TAILORING FARMED ATLANTIC SALMON WITH LOWER LEVELS OF PERSISTENT ORGANIC POLLUTANTS

Marc H.G. Berntssen[1*], Åge Oterhals [2], Øyvind Lie[1], and Anne-Katrine Lundebye[1]

[1]National Institute of Nutrition and Seafood Research, P.O. Box 2029 Nordnes
5817 Bergen Norway.
[2] Norwegian Institute of Fisheries and Aquaculture Research, 5141 Fyllingsdalen, Bergen, Norway

* Corresponding author. e-mail: marc.berntssen@nifes.no

Introduction

Fatty fish can be an important source for human exposure to persistent organic pollutants (POPs) such as PCDD/F, DLPCB, and PBDE, however farmed fatty fish can be tailored in such a way that consumer exposure to POPs is reduced. Fish oils, extracted from marine pelagic fish species, used in high energy fish feeds are considered to be the main source of POPs in farmed salmon [1, 2]. Several strategies are being developed to produce farmed fatty fish low in POPs by designing diets and optimizing feeding strategies taking into account sustainable aquaculture and fish welfare. There are three main approaches that singularly or in combination can reduce the levels of POPs in fish feed and consequently in farmed fish. One is to select marine fish oils with relatively low natural levels of dioxins [3, 4]. Besides seasonal variation, there is a large variation in fish oil PCDD/F and DLPCB levels depending on factors such as fish species, age, or geographical origin [5, 6]. Another strategy is to substitute fish oil with terrestrial feed ingredients that contain lower levels of dioxins than fish oils. Vegetable oils have lower PCDD/F and DLPCB levels than most commonly used fish oils, and the substitution of fish oil with vegetable oil has great potential to reduce the level of dioxins in farmed salmon [7, 8]. Finally, several techniques exists that can remove POPs from fish oils without affecting the nutritional status of the oils.

The present abstract aims to give an overview of current and envisaged strategies to control and reduce the levels of POPs in farmed fish, partly based on previously published work.

Material and methods

The potential to reduce the levels of persistent organic pollutants, such as PCDD/F and DLPCB was investigated in a series of experiments using different approaches. In the first experiment, Atlantic salmon (*Salmo salar* L) with a inital mean weight of 1.8 kg was fed one two diets with low or high levels of dioxin and dioxin-like PCB for 7.5 months, in triplicate (final mean weight was 4.9 kg). The fish oil with a low natural background level of POPs, including PCDD/F and DLPCB, was based on pelagic fish of Pacific Ocean origin, the fish oil with high natural background levels was based on pelagic fish from the Baltic sea (for details see Lundebye et al. [4]).
In the second experiment Atlantic salmon were fed a fish oil based feed or a 100% substituted vegetable oil based feed throughout an entire production cycle (from start feeding at 0.5 g until slaughter size at 2.2 kg), in triplicate for 22 months (for details see Berntssen et al. [8]). Dietary accumulation efficiency (AE) for PCDD/F, DLPCB and their different groups of chlorination substitution were calculated according to Isosaari et al. [3, 9].

$$AE\ (\%) = \frac{Cfish_{corr}}{FtC_{feed}}$$

Where $Cfish_{corr}$ is the concentration in fish (pg WHO-TEQ g^{-1} ww) corrected for growth and initial concentration , C_{feed} is the concentration in feed (pg WHO-TEQ g^{-1} ww), and F is the daily feed consumption per growth gain (kg kg^{-1} growth d^{-1}). In calculating accumulation efficiency no corrections were made for elimination, and thus this value represents the net effect of absorption and elimination. In both experiments, fish and feed were analysed for those PCDD/F and DLPCB congeners which have been assigned Toxic Equivalency Factors (TEFs) by the WHO, and results are given as WHO-TEQ (LOQ-upperbound).
Finally, the efficacy of removing PCDD/F, DLPCB as well as PBDE (given as sum 28, 47, 99, 100, 154, 153) was assessed using two commercially relevant cleaning techniques. The two techniques were involved either active carbon absorption or short path distillation. In addition to POPs, levels of lipid soluble vitamins (A, D, K, E) were analysed.

Results and Discussion

Table 1 shows the concentrations of PCDD/F and DLPCB in fish oils, feed and fillets from salmon reared on three different diets designed to give graded levels of PCDD/F and DLPCB. Two diets were based on fish oils, one with a high and one with a low background level, and one on a mixture of vegetable oils. Fish oils that are used in commercial fish feeds, have a large variation in the natural background levels and relative composition of PCDD/F and DLPCB. Fish oils from pelagic fish species of Pacific Ocean origin have generally a much lower PCDD/F and to a lesser degree lower DLPCB levels than fish oils obtained from fish originating from the (North) Atlantic Ocean (EC 2000a). Besides geographical variation, there is a large variation in fish oil PCDD/F and DLPCB levels depending on factors such as fish species, age, or seasonal variation [5, 6]. During early spring, when the fat content decreases in pelagic fish species from the North Atlantic, the concentration of PCDD/F and DLPCB increases four to six times in the obtained oil compared to fish oil obtained during winter [5].

Table 1 shows that the selective use of fish oils from a geographical area with naturally low levels of PCDD/F and DLPCB, such as oil obtained from fish of Pacific Ocean origin, reduced the levels of PCDD/F in the farmed fish but to a lesser degree the DLPCB levels [4]. The relatively low reduction in fillet DLPCB levels by using “low POP fish oils” is the combined effect of the relatively high contribution of DLPCB to the total WHO-TEQ level in these oils, and the dominant carry over of DLPCB from feed to fish. The accumulation efficiency of DLPCB was 72% whereas for PCDD/F the accumulation efficiency was 49%. Among PCDD/F, the high chlorinated congeners (hexa-octa) have a lower accumulation efficiency than the lower chlorinated (tetra-penta) congeners. The dominant accumulation of DLPCB caused the relative level of DLPCB to be higher in fish than in feed and oils. The ratio PCDD/F versus DLPCB in the first diet of table 1 was 1:1 whereas in fish the ratio was 1:2. Salmon fed a “low POP” fish oil diet had a total-TEQ PCDD/F and DLPCB level of 2.9 ng WHO-TEQ kg^{-1}ww, which was not lower than the average level found in commercial Norwegian farmed Atlantic salmon fillets (approximately 2.5 ng WHO-TEQ kg^{-1} ww, [10]).

Substitution of marine oils with vegetable oils has been shown to be an effective approach to reduce the levels of both dioxins and dioxin-like PCBs in fish feeds and farmed salmon [8]. The full substitution of fish oil with a vegetable oil mixture gave a sum-TEQ PCDD/F and DLPCB (0.2 ng WHO-TEQ kg^{-1}ww, Table 1) that is eleven to twelve times lower than the current level found in commercial Norwegian farmed Atlantic salmon fillets. The use of vegetable oils in commercial fish feeds seems to be a valuable tool for tailoring farmed Atlantic salmon low in dioxins and dioxin-like PCBs, and can therefore reduce the total intake of these contaminants by the consumers of farmed fish. The increased use of vegetable oils in fish farming, however, will also reduce the level of the health promoting nutrients such as very long chain omega 3 poly unsaturated fatty acids (VLCn-3 PUFAs) [11]. Clearly, there is a trade-off between reducing undesirable substances and maintaining the nutritional value when tailoring farmed fish that is low in contaminants by using vegetable oils in the diet. One approach to reconstitute the typical marine fatty acids in salmon fed on vegetable diets, is feeding with a full fish oil diet as a finishing diet during the last phase of salmon culture, until market size.

Table 1. Concentrations and ratio of PCDD/F and DLPCB (as WHO-TEQ pg/g) in fish oil, feed and fillet of consumer sized Atlantic salmon (mean±SD) fed on feeds based on fish oil with high or low natural background levels of POP, as well as feeds based on vegetable oils.

	High POP fish oil		Low POP fish oil		Plant oils	
	PCDD/F	DLPCB	PCDD/F	DLPCB	PCDD/F	DLPCB
Oil	14.05	14.91	1.08	6.01	0.40	0.05
Fish feeds	4.89	5.40	0.71	2.79	0.25	0.08
Fillet	1.86±0.04	3.23±0.06	0.48±0.05	1.81±0.11	0.07±0.01	0.12±0.01

Table 2. Accumulation efficiencies (α %) for PCDD/F and DLPCB congeners in Atlantic salmon fed a fish oil diet (n=3, mean±SD). Dioxins are divided into a group with a low degree of chlorination (Tetra-Penta chlorine) and relatively low WHO-Toxic Equivalency Factors (WHO-TEF), and high chlorination (Hexa-Octa) and high WHO-TEF. Dioxin-like PCBs were divided into non-ortho chlorinated PCB with relatively high WHO-TEF and mono-ortho PCB with lower WHO-TEFs.

Congeners (chlorination)	TEF WHO	α (%)	Congeners (chlorination)	TEF WHO	α (%)
PCDD/F	1.0-0.0001	43±6	**DLPCB**	0.1-0.00001	74±9
Tetra-Penta	1.0-0.5	49±7	Non-ortho	0.1-0.0001	72±9
Hexa-Octa	0.1-0.001	27±5	Mono-ortho	0.0005-0.00001	75±8

Decontamination of fish oils by the technical removal of POPs while maintaining the oil's nutritional value, is a further option that may support the production of Atlantic salmon low in contaminants and high in health promoting nutrients. The use of active carbon as a cleaning technique removes PCDD/F but to a lesser degree DLPCB, of which the mono-ortho PCB are removed least effectively. PBDEs are not removed by active carbon. The use of short path distillation techniques gave, depending on the process conditions, a maximum 98-99% reduction in PCDD/F and DLPCB, as well as PBDE (Table 3). However, there was a concomitant decrease in the concentrations of lipid soluble vitamins such as E and D (Figure 1). The maximum loss of vitamin D and E occurred during the optimal processing conditions for removing POPs which includes the use of an additive that enhances POP removal, vitamin D and E were 70% and 85% of control levels, respectively.

Table 3. Concentrations of PCDD/F, non-ortho DLPCB, mono-ortho DLPCB (as WHO-TEQ pg/g), and PBDE (as sum of PBDE 28, 47, 100, 99, 154, 153 pg/g) in commercial fish oil (control) cleaned with active carbon or short path distillation.

	PCDD/F	Non-*o*-DLPCB	Mono-*o*-DLPCB	PBDE
Control	8,83	9,4	2,62	20588
Active carbon	0,13	1,22	2,02	20313
Short path distillation	0,21	0,12	0,03	292

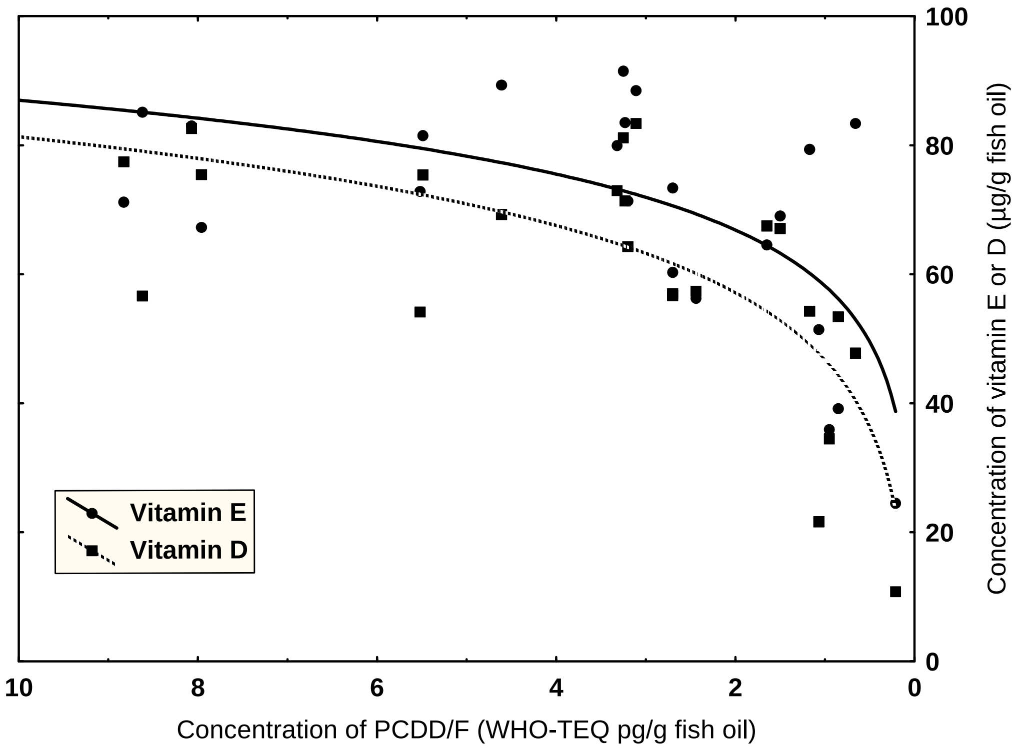

Figure 1. Concentration of vitamin E and D in fish oils under processing conditions during short path distillation causing increased removal of PCDD/F from fish oil.

Conclusion

Farming of fish gives the opportunity to control and reduce the levels of contaminants that are important with regards to seafood safety. Current and future development of novel feeds in aquaculture will be a trade-off between reducing contaminants and maintaining the nutritional value of farmed fish.

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