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# Chemical and sensory evaluation of fillets from Atlantic salmon (*Salmo salar*) fed three levels of N-3 polyunsaturated fatty acids at two levels of vitamin E

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Atlantic salmon (*Salmo salar*) were fed three dietary levels of *n*-3 polyunsaturated fatty acids (PUFA) (1·0, 2·5 and 5·0% of the diets at 17% feed lipid level), each with two levels of vitamin E supplementation (0 and 300 mg $\alpha$-tocopherol acetate/kg diet). The varying dietary *n*-3 PUFA contents were achieved by using soybean oil, capelin oil and sardine oil, respectively. Sensory evaluation of cooked fillet from fresh, 4-days frozen, 5-weeks frozen (−18°C) and traditionally smoked fresh fish was performed.

Fillet proximate composition did not differ between high-quality cultured and wild Atlantic salmon. The total lipid fatty acid composition and vitamin-E content of the fillets were highly influenced by the fish diets. The vitamin-E content of the fillets did not influence the fatty acid composition.

Significant differences were found for 7 of 14 sensory parameters when comparing for homogeneity between the dietary groups. Rancid flavour was significantly higher in fish raised on a high *n*-3 PUFA and low vitamin-E diet. The results indicated a combined effect according to vitamin E and *n*-3 PUFA contents. Coloration of the fillet seemed to depend upon lipid quality and vitamin E, in addition to the feed content of pigments. The differences in fatty acid composition of the fillets caused differences in the sensory perception of fattiness, juiciness and taste intensity.

Twelve of the sensory parameters showed significant differences between treatments. The freshly sampled fish was most white, tasted less intense, was most juicy and least firm. The smoked fish showed most coloration, least taste of soya, herring, rancidity and off-flavour, probably as a masking effect of the smoking procedure.

Several sensory parameters were affected by freezing and storage, including decreased whiteness and increased colour strength, taste intensity, rancid flavour and off-flavour.

## INTRODUCTION

Dietary lipid level and fatty acid composition affect the chemical composition of farmed Atlantic salmon, which is important with respect to taste and nutritional quality of the product (Hardy *et al.*, 1987; Lie *et al.*, 1988; Thomassen & Røsjø, 1989; Waagbø *et al.*, 1991). Thus, marine lipids have been recommended in human health care as beneficial in protection against heart disease and other disorders due to the high contents of *n*-3 polyunsaturated fatty acids (PUFA) (Herold & Kinsella, 1986; Stansby, 1990).

Marine fish oils are the most used lipid sources in Atlantic salmon feeds, and a normal content of *n*-3 PUFA in fillets from farmed adult Atlantic salmon constitutes about 20% of the total lipid fraction, or 2·5 g of *n*-3 PUFA per 100-g fillet (Lie *et al.*, 1988). The dietary support of essential fatty acids in Atlantic salmon may be increased to obtain products with a nutritive composition which accords with special market preferences.

As an antioxidant, vitamin E protects biomembranes, and it has been shown that the dietary requirement of vitamin E for fish increases as the dietary

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PUFA content increases (Watanabe *et al.*, 1981; Cowey *et al.*, 1984; Roem *et al.*, 1990; Waagbø *et al.* 1991). A high dietary supplementation of vitamin E has been shown to be beneficial for fish health (Hardie *et al.*, 1990), and it has been demonstrated that the content of vitamin E in the fillet is increased by increasing the dietary supplementation (Frigg *et al.*, 1990; Waagbø *et al.*, 1991). Vitamin E may improve the storage stability of fish fillets with high contents of PUFA by preventing oxidation, as demonstrated in poultry (Guenther & Kohler, 1989; Frigg *et al.*, 1990). However, efforts to obtain optimal nutritive composition of fatty acids and vitamin E in fish fillets have to take into account the influence of these variables on the food acceptance and suitability of fresh and processed products.

This paper is part of a series of communications on the impact of three levels of dietary *n*-3 PUFA, each at two levels of vitamin E, on organ fatty acid and vitamin-E retention in Atlantic salmon during different stages of the life cycle. The aim of the present study was to focus on chemical composition and sensory quality of salmon fillets with regard to human consumption.

The sensory evaluation included parameters monitoring changes in odour, coloration, flavour and texture in four treatments of fillets from the experimental groups, including cooked and smoked fresh salmon, and cooked fillets after freezing for 4 days and after 5 weeks. Proximate composition, lipid fatty acid composition and vitamin-E content were determined on the same material.

## MATERIALS AND METHODS

### Fish and diets

Atlantic salmon (*Salmo salar*) were fed the experimental diets in duplicate at Matre Aquaculture Research Station in net pens in the sea (2·75 m × 5·5 m × 6·0 m) for 18 months. The number of fish per unit was 150 at the time of sampling. The fish were fed *ad libitum* twice a day. The water temperature and salinity were recorded regularly and mean values were 7·5°C and 28·2 ppt at sampling (April–May).

The diets used in this experiment were extruded dry pellets (12 mm) of a conventional composition used for salmonids as regards the main nutrient composition. Three levels of *n*-3 PUFA were obtained by using either soybean oil (A/S Denofa & Lilleborg Fabrikker, Fredrikstad, Norway), capelin oil (Norsalmoil; Nordsildmel, Bergen, Norway) or sardine oil (Pescomar; J. C. Martens & Co., Bergen, Norway) as lipid sources. Vitamin E was added as 300 mg α-tocopheryl acetate (Rovimix 50, Roche, Basle, Switzerland) per kg feed (+E) or omitted (−E) in each of the *n*-3 PUFA groups. The dietary groups fed diets containing soybean oil, capelin oil and sardine oil are referred to as Low *n*-3 ± E, Medium *n*-3 ± E and High *n*-3 ± E, respectively.

The total *n*-3 PUFA contents (g/100 g) analysed in the feeds were 1·9 in the Low *n*-3 diet, 3·5 in the Medium *n*-3 diet and 6·0 in the High *n*-3 diet. The total *n*-6 PUFA were 44·6, 6·5 and 6·3 g/100 g feed respectively. Feed analyses of vitamin E ranged from 45 to 70 mg α-tocopherol/kg in the (−E) diets and 240 to 300 mg α-tocopherol/kg in the (+E) diets. The detailed feed composition and fatty acid contents in the diets were presented by Waagbø *et al.* (1991).

### Sampling procedure

The fish were anaesthetized with $CO_2$ and bled in ice water. After gutting, the fish were individually packed in plastic bags. After sampling, the fish were (a) stored frozen for 5 weeks at −18°C prior to sensory evaluation, (b) frozen 4 days to ensure completely frozen material and (c) used freshly. The mean gutted weight was 3·7 ± 0·65 kg ($n$ = 48). The fish were transported on ice in isolated containers to the Norwegian Food Research institute, Ås, Norway, for sensory evaluation.

### Chemical analyses

Transverse sections of fillets used for sensory evaluation were returned to our institute and analysed for proximate composition, total fatty acid composition and α-tocopherol.

Dry matter, protein, lipid (ethyl acetate extraction), ash content and fatty acid composition of total lipid were analysed according to Lie *et al.* (1988). Levels of α-tocopherol were assayed according to methods described by Lambertsen (1983) and Hvidsten & Lambertsen (1987).

The chemical data were statistically evaluated using ANOVA and linear regression ('Statgraphics', a Plus*Ware[IM]Product, STSC, Inc., Rockville, Maryland, USA).

### Sensory evaluation

The sensory evaluation was performed according to standardized procedures at the Norwegian Food Research Institute. The taste panel included ten skilled judges and the tests were carried out in laboratories specially constructed for sensory analyses to obtain objective evaluations, including the light conditions (colourette luma day light, 450 lux at the table desk).

The evaluation included the following parameters: (1) odour intensity, (2) off-odour, (3) whiteness, (4) colour tone, (5) colour intensity, (6) taste intensity, (7) soya flavour, (8) herring flavour, (9) rancid flavour, (10) off-flavour, (11) fattiness, (12) juiciness, (13) coarseness and (14) firmness. The judges were not informed about the experimental approach and the samples were blind coded. The sensory evaluation was performed twice.

The results from the evaluation were converted to numeric values ranging from 1 (no) to 9 (evidently) by use of a special sensory registration equipment (Sentec,

Tecator AB, Höganes, Sweden) and statistically evaluated according to a Statistix 3.0 software, using ANOVA and Tukey (HSD) pairwise comparison.

### Cooking

The fish were divided into five slices (2-cm thickness) and vacuum-packed in plastic bags prior to heating in a water bath at 70°C for 30 min. Each of the judges was given a hot half of a slice randomly with regard to feeding group, repetition, treatment and order of serving. Freshly-sampled, short-time-frozen and long-time-stored frozen fish were tested according to this procedure.

### Smoking

The fish were smoked according to a standardized procedure for salmon (Program no. 19 in the MC-3 library at the Norwegian Food Research Institute). The salmon were prepared in a salt–sugar solution (12 g salt and 0·50 g sugar/1000 g solution) for 3 days prior to the drying and smoking procedure which lasted 17 h. The judges were given a room-tempered 1-cm slice from the mid-fillet, randomly according to group, repetition and order of serving.

## RESULTS AND DISCUSSION

The present data confirm that lipid composition (Thomassen & Røsjø, 1989; Waagbø *et al.*, 1991) and vitamin E (Boggio *et al.*, 1985; Frigg *et al.*, 1990; Waagbø *et al.*, 1991) can be modified by the dietary contents of these nutrients. The lipid sources used in this study are commercially available, and the fillet levels of *n*-3 fatty acids in the medium *n*-3 groups are comparable to what have been found in wild Atlantic salmon (Lie, pers. comm., 1992).

The mean fatty acid composition of fresh fillet from the experimental groups (Table 1) shows that the characteristic fatty acids of the dietary oils were found in the fillet lipids. High contents of 18:2 *n*-6 and 18:3 *n*-3 and low *n*-3 PUFA (12·9%) relative to the other groups were seen in fillets from the Low *n*-3 groups, while high levels of long-chain monoenes and medium levels of *n*-3 PUFA (21·4%) were found in fillet from Medium *n*-3 groups. The High *n*-3 groups were characterized by the high content of *n*-3 PUFA (34·3%). The Low, Medium and High *n*-3 diets resulted in fillet contents of 13·4, 21·8 and 34·8 g *n*-3 PUFA/100 g total lipid or 1·2, 2·0 and 3·5 g/100 g fillet, respectively. No apparent declines in PUFA were seen during freezing, storing or smoking.

The α-tocopherol contents in the fillet (Table 1) were three times higher in the vitamin E–supplemented groups (27·5 mg/kg) compared to the non-supplemented groups (8·5 mg/kg). The different vitamin-E supplementations did not induce changes in fillet fatty acid composition or lipid levels. This is in accordance with studies in rainbow trout (*Oncorhynchus mykiss*) carried out by Frigg *et al.* (1990). The α-tocopherol content was not affected by freezing, storing or smoking.

Fresh fillet proximate composition (Table 2) was not affected by any of the dietary factors which is in accordance with Waagbø *et al.* (1991). This was also found by Hardy *et al.* (1987) in a 23-week feeding experiment using menhaden oil, soybean oil and tallow in diets for Atlantic salmon. The protein and lipid contents, however, were higher in the present experiment due to larger fish. This is confirmed by studies at our institute on adult farmed Atlantic salmon and wild Atlantic salmon (Lie *et al.*, 1988; Lie, pers. comm., 1992). An increase in dry matter was observed during freezing and storage, and in smoked fillets approximately a 65% increase compared to fresh fillet was found.

Table 3 shows the mean sensory scores of the evaluation presented as a comparison of the six experimental groups. Of the 14 sensory parameters tested, 7 showed significant differences ($P < 0·05$) according to diet.

**Table 1. Range of mean fatty acid composition (%) and α-tocopherol (mg/kg) in fillets according to diet**

| Fatty acid | Low − E | Low + E | Medium − E | Medium + E | High − E | High + E |
|---|---|---|---|---|---|---|
| 14:0 | 2·0–2·2 | 2·0–2·1 | 4·8–5·1 | 4·6–5·1 | 5·2–5·6 | 5·3–5·6 |
| 16:0 | 11·7–12·2 | 11·7–12·3 | 12·2–12·5 | 11·9–12·4 | 14·1–14·6 | 14·5–15·0 |
| Σ 16:1 | 2·6–3·0 | 2·5–2·8 | 7·0–7·5 | 7·1–7·2 | 7·0–7·2 | 6·9–7·5 |
| 18:0 | 3·6–3·7 | 3·5–3·8 | 2·0–2·2 | 1·9–2·0 | 2·9–3·0 | 2·8–2·9 |
| Σ 18:1 | 21·6–22·1 | 21·3–22·7 | 16·3–17·3 | 15·7–16·3 | 15·5–16·2 | 15·9–16·2 |
| 18:2 *n*-6 | 32·2–33·7 | 33·3–34·6 | 4·7–4·9 | 4·5–4·7 | 4·2–4·6 | 4·6–4·6 |
| 18:3 *n*-3 | 3·3–3·5 | 3·4–3·7 | 1·0–1·0 | 1·0–1·0 | 0·9–1·1 | 1·0–1·1 |
| Σ 20:1 | 3·7–4·4 | 3·3–3·9 | 14·0–14·7 | 13·9–14·7 | 5·6–5·9 | 5·7–6·3 |
| Σ 22:1 | 3·7–4·0 | 3·3–4·8 | 13·6–14·7 | 14·0–14·8 | 4·7–5·3 | 4·3–5·0 |
| 20:5 *n*-3 | 1·7–2·3 | 2·0–2·2 | 5·2–5·7 | 5·3–5·6 | 10·0–10·3 | 9·7–10·9 |
| 22:6 *n*-3 | 4·7–5·5 | 4·5–5·3 | 8·4–9·1 | 8·2–9·5 | 14·2–15·3 | 14·4–15·2 |
| Σ Sat. | 17·5–18·1 | 17·8–18·3 | 19·1–20·1 | 18·4–19·4 | 22·1–23·5 | 22·9–23·7 |
| Σ Monoen. | 2·3–33·4 | 31·0–32·4 | 53·1–53·3 | 52·2–53·3 | 32·7–35·2 | 34·0–35·3 |
| Σ *n*-3 | 12·2–13·6 | 12·6–13·1 | 20·6–21·7 | 21·1–21·9 | 33·1–35·2 | 33·5–35·3 |
| Σ *n*-6 | 35·4–37·2 | 36·8–38·4 | 5·1–5·3 | 4·8–5·2 | 4·8–5·8 | 5·4–5·7 |
| α-Tocopherol | 6·0–9·4 | 24·6–26·2 | 6·0–10·6 | 27·0–33·8 | 6·2–13·0 | 23·4–30·2 |

Σ Sat.: Sum saturated fatty acids; Σ Monoen.: sum monoene fatty acids.

**Table 2. Proximate analyses of fillets (g/100 g (w/w), mean ± SD) according to treatment**

| Analysis | Fresh | Storage − 20°C | | Smoked |
|---|---|---|---|---|
| | | 4–5 days | 5 weeks | |
| Dry matter | 31·2 (1·1) | 33·3 (1·1) | 33·2 (0·9) | 49·8 (2·1) |
| Lipid | 9·0 (0·9) | 11·6 (1·3) | 11·5 (0·8) | 19·2 (2·4) |
| Protein | 20·0 (1·1) | 19·3 (1·1) | 19·3 (1·1) | 16·2 (0·6) |
| Ash | 1·1 (0·1) | 1·1 (0·1) | 1·1 (0·1) | 3·7 (0·5) |

These parameters were whiteness, colour tone, colour intensity, taste intensity, rancid flavour, fattiness and juiciness.

High *n*-3 −E tasted more rancid than Medium *n*-3 +E. Although not significant, the mean scores from the other groups were ranked according to *n*-3 PUFA content and vitamin-E status.

In general, PUFA is easily oxidized and vitamin E functions as an antioxidant. The combined negative effects of high PUFA and low vitamin-E contents in the fillets resulted in a significantly higher score of rancid flavour in the High *n*-3 −E group compared to the Medium *n*-3 +E group ($P < 0.05$). The overall rank in homogeneity of the groups showed high scores of rancid flavour for groups according to high *n*-3 PUFA content and low vitamin-E status. This is in accordance with other studies, showing that dietary vitamin E improves the oxidative stability of trout fillet measured as malondialdehyde equivalents after forced oxidation (Frigg *et al.*, 1990) and in pork muscle differing in fatty acid composition (Monahan *et al.*, 1991). Frigg *et al.* (1990) generally found significant sensory preferences for trout fillets with higher vitamin-E contents.

Fillets from the Low *n*-3 groups were inferior to the other groups as regards scores on flesh colour (whiteness, colour tone and colour intensity). The rank of homogeneity between the groups always grouped High and Medium *n*-3 −E and Medium *n*-3 +E together, giving the best scores (less whiteness, highest colour tone and colour intensity). Capelin oil, which was used as lipid source in the Medium *n*-3 feeds, contains natural pigments, which in addition to the astaxanthin supplementation, may have caused some better colour in Medium *n*-3 fillets. This was also observed in a study by Thomassen & Røsjø (1989), comparing capelin oil-supplemented fish feed to feeds with added soybean oil and two types of rapeseed oil. The significance of the higher scores in coloration observed for the −E groups at all levels of *n*-3 PUFA is not clear.

The intensity of taste, fattiness and juiciness seems to be related to the fatty acid composition of the fillets, as the proximate composition did not differ between the groups. The dietary lipid sources used differed, not only in *n*-3 fatty acids, but also in other fatty acids, and these differences were reflected in the fillet lipids. The Low *n*-3 fillet contained 35–38% of *n*-6 fatty acids, while the Medium *n*-3 fillet contained 28% long-chain monoenes compared to 5% in fillets from the other groups. It is not clear, however, how these differences influence the perception of fattiness and juiciness, but these aspects may be of importance for processing and food acceptance. Thus, Thomassen & Røsjø (1989) found differences in colour, 'salmon odour' and 'salmon taste' in an organoleptic evaluation of Atlantic salmon fed capelin oil, soybean oil and rapeseed oils. Minor changes in flavour quality were detected by trained panellists in an organoleptic test of catfish (*Ictalurus punctatus*) which were fed diets varying in different least-cost feed ingredients (including lipid sources), while the average consumer was not able to discriminate between fish from the different dietary groups (Johnsen & Dupree, 1991). Despite species differences as regards nutritional requirements, this

**Table 3. Mean sensory scores (range 1—9) evaluated according to fish diets**

| Code | Parameter | Low − E (1) | Low + E (2) | Medium − E (3) | Medium + E (4) | High − E (5) | High + E (6) | Significance[a] |
|---|---|---|---|---|---|---|---|---|
| S1 | Odour intensity | 6·736 | 7·765 | 6·966 | 6·993 | 6·949 | 6·894 | |
| S2 | Off-odour | 1·826 | 1·745 | 1·758 | 1·791 | 2·190 | 1·904 | |
| S3 | Whiteness | 6·110 | 5·989 | 5·493 | 5·674 | 5·350 | 5·971 | 1 > 4, 3, 5; 2 > 3, 5; 6 > 3, 5 |
| S4 | Colour tone | 5·126 | 4·841 | 5·734 | 5·370 | 5·439 | 5·015 | 3 > 1, 6, 2; 5 > 2; 4 > 2 |
| S5 | Colour intensity | 4·456 | 4·339 | 5·331 | 4·728 | 5·103 | 4·370 | 3 > 4, 1, 6; 5 > 1, 6, 2 |
| S6 | Taste intensity | 6·960 | 7·063 | 7·209 | 7·189 | 7·153 | 7·078 | 3 > 1 |
| S7 | Soya flavour | 2·183 | 2·195 | 1·586 | 2·111 | 1·989 | 1·768 | |
| S8 | Herring flavour | 1·705 | 1·734 | 2·188 | 1·640 | 2·084 | 1·901 | |
| S9 | Rancid flavour | 1·743 | 1·701 | 1·875 | 1·479 | 2·120 | 1·754 | 5 > 4 |
| S10 | Off-flavour | 1·439 | 1·476 | 1·385 | 1·474 | 1·723 | 1·375 | |
| S11 | Fattiness | 5·564 | 5·591 | 5·933 | 6·079 | 5·715 | 5·820 | 4 > 2, 1 |
| S12 | Juiciness | 5·598 | 5·554 | 5·904 | 6·023 | 5·766 | 5·814 | 4 > 1, 2 |
| S13 | Coarseness | 4·836 | 4·803 | 4·859 | 5·020 | 4·840 | 4·711 | |
| S14 | Firmness | 5·185 | 5·299 | 5·056 | 4·855 | 5·100 | 4·970 | |

[a] According to Tukey (HSD) pairwise comparison of each parameter by diet. Rejection level at $P > 0.050$.

**Table 4. Mean sensory scores (range 1–9) evaluated according to treatments**

| Code | Parameter | Cooked | | | Smoked | Significance[a] |
|---|---|---|---|---|---|---|
| | | Fresh (A) | Frozen (B) | Stored (C) | (D) | |
| S1 | Odour intensity | 6·638 | 7·065 | 6·899 | 6·933 | B > A |
| S2 | Off-odour | 1·713 | 2·582 | 2·090 | 1·091 | B > A, D; C > D |
| S3 | Whiteness | 6·388 | 5·718 | 5·630 | 5·323 | A > B, C, D |
| S4 | Colour tone | 5·396 | 5·127 | 5·177 | 5·318 | |
| S5 | Colour intensity | 3·990 | 4·658 | 4·797 | 5·440 | D > B, A; C >A |
| S6 | Taste intensity | 6·728 | 7·219 | 7·228 | 7·258 | A < B, C, D |
| S7 | Soya flavour | 2·325 | 2·347 | 1·798 | 1·418 | D < C, A, B |
| S8 | Herring flavour | 1·718 | 2·450 | 2·268 | 1·065 | D < A, C, B |
| S9 | Rancid flavour | 1·573 | 2·235 | 2·272 | 1·034 | D < A, B, C |
| S10 | Off-flavour | 1·314 | 1·676 | 1·760 | 1·164 | D < A, B, C |
| S11 | Fattiness | 6·003 | 5·553 | 5·628 | 5·952 | |
| S12 | Juiciness | 6·506 | 5·463 | 5·562 | 5·574 | A > D, C, B |
| S13 | Coarseness | 4·419 | 5·276 | 5·073 | 4·612 | B > D, A; C > A |
| S14 | Firmness | 4·111 | 5·639 | 5·363 | 5·198 | A < D, C, B |

[a] According to Tukey (HSD) pairwise comparison of each parameter by treatment. Rejection level at $P > 0{\cdot}050$.

points to the possibility of partly replacing feed lipids to overcome adverse effects on organoleptic quality.

The comparison of the fillet treatments showed significant differences in 12 sensory parameters (Table 4). The flavour of soya, herring, rancidity and off-flavour were significantly lower in smoked salmon, indicating a masking by the processing. Less dry matter, salt/sugar treatment and smoking changed flavour and taste. The rancid flavour and off-flavour showed increasing scores with freezing and storage, which is most likely explained by lipid oxidation with time (Frigg *et al.*, 1990).

Fresh fillets were more juicy and less coarse and firm than the frozen, stored and smoked fillets. The slight increase in dry matter during freezing and storage may explain the observed changes in the texture parameters as well as the colour, as no changes in PUFA and $\alpha$-tocopherol content were found.

In summary, the present study clearly demonstrates the relationships between diet and fillet composition and sensory quality of the edible products with regard to *n*-3 PUFA and vitamin E of Atlantic salmon. Fillet fatty acid composition affects taste and texture and a high vitamin-E content improves sensory rancid flavour scores in fillets with increasing contents of *n*-3 PUFA. Thus, feed formulations which take into account preferences of the consumer with respect to sensory acceptability and quality and quantity of nutrients are possible. However, care must be taken to avoid possible negative effects related to taste and texture, and not least important, to the physiology of the fish itself (Waagbø *et al.*, 1992*a,b*).

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