	1.8	88.98 ± 0.18	NS[3]
C20:4(*n*-6)	0.8	89.50 ± 0.02	1.3	89.24 ± 0.05	0.0001
Total (*n*-6)	3.1	88.24 ± 0.11	3.4	88.04 ± 0.22	NS
C18:3 (*n*-3)	0.5	89.75 ± 0.01	0.4	89.74 ± 0.01	NS
C20:5(*n*-3)	8.2	84.86 ± 0.31	9.6	84.48 ± 0.16	0.0010
C22:6(*n*-3)	35.3	69.20 ± 1.10	38.0	67.65 ± 0.73	0.0006
Total (*n*-3)	48.6	60.99 ± 1.42	51.8	58.73 ± 0.82	0.0001
(*n*-3)/(*n*-6)	15.9	80.85 ± 0.85	15.4	81.12 ± 1.09	NS

[1] Means of untransformed and arcsin transformed ± (standard deviation) (n = 12).
[2] Includes C16:1(*n*-7), C18:1(*n*-9), C18:1(*n*-7), C20:1(*n*-9) and the sum of C22:1 isomers.
[3] NS = $p > 0.05$.

cially *Calanus* sp., which following the food chain is consumed by herring. *Calanus* sp. is a calanoid copepod whose dominant fatty-alkyl moieties are 20:1 *n*-9 and 22:1 *n*-11/13 (Sargent and Henderson, 1980), which in turn are reflected in the high MUFA levels found in the herring oil fatty acids profile.

It is well known the strong influence of diets on the fatty acid composition of cultured fish (Steffens, 1997; Geurden et al., 1998; Ruyter et al., 2000). Our data are clearly in accordance to this. Investigations conducted by Thomassen and Røsjo (1989) showed that feeding Atlantic salmon a diet containing capelin oil rich in 22:1 *n*-9 and 22:1 *n*-11 raised the concentrations of those fatty acids in both heart triacylglycerols and muscle total lipids. In the same way, the predominant MUFA present in the herring oil (20:1 *n*-9 and 22:1 *n*-11) are reflected with the higher percentages in the muscle neutral lipids in our data, being the sum of monoenes in neutral lipids equal in percentage than those in the diet. Concentration of MUFA into the polar lipid fraction is smaller than in the neutral lipids. It is of interest how relative low dietary levels of SAFA into the north hemisphere fish oil (18.8%) lead to a percentage of SAFA of 20.7 and 28.5% respectively for neutral and polar lipids. On the other hand, 30.2% SAFA in the diet containing the southern hemisphere fish oil lead to 26.35 and 30.16% SAFA in neutral and polar intramuscular fat respectively. Therefore, the concentrations of SAFA in polar lipids seem to be less affected by dietary fatty acid composition than in neutral lipids. This is in agreement with previous research in which

Table 6
Effect of dietary fish oil from the northern (herring oil) or the southern hemisphere (anchovy oil) on intramuscular lipid and α-tocopherol concentrations in Atlantic salmon[1]

	Herring	Anchovy
Intramuscular lipids (g·100 g^{-1})		
Neutral lipids	6.4 ± 2	7.9 ± 2.7
Polar lipids	5.4 ± 2	6.7 ± 1.6
α-tocopherol (μg·g^{-1})	8.2 ± 2	9.0 ± 1.4

[1] Means ± standard deviation (n = 12).

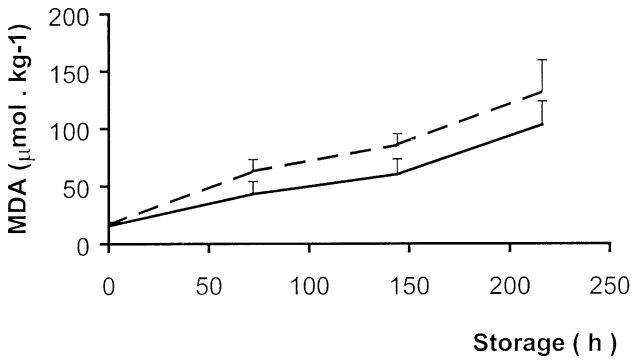

Fig. 1. Lipid oxidation assessed by the concentration of malonyl dialdehyde (MDA, μmol·kg^{-1} wet tissue) along refrigerated storage in dorsal muscle from salmons fed a diet containing herring (—) or anchovy (- - - -) oil.

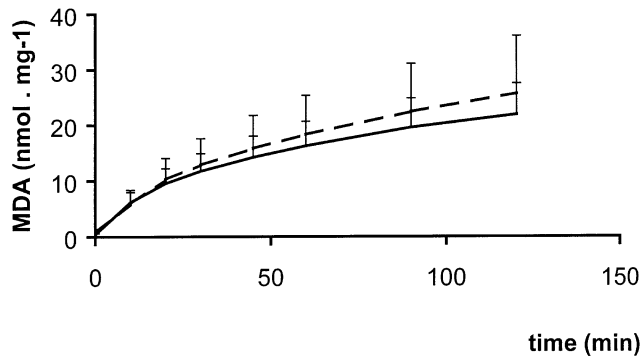

Fig. 2. Induced lipid oxidation assessed by the concentration of malonyl dialdehyde (MDA, nmol·mg^{-1} soluble protein) in dorsal muscle homogenates, from salmons fed a diet containing herring (—) or anchovy (- - - -) oil, incubated at 37 °C for up to 120 minutes.

it was demonstrated that SAFA in polar lipids are little affected by dietary treatment (López-Bote et al., 1997).

In a recent study, Bell et al. (2001) found an increase in AA, EPA and DHA fatty acids in the muscle tissue of Atlantic salmon postsmolts when fed a rich HUFA marine oil compared with experimental rapeseed oil diets at a level inclusion up to the 50%. The results of the present study are consistent with this, since AA, EPA and DHA are incorporated at higher percentages in both muscle lipid classes of fish fed the diet containing anchovy oil (rich in HUFA). For fatty acids of the *n*-6 series, the PUFA concentration of 18 carbon atoms is higher in the neutral than in the polar lipids, while the concentration of long chain (> 20 carbon atoms) PUFA is higher in the polar than in the neutral lipids. This is in agreement with previous research, in which it was observed a selective uptake of long chain PUFA in membrane phospholipids (López-Bote et al., 1997). Both in neutral and polar lipids the concentration of AA is higher than in the experimental diets, indicating a preferential retention of this fatty acid or an elongation and desaturation of dietary C18:2 *n*-6. For the *n*-3 series, the PUFA concentration of 18 carbon atoms is also higher in neutral than in polar lipids. However, for long chain *n*-3 fatty acids, it is interesting to note that EPA concentrations remains below 10% of total fatty acid concentration in neutral and polar lipids, even in the case that the dietary concentration is relatively high (13.3 g·100 g^{-1} total fatty acid in the diet containing anchovy oil). While the percentage of EPA in the diet is higher than that of DHA, the opposite happens in the muscle tissue. This is more evident in the polar lipid fraction where DHA reaches the 35-38%, almost fourfold higher than EPA levels. It has been suggested a selective deposition of DHA in Atlantic salmon tissues accounted for the complex catabolic pathway for this fatty acid (Bell et al., 2001). Hence, the higher amount of DHA in muscle compared to that of EPA could be an effect of a better metabolic usage of the latter. It is noticeable the higher *n*-3/*n*-6 ratio and the lower range of variation in the polar than in the neutral lipids, suggesting a restricted physiological control of membranes and thus being less affected by dietary means.

The complex problem of lipid oxidation in flesh, resulting from free radical mechanisms, is of special interest because of its negative impact on the flavour, colour and nutritional characteristics of fresh, frozen or cooked fish and fish products, due to the high PUFA levels on their tissues. It has been shown that cellular membranes rich in PUFA, and especially those with high levels of *n*-3 HUFA, are particularly susceptible to attack by reactive oxygen radicals, and there is a positive correlation between increased PUFA intake, deposition of these fatty acids in tissues and increased incidence of lipid oxidation (Alvarez et al., 1998; Bell et al., 2000). Results in the present study are in accordance to this, and the fish receiving a dietary fish oil from the southern hemisphere (rich in *n*-3 HUFA), showed higher TBARS values during storage. In terrestrial species it has been observed a negative effect of dietary PUFA on α-tocopherol concentration (Meluzzi et al., 2000), indicating a possible competition for absorption and or deposition between long chain PUFA and tocopherols. To assess the possible interaction of dietary fish oil source on vitamin E status, quantification of α-tocopherol in fish dorsal muscle was also carried out but no effect of the diets was observed. Hamre and Lie (1995) pointed out at the marginal vitamin E status in Atlantic salmon fed a sardine oil with about 50% higher whole body polyene fatty acids than fish fed diets containing capelin oil. Maintaining vitamin E levels while increasing the dietary PUFA causes a decreased ratio of α-tocopherol to PUFA in the fish tissues being critical in protection against lipid oxidation, and thus having to take into account this when adding the fat source.

Analysis of the results of this study shows that similar growth and biometry parameters can be achieved by formulating fish diet with oils from the northern or the southern hemisphere, however there is a significant difference on fatty acids composition of neutral and polar lipids and on susceptibility of fish flesh to oxidation. Results from this experiment indicate that quality characteristics (amount of *n*-3 fatty acids, susceptibility to oxidation) should be taken into consideration when including fish oil from different origin in fish diets.

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