

Fish oil replacement in aquafeeds

It is clear that current levels of fish oil use in aquaculture are not sustainable. While sustainable alternatives to fish oil must be identified, a key consideration will be to ensure that aquaculture products provide the same health benefits offered by products from the natural fisheries. This involves handling issues that require a clear understanding of fatty acid requirements and utilization by aquatic species. This article provides a succinct overview of the issues and presents the latest advances in fish oil replacement R&D.

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It is generally accepted that eating fish is beneficial for human health, mainly due to the protective effect of fish lipid against cardio-vascular diseases. The supply of essential fatty acids (EFA) for humans from the aquatic food chain is even considered as having played a major role in human evolution, especially with regard to brain development (Broadhurst et al. 1998; Arts et al. 2001). The major components involved are the poly-unsaturated fatty acids of the w3 series (w3-PUFA), abundant in seafood in general. Since world catches of wild fish have reached a plateau at about 90 million metric tons (MMT) per year, it is clear that this natural source of long chain w3 fatty acids is limited. It follows then that meeting the increasing demands for such beneficial and essential nutrients for human populations relies on aquaculture development. At the present stage, global aquaculture production adds to world fish supplies. However, in order that aquaculture continues to contribute to world fish supplies, it must reduce wild fish inputs in feed.

Indeed, some commentators consider the development of aquaculture as a “mixed blessing for the sustainability of ocean fisheries” (Naylor et al. 2000). The common reproach against aquaculture practices is that at least in some cases, several kilograms of wild fish are required to produce each

kilogram of reared fish, thus aggravating rather than alleviating the predicted wild fish shortage. Indeed, growth of feed-based aquaculture, especially of species such as salmonids or the majority of marine fish and shellfish is also, strangely enough, linked to the availability of “feed-grade” fishery by-products such as fish meal and fish oil. Recent estimations suggest that on a global basis, the aqua feed industry uses about 2.5 MMT of fish meal and about 0.7 MMT of fish oil, representing respectively 40% and 60% of the global fish meal and fish oil production. It is also foreseen that within a decade or so, there will not be enough fish oil to meet the quantity required for aquaculture (New & Wijkstroem 2002).

Following the very early studies by Lee & Putnam (1973), fat levels in fish feeds have been increasing in order to decrease the DP/DE ratios thus bringing about significant improvement in protein utilization and reduction in nitrogenous waste production. Advances in feed processing technology have also contributed towards the development of high energy (fat) diets, especially in the case of salmonids. Currently, salmonid diets often have fat levels in the range of or even exceeding 30%. This has consequently led to an increase in demand for fish oil over the past decade and also increased interest in replacing fish oil by other lipid sources.

Yet another way of looking at this can be from a theoretical mass balance analysis of w3 fatty acids supplied and recovered. Taking the production of nearly 1 MMT of salmon as an example, and assuming a feed : gain ratio of 1 and a dietary fish oil content of about 20%, this would imply that about 200,000 MT of fish oil is used, corresponding to about 25,000 MT of the two major w3-HUFA, namely EPA (20:5w3) + DHA (22:6w3) supplied in the feed. The one million tons of salmon produced correspond to about 600,000 MT of fillets for human consumption. With an

average EPA+DHA content of about 2% (10% fat x 20% EPA+DHA), this supplies about 12,000 tons of these fatty acids to humans in an attractive format along with other nutrients. There is nevertheless a net loss of about 50%, which needs our serious attention.

The limited availability of marine fish oils and the need for improving conver-



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sion efficiencies has indeed strengthened research for substitutes to fish oil, with the final objective still being the provision of adequate amounts of long chain w3-PUFA through aquaculture to the human food basket.

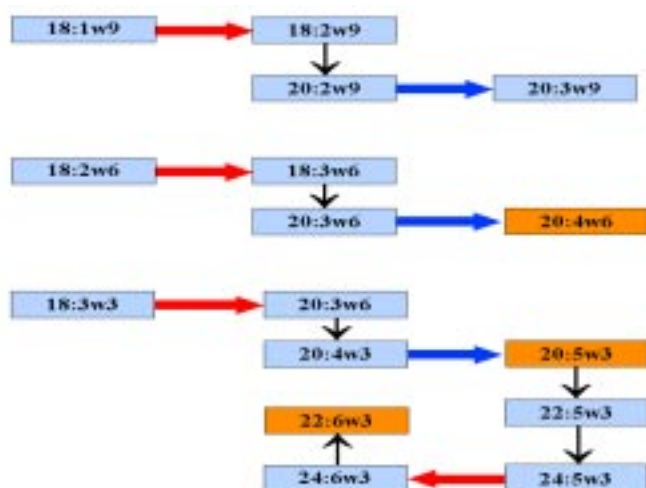
HUFA Requirements of Fish

The earliest studies on partial substitution of fish oil by other sources of lipids date back to almost thirty years (Thieulin et al. 1973; Yu et al. 1977) and have shown that in rainbow trout there was no strong influence of dietary fatty acid composition on growth as long as the required amounts of specific essential fatty acids (EFA) are supplied.

In this context, the central question to answer is how much HUFA are necessary for fish? A close look at available data (see Table) clearly indicates that we do not have precise information for all species and there is still some variability which is mostly linked to methodological problems. Few studies have indeed looked at the EFA requirements using purified diets. More often, data on “requirements” have been derived indirectly. Based on literature data, one can say that the earlier distinctions between fish species requiring w6 and others requiring w3 FA is not valid, as both series are necessary as precursors of eicosanoids. Distinction between freshwater and marine fish, with the former putatively able and the latter unable to convert C18 into C22 fatty acids, needs to be investigated further. However, we need to strengthen our knowledge as regards the EFA requirements at very specific physiologically critical stages such as gametogenesis and larval development.

As most animals including man, fish can elongate and desaturate but cannot synthesize fatty acids of the w3 and w6 series. The C18 fatty acids (18:2w6 and 18:3w3) are commonly provided by vegetable oils. The pathways of biosynthesis of C20 and C22 fatty acids imply elongation and desaturation of the C18 fatty acids. Interestingly, common enzymatic pathways are shared by all FA series, with sometimes competitive interactions between series. While the delta-5 desaturation occurs at only one step, the delta-6 desaturation occurs at two different levels (Fig. 1). The fact that fish manages to spare HUFA efficiently suggests that the absolute HUFA utilization necessary for life is relatively low. Current research is also looking at whether the bioconversion capacities are sufficient to maintain a level compatible with growth and “physiological well-being”. Investigations on desaturation/elongation pathways of fatty acids in order to determine, for instance, the extent to which 18:3w3 is oxidized and

Fig. 1. Pathways of biosynthesis of C20 and C22 fatty acids from C18 precursors. Red arrows indicate delta 6 desaturation steps; Blue arrows those of delta-5 desaturation steps. Down arrows depict elongation and the upward arrow that of retroconversion into DHA.



desaturated have been undertaken using molecular tools (Tocher et al. 2001; Seiliez et al. 2001; 2003).

Given the relatively low requirements for EFA for growth and well being of fish, high dietary supply of HUFA over the long growth periods can be considered as a luxury. The ideal situation is that enough EFA is provided all along the life cycle, with particular care during early life stages and reproduction, and substitute greater amounts of fish oil with vegetable oils acting as the major energy source for improved protein efficiency.

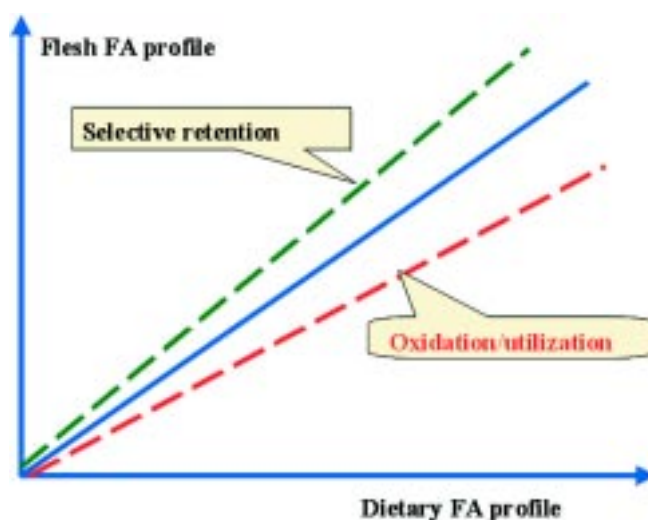
Most studies with salmonids (rainbow trout, brown trout, Atlantic salmon, Pacific salmon) have shown that it is possible to replace fish oil by vegetable oils such as soybean oil, corn oil, linseed oil, rapeseed oil or palm oil without affecting growth or feed efficiencies. Many earlier studies however were undertaken with juvenile fish over relatively short periods. Long-term studies undertaken recently with Atlantic salmon show no adverse impacts of 50% of fish oil replacement by oils such as rapeseed oil (Bell et al. 2001) or soybean, linseed, palm or poultry oils (Rosenlund et al. 2001).

HUFA to Humans

In contrast to proteins, the lipid composition of fish is not genetically determined and depends largely on the dietary fatty acid profile. Feeding vegetable oils (without the long chain PUFAs such as EPA and DHA) will naturally lead to a reduction in the levels of these fatty acids in cultured fish and alter their nutritional value. Almost all studies undertaken in different species thus clearly point out that replacement of fish oil by plant oils modifies flesh fatty acid composition in a significant manner. The degree of changes in fatty acid profiles and the consequences in terms of nutritional value depends upon several factors: dietary fat level, level of substitution, duration of feeding, size and growth rates of fish.

That the whole body fatty acid profile reflects that of the diet is well demonstrated. The relation between dietary fatty acid profile and flesh fatty acid profile is also known. The relative efficiencies with which a given fatty acid is utilized or preferentially retained (Fig 2) is also a matter of interest which bears significance especially in terms of understanding FA gain and loss and for exerting economy of fish oil. Since there is a relationship between dietary FA composition and flesh FA composition, it follows that any possible effects of dietary vegetable oils can be reversed by re-feeding fish with diets containing adequate amounts of fish oil. Some models have been proposed, to address

Fig. 2. Theoretical relationship between fatty acid profile in the diet and fish. Understanding this relationship will help to understand the relative efficiencies with which a given fatty acid is utilized or preferentially retained.



EFA requirements (% of dry diet) of fish

Species	EFA	Larvae & Post larvae	Juveniles/ Growers
Freshwater			
Common Carp	w6 PUFA (18:2 w6)	0.25%	1.0
	w3 PUFA		
	18:3w3	~0.05	0.5-1.0
Grass carp	18:2w6 & 18:3w3		1.0 & 0.5
<i>Tilapia zilli</i>	18:2w6		1.0
Nile Tilapia	18:2w6		0.5
Rainbow trout	w3 HUFA	DHA essential?	0.4-0.5
	18:3w3		0.7-1.0
Chum salmon	18:2w6 & 18:3w3		1.0 of each
Coho salmon	18:2w6 & 18:3w3		1.0 of each
Cherry salmon	18:3w3 or w3 HUFA		1.0
Arctic charr	18:3w3		1.0-2.0
Striped bass	18:3w3	?	
	w3 HUFA	>0.5	1.0
Channel catfish	18:3w3		1.0-2.0
	w3 HUFA		0.5-0.75
European catfish	18:3w3		1.0
Whitefish	w3 HUFA		0.5-1.0
Japanese Eel	18:2w6 & 18:3w3		0.5 of each
Ayu	18:3w3		1.0
Milkfish	18:2w6 and 18:3w3		0.5 of each
Marine			
Cod	DHA	~1	
Gilthead sea bream	w3 HUFA	1.5-5.5 (DHA:EPA=0.3-2) 1.5 (in phospholipid)	0.5-1.9 (DHA:EPA =0.5-1)
European sea bass	w3 HUFA		< 1.0
Turbot	w3 HUFA	DHA required?	0.8
	w6 HUFA	AA required?	Required?
Flounder	w3 HUFA		0.9
Asian sea bass	w3 HUFA		1.0
Grouper	w3 HUFA		DHA > EPA
Yellowtail	w3 HUFA	3.9 (DHA:EPA = 0.5)	2.5
	DHA	1.4-2.6	
	EPA	3.7	
Striped jack	DHA	1.6-2.2	1.7
	EPA	< 3.1	
Mahimahi	w3 HUFA	0.6-1.0	
Silver bream	w3 HUFA		1.3
Korean rockfish	w3 HUFA (EPA or DHA)		0.9-1.0
Red drum	w3 HUFA		0.5-1.0
	EPA + DHA		0.3-0.6

the question whether the changes in FA composition which occur or simply due to “dilution” or a “wash-out”. It appears that while muscle neutral lipid FAs roughly follow the dilution model (Robin et al. 2003).

Over the past few years, significant breakthroughs have been shown in total replacement of fish oil by plant oils in species such as turbot, brown trout, rainbow trout or Atlantic salmon. Once the fish are grown with vegetable oils over the major part of the life cycle, a finishing diet based on fish oil as the major lipid source can be used to tailor the final flesh fatty acid composition to a desired level for human nutrition and dietetics (Bell et al. 2003; Glencross et al. 2003; Regost et al. 2003). Major coordinated research efforts have been initiated under the EU RTD projects such as RAFOA (“Researching alternatives to fish oils for aquaculture”) analyzing the consequences from different angles: biochemical, metabolic, flesh quality, etc.

Data available to date do not seem to indicate any significant effect of partial replacement of fish oil on flesh quality attributes (Rosenlund et al. 2001; Izquierdo et al. 2003; Regost et al. 2003). Even when full substitution was done as in brown trout or turbot, there were no remarkable changes in sensory evaluation parameters. Studies under way in different species (rainbow trout, Atlantic salmon, European sea bass and gilthead sea bream) also confirm such observations. Unpublished data suggest that novel instrumental analysis using an “electronic nose” might be more discriminative than human perception. The importance of fillet fatty acid composition on processing and sensory characteristics requires further evaluations.

Another question of importance is how much of the beneficial FA should be made available through farmed fish to the consumer. Data on the recommended dietary allowance on long chain PUFA from different health organizations suggest a value of 0.1 to 0.2 g of DHA per day, the higher value for pregnant or breast-feeding mothers. Given the importance of fish fats and the relative ease with which the fatty acid composition of fish body oils can be tailored by altering the fatty acid composition of their feeds is indeed a very positive aspect of aquaculture.

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