Effects of Oxidized Herring and Canola Oils in Diets on Growth, Survival, and Flavor of Atlantic Salmon, *Salmo salar*†

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Atlantic salmon (*Salmo salar*) held in seawater were fed diets containing 10% added herring and canola oils or the same oils oxidized to two levels of peroxidation. Peroxide values (POVs) of test oils added to each of the test diets were, respectively, <1, 14, and 40 mequiv/kg of oil for fresh, slightly oxidized, and mildly oxidized oils for the herring oil based diets, while POVs were, respectively, <1, 5.5, and 17 mequiv/kg of oil for the corresponding canola oil based diets. The effect of oxidized oil on growth, survival, and flavor of Atlantic salmon after a 52-day feeding trial was examined. Oil type was not an important factor affecting fish survival and growth, but the weight gain of fish fed the diet containing mildly oxidized oil was significantly less than that of fish fed the diets containing fresh oil. Fillets from salmon fed the mildly oxidized herring and canola oils supplied in this study could not be distinguished by sensory panelists from fillets of fish fed the diets prepared with fresh oils.

INTRODUCTION

The world aquaculture industry continues to develop (Isaksson, 1988; Hoffmann, 1991), and the demand for formulated feeds (Haumann, 1989; Das et al., 1993) will increase. The market value of cultured fish such as salmon largely depends on their quality, and feed composition is one of the factors which controls that quality. Therefore, it is necessary to develop high-quality feeds that can produce faster growth in fish but at the same time retain flavor and taste similar to that of wild fish (Blokhus, 1987; Grant, 1989; Cho, 1990).

Fish oils have been a major lipid source in Atlantic salmon, *Salmo salar*, diet formulations due to the inclusion of highly unsaturated *n*–3 fatty acids (HUFA), which are essential for normal growth and survival of salmonids (Halver, 1989; Watanabe and Takeuchi, 1989; Cho, 1990). Marine lipids such as fish oil, in spite of their often high quality, are susceptible to oxidation due to the high content of HUFA of the *n*–3 series (Lindsay, 1990; Stansby, 1990; Bimbo and Crowther, 1992a,b). Although other fats have been tested (Hardy et al., 1987; Higgs et al., 1987; Dosanjh et al., 1988; Thomasson and Røsjø, 1989; Polvi and Ackman, 1992), their use is not common.

Despite ample research on salmonid survival and growth (Hung et al., 1981; Ketola et al., 1989; Oberbach et al., 1989; Hartfiel and Oberbach, 1990), very little is known about how the flavor of Atlantic salmon is affected by the degree of oxidation of oil in feeds, and this topic has received little attention despite its obvious importance (Blokhus, 1987; Hsieh and Kinsella, 1989). In our experiment, two types of oil, a marine (herring) oil and a vegetable (canola) oil, were used to investigate and compare the effect of dietary oxidized oils on growth and survival, together with fillet flavor, for Atlantic salmon.

It is known that oxidation of unsaturated fats and oils produces hydroperoxides and volatiles such as aldehydes and ketones, which change the flavor and taste of fish (Koizumi, 1989; Eun et al., 1993). Commercially available feeds are usually prepared by steam pelleting, or more recently by extrusion processes, and prior to use may be stored at ambient temperature for varying periods. Fish meal is a major ingredient in most diets, and not only can flavor components be stored in lipids, but they can also be taken up by proteins (Kinsella, 1990), an unexplored sector of salmon feed processing. We elected to use diets prepared by steam pelleting in case this feed produced or stored oxidation products as a consequence of the surface temperature effects during pelleting.

MATERIALS AND METHODS

Oxidation of Oils. The herring oil employed was a standard commercial oil from reduction of *Clupea harengus* in Nova Scotia. The canola oil was a retail product produced from *Brassica* sp. seed in Canada (Ackman, 1990), fully refined and with stabilizing antioxidants added.

About 1 kg each of herring and canola oils was oxidized at 40 °C in a 1-L flask by passing a slow flow of oxygen through the oil via a glass pipet. Peroxide values (POVs) of oils were measured according to AOCS method Cd-8-53 (AOCS, 1984). α-Tocopherol was measured as described by O'Keefe and Ackman (1987).

Test Diets. The fresh and oxidized oils were added with thorough mixing to steam pellet-type diets (4-mm diameter) at a 13.8% level (Tables 1 and 2). The protein (48%) was provided by five protein sources. Vitamin E (α-tocopherol) was *not* added to the vitamin mixture. Protein analysis of test diets was conducted according to AOAC method 7.010–7.059 (AOAC, 1984). The fatty acid compositions of the diets were determined as described by Polvi and Ackman (1992). Test diets were stored at −20 °C until feeding.

Growth Trial. Atlantic salmon smolts were placed in 2-m³ fiberglass round tanks in the Aquatron Laboratory of Dalhousie University, Halifax, NS. Fish were fed on a commercial feed (Fundy Choice, Corey Feed Mills Ltd., Fredericton, NB) under ambient temperature and salinity conditions until ready for use in the experiment.

Twenty-eight or 29 fish (mean wet weight 266 g), per tank per dietary treatment, were redistributed in the tanks for the growth trial. They were individually identified by jet injection of Alcian

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Table 1. Composition of Test Diets

ingredient	g/100 g of dry wt	ingredient	g/100 g of dry wt
herring meal	42.5	whey, spray dried	8.0
feather meal	4.2	added oil[a]	13.8
soybean meal	10.0	vitamin mixture[b]	2.0
brewers' yeast	4.0	mineral mixture[c]	2.0
blood meal	3.0	DL-methionine	0.2
wheat middlings	10.1	choline chloride	0.2

[a] Two kinds of oil (herring and retail canola oil) were oxidized to different extents: HF, fresh herring oil; HS, slightly oxidized herring oil; HM, mildly oxidized herring oil; CF, fresh canola oil; CS, slightly oxidized canola oil; CM, mildly oxidized canola oil. [b] (IU or mg/kg): thiamin, 40; riboflavin, 50; *d*-calcium pantothenate, 150; biotin (1%), 0.08; folic acid, 15; vitamin B_{12}, 0.1; niacin, 200; pyridoxine hydrochloride, 30; ascorbic acid, 1000; inositol, 400; ethoxyquin, 125; vitamin K, 30; vitamin A, 6000 IU; vitamin D_3, 4000 IU. [c] (mg/kg): manganese, 50; iron, 60; zinc, 120; copper, 15.

Table 2. Analytical Results for POV and α-Tocopherol Contents of Dietary Oils and Proximate Composition of Test Diets

	herring oil[a]			canola oil[a]		
	HF	HS	HM	CF	CS	CM
oil POV (mequiv/kg)	<1	14	40	<1	5.5	17
oil α-tocopherol (μg/g of oil)	227	226	<1	262	249	245
moisture (%)	3.8	4.6	5.5	4.1	4.8	4.0
crude protein[b] (%)	48.0	48.0	48.0	48.0	48.0	48.0
crude lipid[b] (%)	19.6	20.2	19.6	20.4	21.6	20.7
crude ash[b] (%)	8.1	8.2	8.0	8.3	8.1	8.2

[a] HF, fresh herring oil; HS, slightly oxidized herring oil; HM, mildly oxidized herring oil; CF, fresh canola oil; CS, slightly oxidized canola oil; CM, mildly oxidized canola oil. [b] Dry weight basis.

Blue (Coombs et al., 1990) on one side of the body. Oxygen-saturated, sand-filtered seawater was continuously supplied to each tank at a flow rate of 7–9 L/min; while the trial was conducted the water temperature ranged from 4 to 10 °C over a 52-day period. Tanks were illuminated from 8:00 a.m. to 7:00 p.m. during the experimental period, and fish were fed to satiation twice a day, at 9:00 a.m. and 5:00 p.m.

The following parameters were used to evaluate fish growth: final wet weight (FW, g); percentage weight gain (WG) = $(W_1 - W_0) \times 100/W_0$; final fork length (FL, cm); percentage fork length increase (LI) = $(L_1 - L_0) \times 100/L_0$; feed conversion efficiency (FCE) = $(W_1 - W_0)/D_i$; and condition factor (CF) = $W_1 \times 100/L_1^3$ [W_1 is the final wet weight (g), W_0 is the initial wet weight (g), L_1 is the final fork length (cm), L_0 is the initial fork length, and D_i is the dry diet intake (g)].

Two-way analysis of variance (ANOVA, Super Anova, Abacus Concepts Inc., Berkeley, CA) was applied to the data and Duncan's multiple-range test (Super Anova, Abacus Concepts) was used to determine significant differences between individual treatments when significance ($p < 0.05$) of factors was detected by ANOVA.

Sensory Evaluation. The effect of dietary oxidized oil on taste of Atlantic salmon was evaluated using a triangle test with 10 panelists (Larmond, 1982). Cooked fillets of Atlantic salmon randomly selected from each diet group were supplied to the panelists.

RESULTS

Changes of POV and α-Tocopherol Contents in Herring and Canola Oils by Oxidation. The POV was used to monitor the degree of oxidation for herring and canola oils. POVs of fresh (HF), slightly oxidized (HS), and mildly oxidized (HM) herring oils were 1, 14, and 40, respectively, while those of fresh (CF), slightly oxidized (CS), and mildly oxidized (CM) canola oils were 1, 5.5, and 17, respectively. The patterns of oxidation are presented in Figure 1. Although POVs increased with time in both oils, the POV of herring oil increased faster

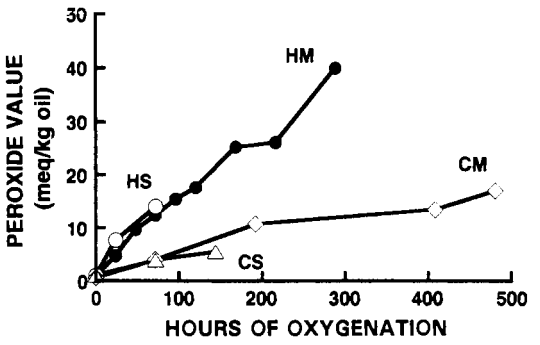

Figure 1. Development of oxidation in herring and canola oils. HS, slightly oxidized herring; HM, mildly oxidized herring; CS, slightly oxidized canola; CM, mildly oxidized canola.

Table 3. Composition (W/W%) of Important Fatty Acids in Test Diets

	herring oil based diet[a]			canola oil based diet[a]		
fatty acid	HF	HS	HM	CF	CS	CM
14:0	7.5	7.9	7.4	1.8	1.5	1.8
16:0	13.0	13.2	13.1	8.2	7.4	7.8
18:0	1.2	1.2	1.2	1.9	1.9	1.8
16:1*n*-7	6.6	6.7	6.7	1.9	1.7	1.9
18:1*n*-9	8.3	8.2	8.3	42.4	44.4	42.3
Σ 20:1	15.8	15.5	15.8	5.0	4.8	5.2
Σ 22:1	21.4	21.0	21.1	4.9	4.6	5.1
Σ satd + mono FA	73.8	73.7	73.6	66.1	66.3	65.9
18:2*n*-6	3.7	3.7	3.7	17.3	17.7	17.1
18:3*n*-3	0.9	0.9	0.9	6.5	6.7	6.4
18:4*n*-3	1.8	1.8	1.8	0.3	0.3	0.3
20:4*n*-6	0.3	0.3	0.3	0.1	tr	tr
20:4*n*-3	0.3	0.3	0.3	0.1	0.1	0.1
20:5*n*-3	5.3	5.3	5.2	1.6	1.5	1.6
22:5*n*-6	0.1	0.1	0.1	0.1	0.1	tr
22:5*n*-3	0.6	0.6	0.8	0.1	0.2	0.3
22:6*n*-3	5.0	4.9	4.8	2.4	2.2	2.5
total PUFA	18.0	17.9	17.9	28.5	28.8	28.3
others	8.2	8.4	8.5	5.4	4.9	5.8
Σ dietary *n*-6 FA	4.1	4.1	4.1	17.5	17.8	17.1
Σ dietary *n*-3 FA	13.9	13.8	13.8	11.0	11.0	11.2
Σ dietary *n*-3 HUFA	11.2	11.1	11.1	4.2	4.0	4.5

[a] Abbreviations are the same as those in Table 2.

than that of canola oil under the same conditions of heating and rate of oxygen flow. POVs for herring oil of 14 mequiv/kg of oil for mildly oxidized oil and 40 mequiv/kg of oil for slightly oxidized oil were obtained at 72 and 288 h, respectively, while for canola oil 6 mequiv/kg of oil for mildly oxidized oil and 17 mequiv/kg of oil for slightly oxidized oil required, respectively, 144 and 480 h.

The initial α-tocopherol contents (Table 2) were typical of herring oil (Ackman and Cormier, 1967) and canola oil (Ackman, 1990). The α-tocopherol content during oxygen exposure was followed over time in both oils, but the patterns were very different. In mildly oxidized herring oil, the α-tocopherol content fell abruptly to less than 1 μg/g of oil (Table 2), whereas in canola oil little or no change with time was found. The retail canola oil contained a standard antioxidant mixture (BHA, BHT, citrate, total <200 ppm).

Effects of Supplemental Oxidized Oil and Type of Oils on Fatty Acid Composition of Test Diets. The fatty acid composition (w/w%) of the lipid of the test diets is shown in Table 3. The degree of oxidation of the added oils did not change the fatty acid composition of those oils (not shown) and so had no effect on the total dietary fatty acids supplied to any group. The lipids of the herring oil diets contained about 11% *n*-3 highly unsaturated fatty acids (HUFA), whereas the canola oil diets contained 4%

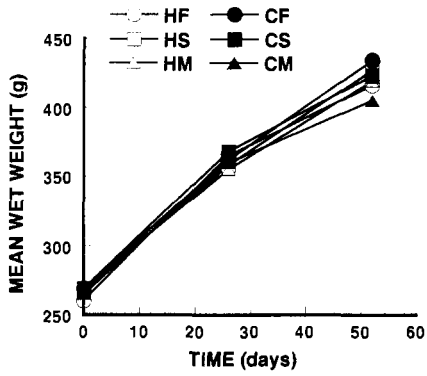

Figure 2. Mean wet weight of Atlantic salmon fed test diets. HF, fresh herring oil based diet; HS, slightly oxidized herring oil based diet; HM, mildly oxidized herring oil based diet; CF, fresh canola oil based diet; CS, slightly oxidized canola oil based diet; CM, mildly oxidized canola oil based diet.

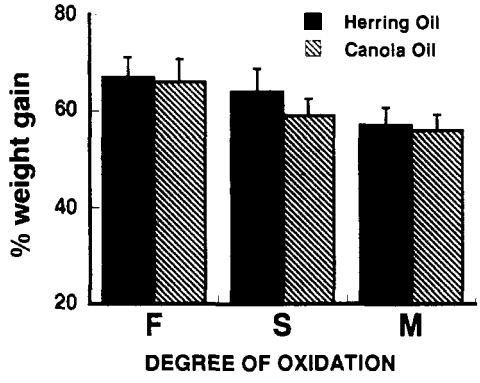

Figure 3. Percent weight gain of Atlantic salmon fed test diets. F, fresh oil; S, slightly oxidized oil; M, mildly oxidized oil.

HUFA contributed by the fish meal. The 18:3*n*–3 (linolenic) acid is not included in this HUFA total. Total dietary *n*–6 fatty acids in the lipids of the canola oil diets were much higher than those in the herring oil diets (17% vs 4%, respectively). The herring oil diets had more saturated acids. The fatty acids of the canola oil diets, which were higher than those in the herring oil based diets, were 18:1*n*–9, 18:2*n*–6, and 18:3*n*–3 (Table 3). Conversely, the herring oil diets contained much higher proportions of the longer-chain monoethylenic acids 20:1 and 22:1, leading to the monoethylenic totals being about the same.

Survival and Growth. There was no mortality during the trial. As shown in Figure 2, fish in all diet groups grew well. The highest mean wet weight at the end of trial was obtained in fish fed on CF followed by HS, CS, HM, HF, and CM, respectively (Figure 3 and Table 4). The percent weight gains of fish fed on herring oil diets were higher than those of fish fed on canola oil diets of the same degree of oil oxidation (Figure 3 and Table 4), but statistical significances were not detected. Within each oil group the degree of oxidation had a significant effect on the percent weight gain. When the effect of oil sources, which was not statistically significant, was eliminated, the percent weight gains of fish fed on diets containing either fresh oils or slightly oxidized oils were not statistically significant. However, significant differences were detected between diets with fresh and mildly oxidized oils. Neither the effects of oil sources nor of degree of oxidation were significant with respect to FCE (Table 4). Percent fork length increase was significantly reduced as POV increased in both herring and canola oil diet groups. Furthermore, percent fork length increase was significantly higher in fish fed diets containing herring oil than in fish fed canola oil of the same degree of oxidation. Neither oil sources nor degree of oxidation significantly affected the condition factor in any treatment group (Table 4).

Sensory Evaluation. As shown in Table 5, there were no statistically meaningful flavor results due to sensory panelists detecting different-tasting fillet samples from any treatment groups. Although 4 panelists of 10 marked fish muscle from the HS, CF and CS groups as different and 3 panelists of 10 marked odd samples of fish muscle from the HM and CM groups compared to the HF group (serving as a control), these could all represent a random choice (Larmond, 1982).

DISCUSSION

It should be noted that herring and other fish meals usually contain about 10% lipid (Gunnlaugsdottir and Ackman, 1993). Basically this is a mixture of fish oil triacylglycerides and muscle phospholipids, with some free acids (de Koning et al., 1986; Urdahl, 1992; Bimbo and Crowther, 1992b). This lipid may include some oxidation products. It is usually assumed that these have reacted with protein and the balance of the lipid, including the fish lipid HUFAs, may be protected by ethoxyquin, which is usually added at about 300 ppm in the final stage of fish meal manufacture (Bimbo, 1990; Bimbo and Crowther, 1992b).

The contents of polyunsaturated fatty acids (PUFA) in the oxidized oils were expected to be reduced through the destruction of the *n*–3 fatty acids by oxidation (Ke et al., 1975; Hung et al., 1980; Hung and Slinger, 1981; Kaneda, 1983; Cho et al., 1987; Murai et al., 1988). However, the degree of oxidation applied to the oil in this study was not severe enough to recognizably deplete the dietary content of total *n*–3 fatty acids after the oils were mixed with other ingredients such as fish meal or soybean meal, respectively, additional sources of HUFA and 18:3*n*–3.

The different patterns of oxidation between herring and canola oils may be due in part to inclusion of synthetic antioxidants in canola oil. Although there were no measurements made on the contents of synthetic antioxidants in canola oil after oxidation, the relatively modest starting contents were clearly effective in protecting against autoxidation. They were no doubt aided by the γ-tocopherol (Hartfiel and Oberbach, 1990). This is the major tocopherol in canola oil (Ackman, 1990) and a very effective oil antioxidant in the right circumstances (Gottstein and Grosch, 1990; Jung and Min, 1990). It was therefore difficult to oxidize canola oil up to the same POV as herring oil through the same times of heating and rate of oxygenation. The fact that the contents of α-tocopherol in canola oil did not appreciably decrease under the condition of oxidation applied in this experiment is of interest since the POV of the CS oil exceeds that acceptable in such oils for human nutrition (Hawrysh, 1990).

In the hepatopancreas of juvenile shrimp *Penaeus monodon*, *all* synthetic dietary antioxidants tested (BHA, BHT, propyl gallate, ethoxyquin) affected organ histopathology adversely but did not affect growth (Bautista et al., 1992). However, the hepatopancreas in crustacea is not only the main depot fat storage organ but also a functional organ (Ouellet et al., 1992). Subcellular effects of such synthetic antioxidants have been noted in catfish muscle microsomes (Eun et al., 1993), but α-tocopherol is assumed to be always normal and beneficial in fish (Ferguson et al., 1986). The role of γ-tocopherol is less clear (Erickson, 1992).

Since there was no mortality in any treatment group, the degree of oxidation in dietary oils employed in this experiment was not toxic enough to cause mortality of

Table 4. Growth Performance of Atlantic Salmon Fed Diets Containing Oxidized Herring and Canola Oil[a]

parameter	herring oil based diet[b]			canola oil based diet[b]		
	HF	HS	HM	CF	CS	CM
initial wt (g)	260.4 ± 50.0	266.5 ± 67.9	268.9 ± 64.8	269.1 ± 71.3	268.9 ± 42.1	264.6 ± 57.8
initial fork length (cm)	29.7 ± 1.9	29.9 ± 2.2	30.0 ± 2.2	30.0 ± 2.4	30.3 ± 1.5	29.8 ± 2.0
final wt (g)	415.5 ± 59.1	426.9 ± 78.3	419.1 ± 78.7	434.2 ± 85.6	423.0 ± 54.1	405.0 ± 72.1
final fork length (cm)	33.4 ± 1.8	33.4 ± 1.9	33.2 ± 1.8	33.4 ± 2.2	33.4 ± 1.4	32.7 ± 1.9
wt gain (%)	66.7 ± 20.8	64.0 ± 26.4	57.2 ± 19.7	66.2 ± 27.3	59.1 ± 19.2	55.5 ± 17.7
length increase (%)	12.7 ± 2.5	11.6 ± 3.7	10.7 ± 3.3	11.6 ± 3.2	10.3 ± 3.6	9.9 ± 2.8
condition factor[c]	1.1	1.1	1.1	1.2	1.1	1.2
FCE[d]	1.1 ± 0.2	1.1 ± 0.3	1.0 ± 0.3	1.1 ± 0.3	1.1 ± 0.3	1.0 ± 0.2
no. of fish	29	29	29	29	28	29

[a] Values are mean ± standard deviation. [b] Abbreviations are the same as those in Table 2. [c] Body weight (g) × 100/(fork length (cm))^3. [d] Feed conversion efficiency = (wet wt gain/dry diet fed).

Table 5. Results of Sensory Evaluation for Atlantic Salmon Fed Diets Containing Herring and Canola Oils with Three Levels of Oxidation (Fish on HF Diet Served as the Control)

dietary treatment[a]	no. of panelists[b]	dietary treatment[a]	no. of panelists[b]
HS	4	CF	4
HM	3	CS	3
		CM	4

[a] Abbreviations are indicated in the text. [b] Panelists who identified odd samples as different from HF samples (of 10 panelists).

salmon under the experimental conditions applied. It can be assumed that the POV of lipids extracted from the test diets should be lower than that of the test oils used due to the mixing of oxidized oils with other ingredients (Table 1). For example, a reduction of POV from 84 to 26 mequiv/kg of oil in diet fat occurred when oxidized Alaska pollock liver oil was mixed with other dietary ingredients in the study of Murai et al. (1988). A POV of <10 mequiv/kg of oil is recommended for oils for feeding fish (Hilton and Slinger, 1981). Since peroxides, primarily hydroperoxides (HPO), are thought of as early toxic products of autoxidation (Hung et al., 1981; Oberbach et al., 1989), it is usually assumed that any effect on the fish performance in a trial is likely from HPO, although many animals cope with peroxidized lipids at the intestinal wall. This presumes that sufficient selenium in the form of glutathione peroxidase is available (Aw et al., 1992; Chow, 1992). The total weight gain in 52 days was superior to that of Atlantic salmon of comparable initial size fed herring silage or a commercial pelleted feed (Li et al., 1990). The latter study was, however, conducted at a water temperature of as low as 2.5 °C, which would presumably reduce feed intake.

Although no oxidized oil significantly reduced FCE, the percent weight gain and length increase were significantly decreased by feeding diets containing either of the mildly oxidized oils (HM and CM groups) in this experiment. The degree of oxidation in this mildly oxidized oil may be close to an upper limit which still maintains good survival and growth in Atlantic salmon. Recently, it was reported that yellow tail, *Seriola quinqueradiata*, showed 23% mortality and poor growth when fed on a diet with a POV of 26 mequiv/kg of oil (Murai et al., 1988), yet in a later study a sardine oil with a POV of 100 mequiv/kg of oil was tolerated by this species (Sakai et al., 1992). However, weight gain and mortality of rainbow trout were not significantly different when fed diets containing herring oil in which the POV ranged from 6 to 51 mequiv/kg of oil (Hung et al., 1980). A mixture of fish oil and sunflower seed oil with a POV as high as 550 mmol/kg will affect the health of rainbow trout (Oberbach et al., 1989). In another study, when rainbow trout were fed on a diet containing herring oil with a POV of 120 mequiv/kg of oil, mortality occurred although growth was not reduced by the oxidized oil (Thomassen and Røsjø, 1989). Peroxides will partially degrade in carp intestine (Hata et al., 1981). Important levels of (hydro)peroxides are not necessarily lethal in mammals (Chow, 1992), suggesting that the secondary decomposition products of shorter chain length are the toxic agents (Oarada et al., 1986, 1988). This toxicity of secondary products of peroxide breakdown (e.g., aldehydes, ketones) is commonly ignored as a possibility, possibly because analytical methodology is far more complex than are simple POV units. In future research more attention should also be paid to aldehydes and similar peroxide degradation products from both the toxicity and flavor points of view. Although the anisidine value (AV) is available to complement POV, it may thus be too simple an approach, and profiles of flavor volatiles may be a better answer to questions of fish health as well as quality. Dietary factors such as the quantity of selenium biologically available may also explain some of the variability in results for fish exposed to oxidized fats as summarized above. In one study selenium appeared to be less critical than vitamin E (Oberbach and Hartfiel, 1988).

Physiological effects of thermally oxidized oils undoubtedly can be observed (Chow, 1992; Ruiz-Guitierrez and Muriana, 1992), but reduced growth has an alternative and frequently ignored explanation. This is the reduced digestibility of partially polymerized triacylglycerides due to their partial resistance to digestive lipases (Márquez-Ruiz et al., 1992). It is now possible to test the dietary oils for dimeric compounds by high-performance liquid chromatography (HPLC), as shown by these authors, and this oil property should also be included in future studies of the impact of oxidized fats on animal growth.

Sensory evaluation in the present study failed to detect a significant effect of diet on salmon muscle flavor. Although 3–4 of 10 panelists reported a different taste of fish fed diets containing slightly and mildly oxidized herring and canola oils, this could have been from a random choice. In a study of Atlantic salmon, Thomassen and Røsjø (1989) suggested that dietary vegetable oils should be added to practical diets with caution due to possible changes of taste and odor. We did not find this effect with canola oil, confirming our previous results (Polvi and Ackman, 1992). The Atlantic salmon is a relatively strong-flavored fish, and parts of this flavor could be normal shorter-chain oxidation products (Ke et al., 1975; Karahadian and Lindsay, 1989). These can be produced biochemically *in vivo* (Lindsay, 1990). It is more difficult in salmon to distinguish oxidation effects among natural fresh fish flavors with the facility demonstrated in the more bland-flavored chicken fed fish meal (O'Keefe et al., 1994). However, it is likely that the degrees of oxidation of the canola oil fed in the present study are completely acceptable for the practical diet of Atlantic salmon in terms

of survival, growth, feed conversion efficiency, and taste under the experimental conditions applied in the present study. As long as growth is adequate, some small quality changes may be of little interest to growers of commercial fish for food purposes. For example, color of salmon is a more critical feature of salmon at the point of sale (Waagbø et al., 1993).

The 45% herring meal (Table 1) presumably provided some α-tocopherol and ethoxyquin to both diets. In catfish fed oxidized menhaden oil these antioxidants have different roles *in vivo* (Murai and Andrews, 1974). Similar results were obtained with rainbow trout by Hung et al. (1981), who found a minimal need for additional vitamin E in practical diet studies lasting 24 weeks. Sakai et al. (1992) also confirmed for yellowtail that pathological changes did not necessarily follow feeding of moderately oxidized oils. Our experiment did not include the physiological details recorded by these authors.

The present study demonstrates that canola oil, containing more γ- than α-tocopherol (Ackman, 1990), can be useful as a supplemental dietary lipid for growing Atlantic salmon in seawater. Flavor was not differentiated from a commonly used herring oil type of diet. Similar good growth results were also obtained from other studies with the same vegetable oil in the same species reared in seawater (Thomassen and Røsjø, 1989; Polvi and Ackman, 1992). Other salmon studies have indicated that canola oil can be useful as a dietary lipid source for the Pacific coho and chinook salmon reared in freshwater before smoltification (Higgs et al., 1987; Dosanjh et al., 1988).

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