RENDERED PRODUCTS IN FISH AQUACULTURE FEEDS

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Summary

Aquaculture is an extremely diverse industry expanding rapidly. An ever growing segment of this industry utilizes high quality, but expensive, compounded feeds. Most fish culture operations are confronted with the challenges of improving their profitability and economical sustainability. Studies have also clearly shown that fish feeds can be formulated with very low levels of fish meal and fish oil through the use of more economical protein and lipid sources.

Rendered animal proteins and fats have been used in aquaculture feeds for several decades. Early research studies had suggested that rendered animal proteins and lipids were of relatively poor quality and poorly digestible to fish. However, the large number of studies published in recent years has shown that rendered animal by-products available today are of much higher quality than those produced 20 or 30 years ago. Most rendered products are a cost-effective source of digestible protein and digestible energy, bio-available essential amino acids, fatty acids, and minerals for most aquaculture species. Rendered proteins and fats are especially valuable for the formulation of aquaculture feeds since these feeds are formulated with much higher protein and lipid levels than feeds for other livestock species. Feeds formulated with high levels of rendered proteins, alone or in combination, support high performance and excellent feed conversion ratio. Studies have shown that blood meal is an excellent source of highly bio-available lysine which compares advantageously with synthetic lysine. Significant amount of rendered fats (tallow, lard, poultry fat) can also be used in fish feeds provided the feed is formulated to contain sufficient amounts of mono or polyunsaturated fatty acids to promote the digestibility of saturated fatty acids, and contain adequate levels of essential fatty acids to meet the requirement of the animals.

The Aquaculture Industry

Aquaculture is one of the fastest growing food producing sectors in the world. The United Nations' Food and Agriculture Organization estimated the total production of cultured finfish, shellfish, and aquatic plants at 51 million metric tons (112 billion pounds) valued at $60 billion in 2003. Asia accounted for more than 80 percent of the world production. China, the leading producer, contributed for more than 50 percent of world production. Today, about one-third of the fish consumed by humans is the product of aquaculture and this proportion is growing yearly. Products of aquaculture, such as shrimp, salmon, trout, catfish, tilapia, mussels, and oysters are nowadays "main stream" products in North American supermarkets.

Aquaculture is an extremely diverse industry, both in terms of species cultivated and production systems used. It is estimated that more than 200 species of fish, crustaceans, and molluscs are cultivated around the world. The bulk of world production, especially in Asia, consists of lower value species (carp, milkfish, catfish, and mullet) produced semi-intensively. In this type of production system, growth is based on food items naturally present in the rearing environment (pond). The production of natural food is generally stimulated through fertilization (fodders, manure, inorganic fertilizer), and low value supplemental feeds (such as, grain by-products, oilseed cakes, tubers, poultry offals, and kitchen wastes) are also used to improve fish production. The aquaculture industry is, nonetheless, in rapid evolution and the production of fish and other aquatic animals is done using increasingly intensive practices (higher stocking densities, lower contribution of natural food items to nutrition of the cultivated organisms). Very substantial increases in the use of formulated feeds have been observed over the past three decades, both as a result of and the progressive intensification of the culture of lower value species and the increasingly widespread culture of higher value fish species (such as, shrimp, eel, sea bass, sea bream, grouper, croaker, salmon, and turtle).

Formulated Aquaculture Feeds

It is estimated that the use of compound feeds in aquaculture is close to 20 million tons (Tacon, 2004). Aquaculture feeds are generally significantly more costly than feeds for other livestock species. Typical cost of aquaculture feeds varies from $300 to $1,500 per metric ton. Aquaculture feeds are also characterized by the widely ranging nutritional composition to which they are formulated. The protein, lipid, and starch contents of feeds vary very significantly, not only as a function of species and life stages for which they are formulated (trout versus tilapia versus shrimp feed, larval versus starter versus grower feed), but also as a function of a myriad of other factors such as production and environmental constraints, market or manufacturers' preference, and economic climate (such as, fish price and access to financing). The composition of feeds used for some species has also dramatically changed over the past two or three decades. The most striking example of this is the dramatic increase in the fat content of feeds used for Atlantic salmon production over the past 30 years. Atlantic salmon feeds were routinely formulated to eight to 10 percent lipids in the 1970s and are currently formulated to contain 35 to 40 percent lipids.

Part of the high cost of formulated aquaculture feeds is due to the fact that the feeds are, in general, of high nutrient density and manufactured using costly processes (extrusion, steam-pelleting). Their high cost is also largely attributable to the use of high levels of expensive ingredients (fish meal, fish oil, pigments, krill, squid meal, cholesterol, and lecithin.). Fish meal and fish oil are still considered key ingredients in the formulation of feeds for aquaculture species. Fish meal and fish oil, combined, currently account for 30 to 80 percent of the weight of most of the salmon, trout, marine fish, and shrimp feeds sold worldwide. Most fish culture operations are confronted with the challenges of improving their profitability and economical sustainability. Studies have also clearly shown that fish feeds can be formulated with very low levels of fish meal and fish oil through the use of more economical protein and lipid sources.

Progressive fish feeds are formulated to contain lower levels of fishery by-products, and higher levels of more economical agricultural commodities. However, most economical protein and lipid sources (soybean meal, corn gluten meal, canola meal, meat and bone meal, feather meal, and animal fats) have been shown to have significant limitations and these cannot be used at extremely high levels in the diet of most fish species. Formulating successful cost-effective feeds, relying less on fish meal and fish oil, requires access to a variety of economical ingredients. It also requires an understanding of the nutrient requirement of the animal but also several other, less well-defined, factors (tolerance to anti-nutritional factors, interactions between nutrients, and palatability of the finished feed).

Rendered Products

Terrestrial animal products have been used in aquaculture feeds for several decades. From the 1930s to the mid-1970s, salmon and trout species raised in hatcheries in the United States and Canada were mainly fed with semi-moist "meat meal mixtures" that were made of slaughter house by-products (beef, pork, or horse liver and spleen), fresh or frozen fishery products, and dry "meals" (mix of cottonseed meal, soybean meal, skim milk, wheat, salt, vitamin and mineral premixes). The first nutritionally complete dry fish feeds were developed in the 1960s and rendered proteins and fats have found wide use in dry fish feeds from their inception.

The use of rendered animal proteins was limited in the 1970s and 1980s because a small number of studies indicated that some of these ingredients had poor digestibility for fish or were of highly variable quality (e.g., Cho and Slinger, 1979; Cho et al., 1982; NRC, 1993). Studies conducted more recently have shown these quality issues are a problem of the past (Bureau et al., 1999; Bureau et al., 2000, 2002). Ingredients produced today appear to be of much higher quality than those produced 20 to 30 years ago. More than 200 studies on the nutritive value of rendered animal proteins for aquaculture species have been published in the scientific literature over the past three decades. The results from a large majority of these studies suggest that rendered products are cost-effective sources of highly available amino acids, fatty acids, and several other nutrients.

Rendered proteins and fats are economical commodities that are very valuable for the formulation of cost-effective aquaculture feeds. Their high protein and lipid content make them especially well-suited for use in the high protein and lipid aquaculture feeds. These ingredients are also effective sources of several key nutrients (lysine, sulphur amino acids, histidine, arginine, and phosphorus) and they complement very well certain plant protein ingredients (e.g., corn gluten meal and soybean meal). In addition, most animal by-products are highly palatable to most fish species. Rendered animal proteins and fats are key components of cost-effective aquaculture feeds in many countries, including the United States and Canada. Table 1 presents an example of the composition of rainbow trout feed used in North America.

Protypical perceived food safety issues (the main one being bovine spongiform encephalopathy (BSE)) are currently the main road block hindering the use of all rendered products in aquaculture feeds. This is largely due to the fact that Europe is a significant export market for several aquaculture products (shrimp, salmon, sea bass, and sea bream). European Union requirements or guidelines have profound influence on feed manufacturing practices, even in countries where the European Union is only a minor export market. Despite this conjecture, rendered animal proteins and fats, such as poultry by-product meal, feather meal, blood meal, and poultry fat have, for example, found widespread use in very high quality fish feeds used in salmon and trout production in Canada, the United States, and Chile. In many countries, ingredients of avian origins are subject to less significant import and export restrictions, and, consequently, are more widely used. Mixed species or ruminant by-products have also been shown to be of high nutritive value but their use is generally more limited. However, significant growth in some markets can be foreseen.

Table 1. Composition of a Prototypical Rainbow Trout Feed.

Ingredients	**Percent**
Fish meal	25
Corn gluten meal	12
Poultry by-product meal	12
Soybean meal	8
Blood meal, spray-dried	5
Feather meal	5
Wheat	12
Vitamins and minerals	2
Dicalcium phosphate	1
DL-Methionine	0.5
Lysine HCL	0.5
Fish oil	17
Total	100

Nutritive Value of Rendered Animal Protein Ingredients in Fish Feeds

Digestibility of Animal Proteins

A relatively large number of studies have examined the digestibility of rendered animal protein ingredients. Estimates of apparent digestibility of crude protein among studies appear quite variable for most ingredients. This variation may be due to the quality of the ingredients investigated but may also be due to differences in the methodology used. Overall, recent studies indicate that most rendered animal proteins produced using modern manufacturing practices are quite highly digestible for fish.

Poultry By-product Meal

One of the first studies examining the digestibility of animal proteins was that of Cho and Slinger (1979). These investigators observed that the digestibility of protein in poultry by-product meal (PBM) was relatively low (approximately 70 percent). In a more recent digestibility trial, high digestibility of crude protein (87 to 91 percent) were observed for two batches of regular PBM fed to rainbow trout (Bureau et al., 1999; Table 2). These results were obtained using the same equipment, fish strain, and methodology as that of Cho and Slinger (1979). Comparison of the results of Cho and Slinger (1979), Dong et al. (1993), Hajen et al. (1993), Sugiura et al. (1998), and Bureau et al. (1999) suggests progressive improvements in the digestibility of protein in regular PBM for rainbow trout over the past three decades. High digestibility of protein for PBM appears to be observable in other fish species. For example, Lupatsch et al. (1997) observed a digestibility of crude protein of about 80 percent for PBM fed to gilthead seabream (*Sparus aurata*), a marine fish species widely cultured in the Mediterranean region.

Blood meal

The digestibility of crude protein of blood meal (BM) manufactured using different techniques has been shown to differ significantly (Cho et al., 1982; Bureau et al., 1999). Blood proteins appear to be especially sensitive to heat damage, and the drying technique used can have a very significant effect on digestibility of BM. Cho et al. (1982) observed that a flame-dried BM had crude protein digestibility of only about 12 percent, whereas the protein in spray-dried BM was almost completely digestible. Bureau et al. (1999) observed that the digestibility of crude protein in spray-dried blood products was significantly higher than that of rotoplate-dried, steam-tube dried, and ring-dried BMs (Table 2).

A recent study with rainbow trout suggested that the bioavailability of lysine in spray-dried or flash-dried BMs was slightly higher than that of L-lysine HCL (Table 3) (El-Haroun and Bureau, 2004). These results suggest that BM can be a very good source of bio-available amino acids. However, some differences between BMs exist. For example, disc-dried BM appears to be an inferior source of available lysine to spray-dried or flash-dried BMs (Table 3).

Feather Meal

In the late 1970s, the digestibility of crude protein of feather meal (FeM) for rainbow trout had been estimated to be between 58 percent and 62 percent (Cho and Slinger, 1979). Digestibility trials conducted in more recent years suggested significant improvements. Bureau et al. (1999), for example, estimated the digestibility of crude protein of four FeMs to be between 77 percent and 86 percent (Table 2). A very comparable apparent digestibility coefficient (ADC) value was reported by Sugiura et al. (1998) for a FeM fed to rainbow trout. It also appears to be relatively well digested by other fish species. For example, Lee et al. (2002) estimated that the digestibility of crude protein of FeM was about 79 percent for rockfish (*Sebastes schlegeli*).

Table 2. Manufacturing Characteristics, Crude Protein (CP) Content, and Apparent Digestibility Coefficients (ADC) of Dry Matter (DM), CP, and Gross Energy (GE) of Rendered Animal Protein Ingredients from Various Origins.

Ingredients	Processing Conditions	CP	ADC		
		as is	DM	CP	GE
Feather meals		%	%	%	%
1	Steam hydrolysis, 30 min at 276 kPa, disc dryer	75	82	81	80
2	Steam hydrolysis, 5 min at 448 kPa, disc dryer	82	80	81	78
3	Steam hydrolysis, 40 min at 276 kPa, ring dryer	76	79	81	76
4	Steam hydrolysis, 40 min at 276 kPa, steam-tube dryer	75	84	87	80
Meat and bone meals					
1	125º-135ºC, 20-30 min, 17-34 kPa	57	61	83	68
2	same as above but air classification of final product to reduce ash content	55	72	87	73
3	133ºC, 30-40 min, 54 kPa	50	72	88	82
4	128ºC, 20-30 min, 17-34 kPa	48	66	87	76
5	132º-138ºC, 60 min	50	70	88	82
6	127º-132ºC, 25 min	54	70	89	83
Poultry by-product meals					
1	138ºC, 30 min	65	76	87	77
2	127º-132ºC, 30-40 min, 54 kPa	63	77	91	87
Blood meals					
1	Steam-coagulated blood, rotoplate dryer	83	82	82	82
2	Steam-coagulated blood, ring dryer	84	87	88	88
3	Whole blood, spray dryer	83	92	96	92
4	Blood cells, spray dryer	86	92	96	93
5	Blood plasma, spray dryer	71	99	99	99
6	Steam-coagulated blood, steam-tube dryer	91	79	84	79
7	Whole blood, spray dryer	82	94	97	94
8	Steam-coagulated blood, ring dryer	86	87	85	86

Source: Bureau et al., 1999. (Processing conditions provided by manufacturers).

Meat and Bone Meal

The digestibility of protein in meat and bone meal (MBM) appears to be somewhat variable. Bureau et al. (1999) observed digestibility of protein of six MBMs to be between 83 percent and 89 percent for rainbow trout (Table 2). McGoogan and Reigh (1996) and Gaylord and Gatlin (1996) observed protein digestibility of about 74 to 79 percent for MBM fed to red drum (*Sciaenops ocellatus*). Lower digestibility values were reported by Allan et al. (2000) for Australian lamb and beef MBM fed to Silver perch (*Bidyanus bidyanus*). A series of studies carried out in Japan and Portugal indicated that meat meal (i.e., high protein, low ash MBM) were very highly digestible for several freshwater and marine fish species (Gomes et al., 1995; Watanabe et al., 1996; da Silva and Oliva-Teles, 1998). Results from a number of trials (e.g., Bureau et al., 2000) suggest that the ADC of crude protein tends to overestimate the digestible amino acids of MBM, and that relatively "conservative" estimates of digestibility of protein should be assumed for MBM when formulating fish feeds on a digestible protein basis.

Table 3. Relative Bioavailability of Lysine in Blood Meals of Different Origins, Relative to Lysine-HCL (Assumed to be 100 percent Bio-Available) and Based on Different Parameters: Weight Gain, Feed Efficiency, and Retained Nitrogen in Rainbow Trout.

Parameters	Lysine HCL	Spray-dried blood meal	Flash-dried blood meal	Disc-dried blood meal
Weight gain, g/fish	100	138	150	84
Feed efficiency, gain-to-feed	100	139	132	85
Retained N, g/fish	100	129	143	86

Source: El-Haroun and Bureau, 2004.

Rendered Animal Proteins as Source of Digestible Phosphorus

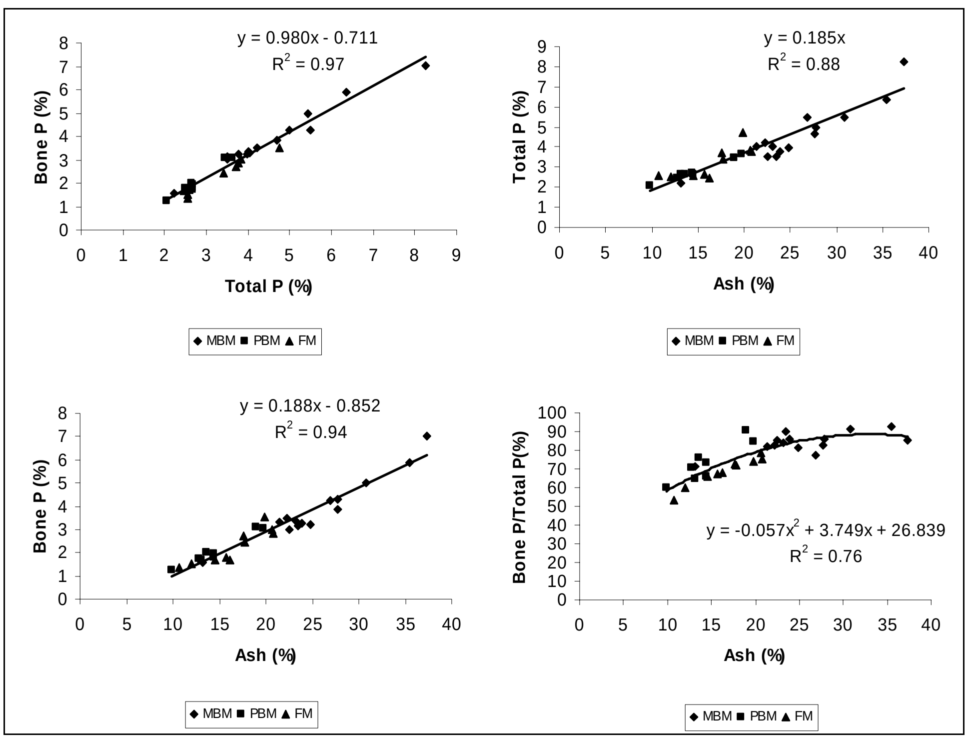
Animal protein ingredients generally have high, but variable, phosphorus (P) content (Table 4). In these ingredients, P is primarily bound with calcium in what is commonly referred to as "bone P." This bone P generally represents a large proportion of the total P of animal protein ingredients (Figure 1). Some of the P is also found as part of several other compounds, such as nucleic acids, amino acids, lipids, and carbohydrates, and is often referred to as "organic P."

The estimates of digestibility of P of animal by-products reported in the literature are highly variable. For salmonid fish, digestibility of P ranges from 17 percent to 81 percent for fish meal, 22 percent to 45 percent for meat and bone meal, and 15 percent to 64 percent for poultry by-product meal. This high variability in the estimate of P digestibility of animal protein ingredients is probably the results of difference in bone P content of the ingredients and the level of different chemical forms of P in the finished feeds. Hua and Bureau (2006) developed a model to estimate digestible P content of salmonid fish feeds based on levels of different P types. Phosphorus types present in feed ingredients were classified into broad chemical categories: bone P, phytate P, organic P, Ca monobasic/Na/K Phosphate (Pi) supplements, and Ca dibasic Phosphate (Pi) supplements (Figure 2). The relationship between digestible P content of feeds and various P chemical compound contents was examined through a multiple regression approach. Multiple regression analysis on data from 22 studies yielded the following model:

> Digestible P = 0.68 bone P + 0 phytate P + 0.84 organic P + 0.89 Ca monobasic/Na/K Pi supplement + 0.64 Ca dibasic Pi supplement + 0.51 phytase/phytate – 0.02 $(\text{phytase/phytate})^2$ - 0.03 $(\text{bone P})^2$ - 0.14 bone P * Ca monobasic/Na/K Pi supplement ($P < 0.0001$, $R^2 = 0.96$).

The results from this model suggest that the digestibility of different P types differ significantly and the apparent digestibility of bone P is not additive, as suspected. The model predicts that animal protein ingredients, such as MBM and PBM, are highly effective sources of digestible P in feeds formulated with high levels of plant protein ingredients.

Figure 1. Bone P Content as a Function of Total P and Ash Contents of Animal Protein Ingredients.

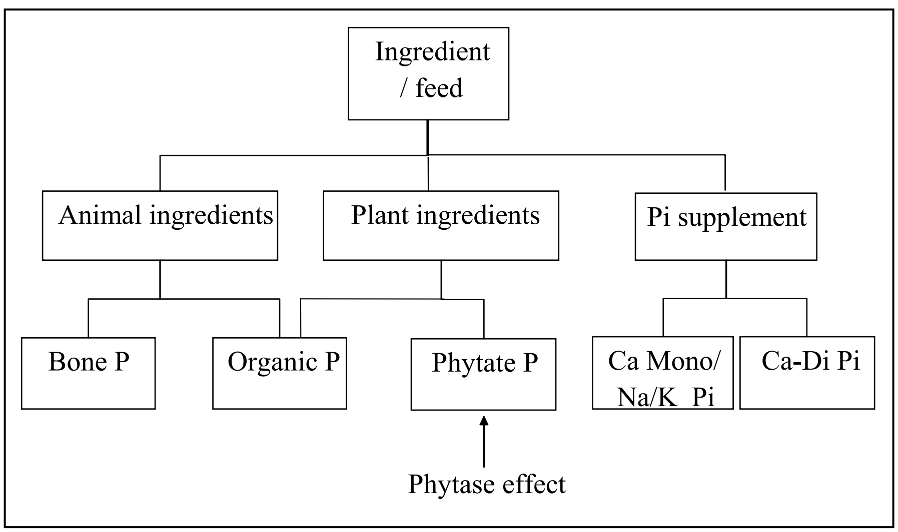


Source: Hua et al., 2005.

Table 4. Phosphorus Content of Common Fish Feed Ingredients (Dry Matter (DM) Basis).

Ingredient	Phosphorus content (g/kg DM)
Fish meal	10.8 - 41.9
Meat and bone meal	24.9 - 70.8
Poultry by-product meal	16.5 - 34.5
Blood meal	0.8 - 17.1
Feather meal	5.4 - 12.6

Figure 2. Schematic Representation of a Model Estimating the Digestible P Content of Fish Feed Based on the Levels of Different P Chemical Forms in Feeds.



Source: Hua and Bureau, 2006.

Use of Animal Proteins in Feeds

Blood Meal

Spray- and ring-dried BMs are widely used in salmonid feeds due to their very high digestibility and consistent quality. Good performance of fish have been observed for fish fed diets containing approximately eight to 20 percent BM in conjunction with high (more than 20 percent) fish meal levels (Luzier et al., 1995; Abery et al., 2002). A study carried out at the University of Guelph also demonstrated that spray-dried BM was of high nutritive value for rainbow trout (Table 5, Trial #1).

Poultry By-product Meal

The use of PBM in fish diets has been studied quite intensively (e.g., Higgs et al., 1979; Alexis et al., 1985; Steffens, 1987; Fowler, 1991; Steffens, 1994). The general conclusion from earlier studies was that approximately 20 to 25 percent PBM can be included in salmonid diet without effect on growth and feed conversion of the animal. More recent studies have indicated that feeds formulated to contain up to 30 percent PBM supported excellent growth performance in rainbow trout (Table 5, Trial #1). PBM is very similar to fish meal in terms of nutritional value for rainbow trout, and this ingredient can effectively replace all the fish meal in the diet of rainbow trout without negative impact on performance (Bureau et al., unpublished).

Feather Meal

Fowler (1990) observed that 15 percent FeM (90 percent CP, four percent lipid) replacing herring meal could be included in the diet of Chinook salmon without effect on growth and feed efficiency of the fish. Henrichfreise (1989, cited by Steffens, 1994) observed that 20 to 25 percent FeM could be included in the diet of rainbow trout without effect on growth and feed efficiency. A more recent study suggested that about 15 percent feather meal (providing 20 percent of total digestible protein) could be incorporated in the diet of rainbow trout without effect on growth and feed efficiency of the fish (Bureau et al., 2000). FeM is quite commonly used in fish feeds at significantly lower levels (five to 10 percent).

Meat and Bone Meal

Shimeno et al. (1993) observed that 10 percent meat meal (68 percent CP, 16 percent lipid, 11 percent ash) along with 20 percent soybean meal could replace 23 percent brown fish meal in diets for yellowtail, a highly carnivorous fish species. Bureau et al. (2000) observed that the incorporation of up to 24 percent MBM (providing about 25 percent of total digestible protein) was possible in feeds for rainbow trout. The results of the study of Bureau et al. (2000) are in agreement with the results of Tacon and Jackson (1985), Davies et al. (1989), and Robaina et al. (1997) who observed that significant amounts of MBM could be included in the diets of rainbow trout, Mozambique tilapia, and gilthead seabream without effect on performance (e.g., Table 5, Trial #2).

Table 5. Performance of Rainbow Trout Fed Practical Diets with Different Rendered Animal Protein Ingredients Alone or in Combination.

	Trial #1				Trial #2			
	Diets				Diets			
	1	2	3	4	1	2	3	4
Protein Sources								
Fish meal, herring	28	24.5	24	20	40	20	20	20
Corn gluten meal	28	24.5	24	20	11	11	11	11
Soybean meal	-	-	-	-	13	-	-	-
Blood meal, spray dried	6	12	-	-	4.5	5	5	5.5
Feather meal	-	-	-	-	-	17	17	-
Meat and bone meal	-	-	-	-	-	25	-	25
Poultry by-product meal	-	-	20	30	-	-	16	16
Composition								
Digestible protein, percent	43.3	43.7	44.5	44.6	42	42	42	42
Digestible energy, MJ/kg	21.3	21.3	21.5	21.6	19	19	19	19
Performance								
Initial weight, g/fish	17	17	16	18	35	35	35	35
Final weight, g/fish	209	215	202	209	278	247*	264	245*
Feed efficiency, gain:feed	1.18	1.26	1.19	1.18	1.26	1.11*	1.20	1.09*
Thermal-unit growth coefficient	0.200	0.205	0.199	0.199	0.261	0.241*	0.252	0.239*

* Significantly different from control diet (Diet 1).
Source: El Haroun et al., unpublished.

Combinations of Animal Proteins

A number of studies have shown that a mixture of high quality rendered animal protein ingredients could replace most of the fish meal in a practical rainbow trout diet sustaining high growth. Dabrowski et al. (1995) observed good performance of rainbow trout fed a diet containing 20 to 30 percent of a fish meal analogue, formulated using BM, MBM, PBM, and FeM. The potential of different combinations of rendered animal protein ingredients was recently examined in a 16-week feeding trial (Table 5, Trial #2). Diets were formulated with combinations of PBM, FeM, and MBM providing about two-thirds of the digestible protein. Growth rates of fish fed diets containing a combination of PBM and FeM was not statistically significantly different than the growth rate of fish fed the control diet. Growth rates of the fish fed diets containing combinations of MBM and FeM or MBM and PBM were slightly lower than that of the fish fed the control diet.

Amino acid supplementation (L-Methionine or L-Lysine), the two amino acids predicted to be the most limiting, had no effect on performance of the fish. It is worth noting that growth rates of fish fed all the experimental diets was superior to what was observed in all previous trials conducted at the University of Guelph. The results clearly indicate that most rendered animal protein ingredients have a high nutritive value and can be very valuable protein sources for fish feed formulation. However, feeds should be formulated on a digestible basis, and relatively conservative estimates of apparent digestibility or safety margins should be used. This is especially critical in the case of FeMs and MBMs.

Use and Nutritive Value of Rendered Animal Fat

Formulated aquaculture feeds are often high in lipids, the bulk of which is generally provided by fish oil. Because of its cost, foreseeable long-term supply problems, and more recently, concerns over contaminant levels, it is widely acknowledged that fish oil should be used more sparingly in aquaculture feeds. Fish oil availability is increasingly problematic since the demand has grown considerably with the expansion of the aquaculture industry. Various projections suggest that within a decade, the demand for fish oil will be well above the available supply. Along with this increase in demand, the price of fish oil has also risen considerably. The market price for fish oil has varied between $0.20 and $0.80/kg over the past decade. Prices in recent years have consistently remained high.

Rendered animal fats, because of their low costs and wide availability, could be interesting alternative for part of the fish oil in fish feeds. Opposite to fish oil prices, the price of inedible animal fats has decreased in the last 10 years by 40 to 50 percent to a current price of about $0.30/kg for good quality choice white grease and tallow. Prices for rendered fats are unlikely to move dramatically over the next few years. Substantial savings could be made immediately by substituting some of the fish oil in feed formulae with these more economical lipid sources. The cost of aquafeed could be reduced by about $3/ton for every percentage point (one percent) of fish oil replaced by rendered fats. There are very few other dietary modifications (e.g., fish meal replacement) to current salmonid feed formulae that could result in such substantial savings.

Animal Fats: Digestibility and Use in Feeds

The ability of fish to use rendered animal fats as an energy source is dependent mainly upon the digestibility of these ingredients. Studies have suggested differences in the digestibility and nutritive value of lipid sources with different fatty acid profiles at different water temperatures. Cho and Kaushik (1990) presented the results from an experiment indicating that the digestibility of fish oil and plant oils (rapeseed, soybean, and linseed) remained high over a wide range of water temperatures (5^{o}C to 15^{o}C). However, the digestibility 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 observations suggest, however, that the digestibility 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 et al. (2002) found that there was no difference in the digestibility of lipid (94 percent) of a feed with 16 percent fish oil and that of a feed with eight percent fish oil and eight percent tallow at a low water temperature (7.5°C). At 15°C, the digestibility of lipid of the diet comprised of eight percent fish oil and eight percent tallow was only slightly lower than that of the feed comprised of 16 percent fish oil (95 versus 98 percent) (Table 6).

Table 6. 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 7.5ºC or 15ºC for 12 Weeks.

	Water Temperature			
	7.5ºC		15ºC	
Ingredients	**Diet 1**	**Diet 2**	**Diet 1**	**Diet 2**
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 lipid digestibility 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. The low digestibility values reported in Cho and Kaushik (1990) for highly saturated lipid sources is probably only the result of the methodology used. Cho and Kaushik (1990) used a reference diet with very low levels of lipids (less than three percent) (Cho, personal communication). This reference diet was then supplemented with significant amounts of the test lipid sources (fish oil, soy oil, lard, tallow) producing test diets in which more than 80 percent of the lipids were provided by the test lipids. It has been demonstrated, more than 40 years ago, that highly saturated lipids, when used alone in the diet, are poorly digested by poultry and other animals. Supplementation of tallow-containing diets with limited amounts of polyunsaturated fatty acids (e.g., from soy oil) resulted in significant improvements in the digestibility of lipids in poultry (Sibbald et al., 1962; Sibbald, 1978). The results presented in Table 6 are consistent with these observations and indicate that saturated fatty acids are effectively utilized by rainbow trout at low water temperature when the diet contains some fish oil. It is suggested that saturated fatty acids levels of the diet should perhaps not exceed 40 percent of total fatty acids of the diet of rainbow trout since digestibility of lipids can possibly decrease quite significantly when more is used.

Several studies have examined the use of poultry fat, tallow, and lard in the diet of various fish species (reviewed by Bureau et al., 2002). Evidence presented in these studies indicate that animal fat incorporation levels corresponding to 30 to 40 percent of total lipids of the diet have no adverse effects on growth performance, feed efficiency, and product quality of most fish species studied. It is transparent from these studies that diets containing animal fats must contain significant amounts 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 lipids.

Conclusion

Formulated aquaculture feeds are often high in protein and fat, and the bulk of those generally provided by fish meal and fish oil. Because of their high cost and foreseeable long-term supply problems, progressive increase in the use of economical protein and lipid sources in aquaculture feeds is inevitable. Feed manufacturers consequently require information on the nutritive value of various economical protein and lipid sources.

Rendered animal proteins and fats produced today in North America are relatively highly digestible and meet high quality criteria required for use in high nutrient density aquaculture feeds. Rendered proteins and fats are cost-effective sources of key nutrients and can also be used to improve the nutritive value of more economical feeds. Sufficient information is available on the nutritive value of rendered products to allow feed manufacturers to judiciously use these products in their fish feeds.

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