Review: Use of Animal Fats in Aquaculture Feeds

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ABSTRACT

Formulated aquaculture feeds are among the most expensive animal feeds on the market. These feeds are often high in lipids, the bulk of which is generally provided by fish oil. Because of its high cost and potential long-term supply problems, it is now widely acknowledged that fish oil should be used more sparingly in aquafeeds. Rendered animal fats are economical lipid sources that have been used in fish feeds for decades but their use has been greatly limited for various reasons, such as poor digestibility and nutritive value, and more recently, fear of disease transmission. Recent studies have indicated that rendered animal fats can be valuable ingredients in fish feeds. Incorporation levels equal to 30-40% of total lipid of the diet do not impose any negative effects on growth performance, feed efficiency, and product quality of most fish species studied. However, the diet must contain sufficient levels of unsaturated fatty acids (mono and polyunsaturated) to allow for proper digestibility of saturated fatty acids, and, obviously, meet essential fatty acid requirements of the fish. The use of rendered animal fats at the expenses of fish oil in aquafeeds could immediately result in significant savings for feed manufacturers.

INTRODUCTION

Formulated aquaculture feeds are among the most expensive animal feeds on the market. The production of these feeds, particularly for carnivorous finfish species, has been dependent on the use of significant amounts of fish oils. Fish oils are highly digestible, while providing essential fatty acids (highly unsaturated omega-3 fatty acids), phospholipids, cholesterol and fat soluble vitamins. Besides the ecological and ethical concerns with the use of fish oils in aquafeeds (Naylor *et al*., 2000), there is also a growing economical concern related to the cost and availability of fish oil (Coutteau *et al*., 2002). As a result, steps need to be taken to reduce the dependence on the use of fish oil in aquafeeds.

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Rendered animal fats, because of their low costs and wide availability, are interesting alternatives to fish oil. Rendered fats are produced from recycled animal and poultry by-products, such as slaughter by-products, trimmings, fat, bone, and hides. Some rendered fats include recycled restaurant grease. Rendered fats, such as tallow, lard, and yellow grease, have found wide use in feeds for livestock, poultry, and swine (Prokop, 1996). However, the use of these products in aquafeeds has been limited or even avoided in the past for various reasons, such as poor digestibility, quality variability, impacts on growth and product quality, and more recently, fear of disease transmission. An increasing number of studies are showing that these concerns have little relevance nowadays and that rendered animal fats can be valuable ingredients in fish feed formulation. In this paper, we present a brief overview of studies on the use of rendered fats in aquafeeds, with a special emphasis on tallow, the most widely available rendered animal fat.

AVAILABILITY AND PRICE OF RENDERED ANIMAL FATS VS FISH OILS

Fish oil availability is increasingly problematic since the demand for aquafeeds has grown considerably with the expansion of the aquaculture industry. Various projections suggest that within a decade, the demand for fish oil may be above the available supply (Coutteau *et al.,* 2002). Along with an increase in demand, the price of fish oil has also risen considerably in recent years (Hardy, Scott & Harrell, 1987). The market price for fish oil has varied between USD $0.20 and $0.80/kg over the past decade (Coutteau *et al*., 2002). Current (summer 2002) market price is around USD $0.60/kg, which is considerably more than feed-grade rendered animal fats. Substantial savings could, therefore, be made immediately by substituting some of the fish oil in feed formulae with these more economical lipid sources.

In 2001, a US census reported that the production of rendered products in the USA was 8.3 billion kg, half of which was rendered fats, mainly tallow and grease (Rudbeck, 2002). Rendered fats are a very diverse group of ingredients. A partial list of different types of rendered fats and a brief description of their characteristics is presented in Table 1.

Table 1. Types and characteristics of rendered fats.

Type of Rendered Fat	Characteristics
Feed-Grade Animal Fat	Derived from by-products of many species, primarily beef and pork Unsaturates to saturated (U to S) ratio between 1:1 and 1.6:1 depending on material used Purchased by a minimum or maximum titre or on a guaranteed U/S FA range.
Poultry Fat	Fat from poultry by-products. U to S ratio about 2:1 A large amount of the product is sold for use in companion animal rations.
Choice White Grease	Derived mainly from the rendering of pork tissue. U to S ratio about 1:1 Certain blends of beef, pork and poultry fat are sold as choice white grease, as they meet the specifications.
Tallow	Derived from rendered beef tissue, but may contain other animal fats. U to S ratio 0.9 to 1.6:1
Yellow Grease	Mainly restaurant grease but can contain dead stock fat and/or dark color, high FFA and high MIU fat from any type of rendering operation. Many times dark color and high FFA tallow is sold as yellow grease.
Blended Animal and Vegetable Fat	Includes blends of all types of animal fat, vegetable oil, acidulated vegetable oil, soapstock and /or restaurant grease.

Source: Adapted from Bisplinghoff (1997)

Contrary to fish oil prices, the price of inedible tallow and greases has decreased in the last 5 years by 40-50% to a current price of about USD \$0.30/kg for choice white grease and tallow. Other rendered fats, such as yellow grease and animal vegetable blends are trading for even lower price. Price for rendered fats are unlikely to move dramatically over the next few years.

Based on their economical price and wide availability, rendered animal fats should be given due consideration as substitutes for part of the fish oil component of current fish feed formulae. Based on the current market prices, the cost of aquafeed could be reduced by about <u>USD \$3/tonne</u> for every percentage point (1%) of fish oil replaced by rendered fats. By using 8% tallow, at the expense of 8% fish oil, in a salmonid fish feed (lipid level = 20-30%), about USD <u>\$24/tonne fish</u> feed could be saved in ingredient costs. This type of saving is very significant, and there are very few other modifications (e.g. fish meal replacement) to current salmonid feed formulae that could results in such substantial savings.

EFFECT ON FEED QUALITY

Feeds containing high levels of fish oils also contain high levels of polyunsaturated fatty acids which can make them more susceptible to oxidation during feed manufacturing and storage (Greene & Selivonchick, 1990). Feed containing some rendered animal fats, such as lard and tallow, may have a lower susceptibility to oxidation (Watanabe 2002; Dosanjh *et al*., 1984).

DIGESTIBILITY

The ability of fish to use rendered animal fats as an energy source is dependent mainly upon the digestibility of the ingredient. Studies have suggested differences in the digestibility and nutritive value of lipid sources with different fatty acid profiles at different water temperatures. Cho & Kaushik (1990) presented the results from an experiment indicating that the apparent digestibility coefficients (ADC) of fish oil and plant oils (rapeseed, soybean and linseed) remained high (ADC = 80-95%) over a wide range of water temperatures (5 to 15°C). However, ADC of lard and tallow (lipid sources high in saturated fatty acids) were affected by the water temperature and lower than that of oils. This suggests strong interactions between the melting point of the lipid employed and water temperature on apparent digestibility of lipids (Table 2).

Table 2. Apparent digestibility coefficients (ADC, %) of oils and fats fed at different water temperatures to rainbow trout.

		Water Temperatures		
Oils and Fats	Low/high melting point °C	5°C	10°C	15°C
Fish Oil		80	81	81
Rapeseed Oil	0/-12	85	89	90
Soybean Oil	-7/-8	92	93	91
Linseed Oil	-18/-27	92	95	95
Lard	28/48	70	76	78
Tallow	45/48	58	64	66

Source: Cho and Kaushik (1990)

The ADC of lard and tallow were clearly poorer at lower water temperatures, in contrast with the lack of effect of water temperatures on the lower melting point oils. Other evidences are provided by Schwarz *et al*. (1988) who found that the digestibility of lipids depended on the fatty acid composition. Fish feeds that contained fish or vegetable oils, and had significantly higher levels of omega-3 and omega-6 fatty acids, were digested about 6% better than feed with rendered animal fats, and with a significantly higher saturated fatty acids content. There are a number of other evidences in the literature that the ADC of saturated fatty acids are less than ADC of unsaturated fatty acids.

Other observations suggest, however, that the ADC of tallow is high for rainbow trout provided the diet contains a certain amount of fish oil (and/or other lipid sources rich in mono and polyunsaturated fatty acids). Bureau, Harris & Cho (1997) found that there was no difference in the apparent digestibility coefficient (ADC) of lipid (94%) of a feed with 16% fish oil and that of a feed with 8% fish oil and 8% tallow at a low water temperature (7.5°C). At 15°C, the ADC of lipid of the diet comprised of 8% fish oil and 8% tallow was only slightly lower than that of the feed comprised of 16% fish oil (95 vs. 98%) (Table 3).

Table 3. Lipid digestibility and growth performance of rainbow trout (initial weight = 7 g/fish) fed practical diets containing fish oil or fish oil and tallow combination reared at 7.5 or 15ºC for 12 weeks.

	Water Temperature			
	7.5ºC		15ºC	
	Diet 1	Diet 2	Diet 1	Diet 2
Ingredients				
Fish meal, herring, 68% CP	50	50	50	50
Corn gluten meal, 60% CP	20	20	20	20
Fish oil, herring	16	8	16	8
Beef tallow, fancy, bleachable	-	8	-	8
Composition				
Digestible Protein (DP), %	44.0	43.5	44.9	44.4
Digestible Energy (DE), MJ/kg	19.5	19.9	20.9	20.8
DP/DE, g/MJ	22.6	21.9	21.5	21.3
Performance				
Lipid digestibility, %	93	94	98	95*
Weight gain, g/fish	13.7	13.1	38.1	39.2
Feed efficiency, gain:feed (as is)	1.32	1.27	1.22	1.15
Retained energy, % digestible intake	47	47	50	48

*Significantly different from control diet (Diet 1).
Source: Bureau *et al*. (1997)

The difference in estimates of digestibility of diets containing rendered animal fats between studies is likely due to the synergetic effect of polyunsaturated fatty acids on the digestibility of saturated fatty acids, a well-described phenomenon in poultry (Sibbald, Slinger & Ashton, 1962; Sibbald, 1978). The low digestibility values reported, in early studies, for highly saturated lipid sources may therefore be an artifact of the methodology used. For example, the study presented by Cho & Kaushik (1990) used a reference diet with very low levels of lipids (3 –5%). This reference diet was then supplemented with significant amounts of the lipid sources tested (fish oil, soya oil, lard, tallow), to produce test diets in which a very significant proportion of the lipids was provided by the lipid tested. It has been demonstrated, more than 40 years ago, that highly saturated lipids, when used alone in the diet, are poorly digested by poultry (Table 4). However, supplementation of tallow-rich diets with small amounts of a lipid sources rich in polyunsaturated fatty acids (e.g. soya oil), resulted in a significant improvement of the digestibility of saturated fatty acids and, consequently, total lipids of the diet (Sibbald *et al*., 1962; Sibbald, 1978).

Table 4. The metabolizable energy values of tallow, crude soybean oil, and a 50/50 mixture of the two fats fed to poultry.

Type of Fat	Metabolizable Energy kJ/g
Tallow	25
Crude Soybean Oil	36
50% crude soybean oil + 50% tallow	34

Adapted from Sibbald *et al.* (1962)

Available results suggest that aquafeeds containing rendered animal fats, should be formulated to contain sufficient amounts of monounsaturated and polyunsaturated fatty acids to allow proper digestibility of saturated fatty acids. A simple analysis of the results of Bureau *et al*. (1997) suggest that when saturated fatty acids levels of the diet should not exceed 35-40% of total fatty acids of the diet of rainbow trout. In excess of that level, the ADC of lipids of the diet can decrease quite significantly (Figure 1). This simple analysis also suggest that it might be wise to assume a slightly lower ADC for lipid and energy for rendered animal fats, compared to fish oil, especially when formulating diets rich in saturated fatty acids. These are only preliminary recommendations. There is a need for a more comprehensive assessment of the effect of dietary fatty acids composition and lipid levels, and water temperature on ADC of lipids.

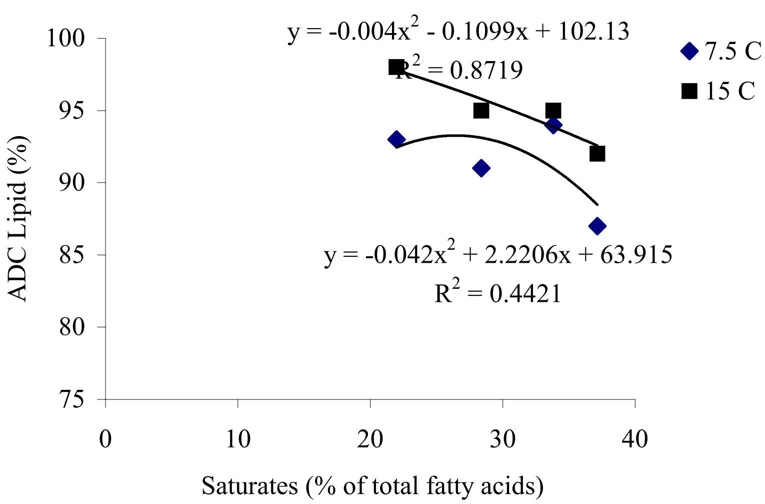

Figure 1. Apparent digestibility coefficient (ADC) of lipid of diets (ca. 18% crude lipid) containing increasing levels of saturated lipids fed to rainbow trout at 7.5 and 15˚C. Data from Bureau *et al*. (1997)

EFFECT ON PERFORMANCE

Table 5 summarizes the results of about two dozen studies on the use of rendered fats as an alternative fat source in the diet of various fish species. A number of these studies suggested that diets containing rendered fats, such as tallow and lard, may not be able to support optimal growth performance. Results from several other studies indicate that diets containing significant amounts of rendered fats are, indeed, able to support optimal growth performance of various fish species. While some differences in the results of some studies are difficult to explain, it is apparent that when rendered animal fats incorporation level represent more than half of the crude lipid of the diet, a significant reduction of performance of the fish is generally observed. Lower incorporation levels of rendered animal fats in the diet had no effect on performance of the fish (compared to fish oil-based control diets) in almost all reported studies (Table 5). It is also noteworthy that rendered animal fats, such as tallow, had no negative effect on reproductive parameters (Hertrampf & Piedad-Pascual 2000; Pustowka *et al*., 2000; Watanabe *et al*., 1984).

As results suggest, rendered animal fats are well utilized by most fish species provided that the essential fatty acid requirements are met and that the diet contains sufficient mono or polyunsaturated fatty acids must be met to ensure proper digestibility of saturated fatty acids.

Table 5. Summary of studies on use of rendered fat in the diet of various fish species.

Species	Diet Composition	Effect on Performance	Reference
Rainbow trout ***Oncorhynchus mykiss***	10% beef tallow **Crude Lipid =10%**	Significantly lower weight gain and feed conversion ratio (FCR) than with pollock liver oil	Takeuchi *et al.,* 1978
	6% beef tallow+ 4% pollock liver oil **Crude Lipid =10%**	No effect on weight gain, FCR or survival Small reduction in digestible energy	Takeuchi *et al*., 1978
	4% hydrogenated beef tallow+ 4% pollock liver oil **Crude Lipid =10%**	No effect on weight gain, FCR or survival Small reduction in digestible energy	Takeuchi *et al*., 1978
	4.8% lard + 7.2% beef tallow **Crude Lipid =18%**	Reduced weight gain	Watson, 1981

Species	Diet Composition	Effect on Performance	Reference
	7% beef tallow + 7% feed oil **Crude Lipid =19%**	Slow growth for first month (15% gain) No adverse effects on reproduction	Watanabe *et al.,* 1984
	6% chicken fat, pork lard, or beef tallow **Crude Lipid =13%**	No effect on weight gain or FCR No effect on carcass composition Absence of physical deformities across all groups	Greene & Selivonchick, 1990
	8% beef tallow + 8% fish oil **Crude Lipid =21%**	No effect on weight gain and FCR No effect on carcass proximate composition	Bureau, 1997
	8% herring oil and 8% beef tallow **Total Lipid =18%**	No effect on weight gain, FCR, retained nitrogen, and recovered energy	Bureau *et al.,* 1997
	12% tallow **Crude Lipid = ?**	High cholesterol levels in spermatozoa Produced higher percentage of eyed embryos	Pustowka *et al*., 2000
Coho salmon *Oncorhynchus kisutch*	4% beef tallow + 12% salmon oil **Crude Lipid =16%**	No effect on weight gain No effect on body protein, moisture and ash	Yu & Sinnhuber, 1981
	8% beef tallow + 8% salmon oil **Crude Lipid =16%**	No effect on weight gain No effect on body protein, moisture and ash Slight increase in fish body lipid saturation	Yu & Sinnhuber, 1981
	12% beef tallow + 4% salmon oil **Crude Lipid =16%**	Significantly lower weight gain No effect on body protein, moisture and ash	Yu & Sinnhuber, 1981
	8.6% lard **Crude Lipid =12%**	No effect on weight gain, FCR, and energy utilization No effect on body composition No effect on fish health or survival	Dosanjh *et al.,* 1984
	4.3% lard + 4.3% herring oil **Crude Lipid =12%**	No effect on weight gain, FCR, and energy utilization No effect on body composition No effect on fish health or survival	Dosanjh *et al,* 1984
	4.3% lard + 4.3% canola oil **Crude Lipid**	No effect on weight gain, FCR, and energy utilization No effect on body composition	Dosanjh *et a.,*. 1984

Species	Diet Composition	Effect on Performance	Reference
	=12%	No effect on fish health or survival	
Chinook salmon *Oncorhynchus tshawytscha*	5% beef suet + 3% linseed oil **Crude Lipid =15%**	No effect on weight gain or FCR No effect on moisture, protein and lipid content of carcass	Mugrditchian *et al.*, 1981
	6.5% beef suet + 1.5% linseed oil	No effect on weight gain or FCR No effect on moisture, protein and lipid content of carcass	Mugrditchian *et al.*, 1981
	3.0% beef suet + 1.5% linseed oil + 3.5% salmon oil	No effect on weight gain or FCR No effect on moisture, protein and lipid content of carcass	Mugrditchian *et al.*, 1981
	8.2% lard **Crude Lipid =16%**	No effect on weight gain and FCR High protein conversion No effect on whole body proximate constituents	Dosanjh *et al.*, 1988
	4.1% lard + 4.1% canola oil **Crude Lipid =16%**	No effect on weight gain and FCR High protein conversion No effect on whole body proximate constituents	Dosanjh *et al.*, 1988
	4.1% lard + 4.1% herring oil **Crude Lipid =17%**	No effect on weight gain and FCR Highest protein conversion No effect on whole body proximate constituents	Dosanjh *et al.*, 1988
Atlantic salmon *Salmo salar*	1.9% herring oil and 5% beef tallow **Crude Lipid =20%**	No effect on weight gain, FCR or proximate composition of the fillets Lower level of carotenoid pigments	Hardy *et al.*, 1987
	4.5% lard+ 3.5% corn oil+ 1% canning oil **Crude Lipid =?**	No effect on weight gain as compared to control diet	Bell *et al.,* 1989
Channel catfish *Ictalurus punctatus*	10% beef tallow **Crude Lipid = 10%**	Higher weight gain than with safflower oil Lower FCR than safflower oil Lowest carcass lipid content	Stickney & Andrews, 1971
	7% beef tallow **Crude Lipid =7%**	Lower weight gain at high temperatures No effect on weight gain at low temperature High survival rates	Fracalossi & Lovell, 1994b
	2.3% beef tallow + 2.3% corn oil + 2.3% menhaden oil **Crude Lipid =7%**	High survival rates Significantly higher weight gain at high temperatures No effect on weight gain at low temperature	Fracalossi & Lovell, 1994b

Species	Diet Composition	Effect on Performance	Reference
	7% beef tallow **Crude Lipid =7%**	Lowest leukotriene B (LTB) production Lowest weight gain	Fracalossi *et al.,* 1994
	2.3% beef tallow + 2.3% corn oil + 2.3% menhaden oil **Crude Lipid =7%**	Lowest LTB production Lowest weight gain	Fracalossi *et al*., 1994
	2% beef tallow **Crude Lipid =?**	No effect on growth, FCR, and survival	Li *et al*., 1994
	7% beef tallow **Crude Lipid =7%**	Low weight gain at high temperature No weight gain at low temperature	Fracalossi & Lovell, 1995
	2.3% beef tallow + 2.3% corn oil + 2.3% menhaden oil **Crude Lipid =7%**	High weight gain at high and low temperature	Fracalossi & Lovell, 1995
	2% beef tallow + 2.7% fish oil **Crude Lipid =ca. 8%**	No effect on survival, live weight at harvest, yield, and dressing percentage No effect on muscle lipid levels No effect on liver and muscle moisture content	Reigh & Ellis, 2000
	4% beef tallow + 2.7% fish oil **Crude Lipid = ca. 8%**	No effect on survival, live weight at harvest, yield, and dressing percentage No effect on muscle lipid levels No effect on liver and muscle moisture content	Reigh & Ellis, 2000
Common Carp *Cyprinus carpio* L.	4.5 beef tallow +5% feed oil **Crude Lipid =10%**	Depressed weight gain No effect on FE No effect on feed intake No effect on lipid content No effect on energy utilization	Murai *et al.,* 1985
	9.5% beef tallow + 5% feed oil **Crude Lipid =15%**	Depressed weight gain No effect on FE Decreased feed intake Increased carcass lipid content No effect on energy utilization	Murai *et al*., 1985
	12% beef tallow + 1.4% linseed oil **Crude Lipid = 16 %**	No effect on growth Lowest carcass fat content (11.3%) No effect on protein/ash content Lowest dry matter content	Schwarz *et al*., 1988
African Sharptooth Catfish	10% tallow **Crude Lipid =10%**	Chemical composition of muscle strongly influenced by diet Lower growth than fish fed sunflower oil	Hoffman & Prinsloo, 1995

Species	Diet Composition	Effect on Performance	Reference
Clarias gariepinus		diet	
Hybrid tilapia *Oreochromis niloticus* x *O. aureus*	5% lard **Crude Lipid =5%**	Significantly lower weight gain, protein efficiency ratio (PER) and higher FCR Significantly lower protein deposition No effect on survival	Chou & Shiau, 1999
	2.5% lard + 2.5% corn oil **Crude Lipid =5%**	Significantly lower weight gain, PER and higher FCR Significantly lower protein deposition No effect on survival	Chou & Shiau, 1999
	2.5% lard + 2.5% cod liver oil **Crude Lipid =5%**	Significantly lower weight gain, PER and higher FCR Significantly lower protein deposition No effect on survival	Chou & Shiau, 1999
	1.7% lard + 1.7% corn oil + 1.7% cod liver oil **Crude Lipid =5%**	Significantly higher weight gain, and PER. Higher FCR Greater protein deposition No effect on survival	Chou & Shiau, 1999
Blue tilapia *Tilapia aurea*	2-14% beef tallow **Crude Lipid =2-14%**	No effect on weight gain No effect on FCR	Stickney & McGeachin, 1984

IMMUNE RESPONSE

The effect of fatty acid profile of the diet on health and immune function of fish has been examined in a few studies. It is clear from results of studies that a deficiency in any essential fatty acids may lead to biochemical abnormalities that may affect health of fish (Lall, 2001).

It has been suggested that the balance of n-3 and n-6 fatty acids may have an effect on immune competence of fish (Lall, 2001). The nature and magnitude of the response may be different between fish species. In general, diets high in n-6 PUFAs should enhance the immune responsiveness, since these fatty acids, through conversion to arachidonic acid (ARA), lead to the production of very potent proinflammatory eicosanoids. Diets high in n-3 PUFAs should result in lower immune responsiveness due to the fact that these fatty acids, through conversion to EPA, lead to the production of eicosanoids which are less potent than ARA-derived one (Lall 2001). This predicted effect is, however, rarely clear, as suggested by differences in results between studies (Laal, 2001; Sheldon & Blazer, 1991; Fracalossi & Lovell, 1994b).

Fracalossi & Lovell (1994b) found that channel catfish fed 7% menhaden oil (rich in 18:3n-3) had a higher mortality rate when exposed to *E. ictaluri* than fish fed a similar diet containing beef tallow. As a result, these authors suggested that a mixture of n-3 PUFA and

18:2n-6 (provided by menhaden oil, beef tallow and corn oil) might be desirable in feeds to optimize immuno-competence of channel catfish. A study conducted at the University of Guelph suggest no significant effects of animal fats incorporation (as well as wide variation in the fatty acid composition) in the diet on different non-specific immunity parameters of rainbow trout (Bureau *et al.*, 1997) (Table 6). More detailed studies on this topic are being conducted by other research groups in Canada. So far, there is no other published evidence indicating that use of animal fats has any effect on health and immune competence of fish, provided the diet meet the essential nutrient requirements of the fish.

Table 6. Non-specific immunity of rainbow trout fed the experimental diet for 12 weeks.

	Packed cell volume	Lysozyme	NBT no SOD	NBT +SOD	Difference SOD
Diet	%	U/mg soluble protein	U/10^6 cells	U/10^6 cells	U/10^6 cells
7.5°C					
16% fish oil	35.2	65.8	0.369	0.199	0.170
8% fish oil +8% tallow	34.4	70.3	0.416	0.248	0.168
15°C					
16% fish oil	33.1	101.6	0.364	0.269	0.096
8% fish oil +8% tallow	34.1	85.1	0.241	0.127	0.114
Temp	NS	*	*	NS	***
Diet	NS	NS	NS	NS	NS
Temp*Diet	NS	NS	NS	NS	NS

Data from Bureau *et al.* (1997)

PRODUCT QUALITY

The fatty acid profile of rendered fats differs greatly from fish oils. Differences can be seen in that the ratio of saturated fatty acids to unsaturated fatty acids or in the proportion of different unsaturated fatty acids (mono vs. polyunsaturated). It is well-recognized that differences in the fatty acid profile of feeds are largely reflected in the composition of the fish (Hardy *et al*., 1987). This phenomenon of changing muscle composition with feed composition is common to most fish species (Chou & Shiau, 1999). Hoffman & Prinsloo (1995) found that African sharptooth catfish fed 10% tallow had the highest saturated fatty acid concentration and the lowest polyunsaturated fatty acid content in the muscle. These results were confirmed by Greene & Selivonchick (1990) in which trout fed diets containing poultry fat, pork lard and beef tallow all exhibited the highest levels of saturated fat in the muscle.

This does not mean, however, that fish absolutely deposit into the muscle the same level of fatty acids present in the diet (Figure 2). Rather, dietary fatty acids may be deposited according to a more narrowly defined physiological level. This is particularly the case with phospholipids, whose fatty acid composition is more narrowly controlled than that of triglycerides (Mugrditchian *et al.,* 1981; Hardy *et al*., 1987; Dosanjh *et al.,* 1988; Greene & Selivonchick, 1990). Bureau *et al*. (1997) observed that phospholipids represented approximatively 10-15% of the total lipid of the body of rainbow trout of 40- 100 g. These authors also observed that the concentration of various fatty acids in the phospholipids were much less responsive to the changes in the dietary concentration of the same fatty acids than triglycerides did. The concentration of DHA (22:6n-6) in the phospholipid fraction of the carcass of rainbow trout was very high (ca. 35% of total fatty acids of phospholipids), and remained unaffected by dramatric changes in the DHA content of the diet (Bureau *et al.*, 1997).

It is expected that the incorporation of small amount of rendered animal fats in the diet may have only marginal effect on flesh composition. This is probably especially true in the case of lean fish, where phospholipids represent a larger proportion of total lipids. Evidence of this can be found in Yu & Sinnhuber (1981) and Bureau *et al.* (1998) who found that body lipid saturation of coho salmon and young rainbow trout (Figure 2) increased only slightly as the concentration of saturated fatty acid in the diet increased.

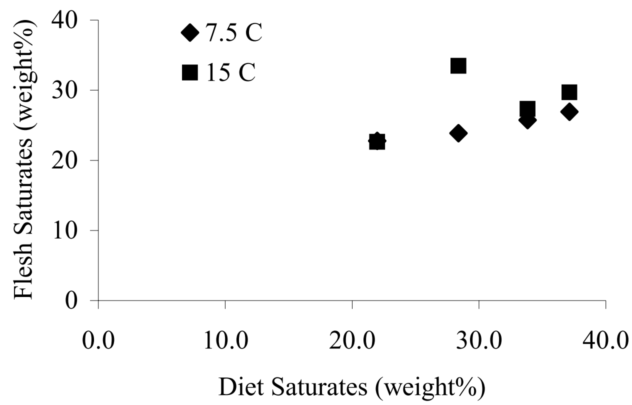

Figure 2. Relationship between saturated fatty acid concentration of the lipid of the diet and saturated fatty acid composition of the fillet of rainbow trout reared at two water temperatures. Data from Bureau *et al.* (1997).

The frequently voiced concern that feeding rendered animal fats may “change” the fatty acid profile of the flesh of fish, and result in a “different product” is often overplayed. While it is true that there are very significant differences in the fatty acid compositions of fish oils and rendered animal fats (Table 7), there are also great differences in fatty acid composition of different fish oils (type of fish oil, origin of fish processed, season, etc.). These differences will also result in variable fatty acid composition of fish fed diets manufactured with fish oils as the sole lipid source. Not only can the fatty acid composition of the fish be changed by replacing some fish oil with animal fats, but it may also be intentionally or unintentionally manipulated by switching the type of fish oil being used in the diet (Hoffman & Prinsloo, 1995). Moreover, most aquaculture products are sold as “generic” products (as opposed to “branded” products) and producers have no “economical” or “marketing” incentives to maintain a certain fatty acid profile or composition for their products.

The concern that the use of animal fats will change the taste of the fish is also another frequently voiced concern in the industry. The effect of lipid sources on the sensory attributes of fish fed different lipid sources has been the topic of a small number of studies, some of which are not yet published. The results from these studies suggest that lipid source has a slight impact on sensory attributes of the flesh and that, overall, the flavor, color and texture of fillets do not appear to be negatively affected by rendered animal fats incorporation in the diet (e.g. Hardy *et al*., 1987). Tallow incorporation at a level equivalent to 30-40% of total fat of the diet appeared to decrease the formation of rancidity products (as assessed by TBARS) in the flesh in a number of cases (Bureau *et al*., 1997). Consequently, flesh of fish fed tallow may have an improved shelf life, especially compared to fish fed highly unsaturated fish oils.

The balance of evidence suggest that there is, consequently, little rational behind the concern/fear that using of rendered animal fats in aquaculture feeds will negatively affect marketability of the product because of changes in the fatty acid composition and taste of the fish produced.

Rendered animal fats are used in all other livestock species feeds in several countries around the world. Since many aquaculture products (trout, salmon, catfish, tilapia) are sold in supermarkets at prices that are very competitive to poultry, swine and beef products, it seems logical that feed for aquaculture species be also based on the same economical ingredients used for production of other livestock feeds.

BOVINE SPONGIFORM ENCEPHALOPATHY (BSE)

The results from many studies indicate that rendered animal ingredients available on the market can be very useful ingredients for fish feed formulation, with relatively limited quality problems. Therefore, the fear of BSE is now the main factor hindering the use of rendered ingredients in aquafeeds. Europe has imposed upon herself very severe restrictions on the use of rendered products to deal with serious animal health and consumer's perception issues. These measures will probably insure eradication of BSE in one or two decades. Based on a number of cases of BSE observed, potential contamination of raw material with BSE-causing agents appears to be mostly a problem for European rendered ingredients. Evidence further suggests that the USA and Canada are probably free of BSE, and highly resistant to introduction of the disease. A recent analysis suggests that the policies, with particular reference to the FDA feed rule, should be effective in preventing either transmission or amplification of the BSE infectious agent. Scrapies, another other transmissible spongiform encephalopathies (TSE), is present in the USA and Canada but evidence strongly suggest that 1) this group of diseases are different from BSE, and 2) that scrapies is apparently not transmissible through ingestion of contaminated materials, like BSE is.

It is also important to note that rendered animal ingredients of swine or poultry origins, as well as lipid ingredients, such as tallow, have never been identified as being involved in the transmission of BSE or other TSE. These materials, therefore, represent extremely low risk materials from that point of view. Finally, to the knowledge of the authors, no TSE have ever been reported for fish.

Table 7. Fatty acid composition of different oils and fats

Fatty Acid	Menhaden Oil	Cod Liver Oil	Salmon Oil	Herring Oil	Soybean Oil	Poultry Fat	Yellow Grease	Choice White Grease	Lard	Tallow
14:0	10.2	2.5	4.3	5.0	0.1	0.8	1.1	1.9	1.5	3.5
16:0	23.5	9.6	15.4	11.0	12.6	23.2	17.3	21.5	25.2	27.9
18:0	4.3	2.3	2.7	2.0	4.8	5.2	11.2	14.9	14.6	20.0
18:1 n-9	15.0	14.2	24.7	20.0	24.9	43.0	56.2	41.1	40.1	42.6
18:2 n-6	1.3	2.9	2.1	2.5	48.6	17.0	9.9	11.6	13.9	2.6
18:3 n-3	1.0	4.8	1.3	0.5	7.2	1.0	2.1	0.4	1.0	-
20:4 n-6	1.1	0.5	0.6	-	-	-	-	-	-	-
20:5 n-3	17.3	18.1	10.4	8.0	-	-	-	-	-	-
22:6 n-3	8.8	14.8	9.4	7.0	-	-	-	-	-	-

Data from various sources.

CONCLUSION

The results from an increasing number of studies clearly indicate that rendered animal fats can be very valuable ingredients for fish feed formulation. In order for animal fats to be properly utilized by the fish, the diet must contain a significant level of n-3 and/or n-6 polyunsaturated fatty acids to meet the essential fatty acid requirements of the fish and to allow for proper digestibility of the diet. The balance of evidence shows that rendered animal fats incorporated at levels corresponding to 30-40% of total lipids, have no adverse effects on growth performance, feed efficiency and product quality of most fish species studied. Overall, the use of these low-cost alternatives to fish oil could result in immediate and very significant savings. The only remaining hurdle in the wider use of animal fats in aquaculture feeds is the fear of BSE and other TSE, a fear that is largely unfounded.

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