Fish Meal and Oil: Current Uses

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World landings of fish and shellfish are approaching 100 million metric tons (MMT) annually. Of this total, around 28% is processed into fish meal and oil. Economic pressures due to poor landings, low prices in traditional markets and high fuel costs have forced the industry to seek new markets and products that can take advantage of the unique properties of fish proteins and oils.

Fish meal processing continues to evolve. Fresh raw materials and new, low-temperature processing techniques lead to products with excellent nutritional value. These new, special meals are finding uses in feeding farmed fish, early-weaned pigs, ruminants and pets.

Fish oils, whether present as fat in the fish meal or as separated oil, are rich in ω3 fatty acids. When fed to food animals, these ω3 fatty acids deposit in the meat and depot fat. Concepts for poultry with an equivalent amount of ω3 fatty acids to lean fish are being developed. Eggs with a high ω3 fatty acid content and good functionality and flavor are under evaluation. Catfish with shelf-stable flavors and high ω3 fatty acids are also under study. ω3 Fatty acids may affect the immune function of livestock. Future research will evaluate the overall immune function of animals, including resistance to disease, survival under stress and hatchability.

KEY WORDS: Aquaculture, by-pass proteins, DHA (docosahexaenoic acid), EPA (eicosapentaenoic acid), fish meal, fish oil, menhaden (*Brevoortia tyrannus* and *B. patronus*), ω3.

World landings of fish are approaching 100 million metric tons (MMT) per year (1). In general, about 28% of the world landings is converted to fish meal and oil; in the U.S., the figure is closer to 32% (2). Table 1 gives a comparison of the disposition of world and U.S. landings for 1989. Those fish converted to fish meal and oil have been called underutilized, nontraditional or latent species and offer the seafood industry an opportunity to increase fish consumption. The Food and Agriculture Organization of the United Nations (FAO) divides fish used for reduction to meal and oil into several categories: i) Fish caught primarily for reduction to meal and oil, such as the U.S. menhaden; ii) by-catch from other fisheries, such as the shrimp fishery (according to some experts, this could amount to as much as 3–5 MMT annually); and iii) fish offal and waste from the edible fisheries, such as cutting waste from filleting plants, roe operations, waste from surimi production and tuna cannery waste (3). According to some recent reports (4), Alaska alone now generates over 1 MMT of fish waste from surimi, ground fish and salmon operations. These categories are similar in that the fish are either considered industrial because of excessive bones or high oil content, or the waste cannot be used for edible purposes and presents a disposal problem. In these circumstances, the raw material is converted into valuable feed and industrial products and often makes its way indirectly into the food supply by conversion to edible protein in livestock and farmed fish.

TABLE 1

Disposition of World and U.S. Catch of Fish and Shellfish —Percentage of Use in 1989[a]

	World	U.S.
Fresh and frozen	44.9	50.1
Canned	12.1	12.5
Cured	14.1	1.2
Fish meal and oil	27.6	31.6
Other	1.3	4.6

[a]Reference 1.

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HARVESTING AND PRODUCTION

Fishing is the last major "hunter/gatherer" industry in the world and involves large vessels capable of carrying 600 metric tons or more of fish. In the North Atlantic area, some large trawlers can carry over 1500 metric tons. In the U.S., we use purse seiners that can carry 500 metric tons of refrigerated fish. The purse seiner consists of a large steamer and two small purse boats that carry the net. When fish are spotted, the purse boats approach the school and encircle them with the net. Once encircled, the net is closed and the fish are pumped aboard the steamer. The production of fish meal and oil from fresh raw material gives the highest yield and the best quality products. The rate of degradation of stored fish doubles for each 6°C rise in temperature (5). Therefore, fish used for production of meal and oil are preserved with ice, refrigerated sea water (or with nothing in areas where the ambient temperature is low or the holding time is short, such as in factory trawlers).

Once a vessel arrives at the factory, the fish are unloaded and processed immediately. The wet reduction process is universal, reduces the fish to three components (solids, water and oil) and then separates them into three products (fish meal, oil and solubles). Figure 1 gives a schematic diagram of the process.

FISH MEAL

General considerations. The world production of protein meals is expected to exceed 139 MMT in 1992 (6). Table 2 gives the production forecast for 12 major protein meals for the 1991/92 growing season (7). In 1992, a production of 6.5 MMT fish meal is forecast. Table 3 gives a five-year average breakdown of fish meal production, imports and exports (8).

Fish meal is used in feeds of poultry, pigs, ruminants, fish, crustaceans, pets and fur-bearing animals because it increases productivity and improves feed efficiency. Table 4 lists world consumption of fish meal by species fed (9). Fish meal has been used as a feed ingredient for farm animals in the U.S. for over a century. It provides

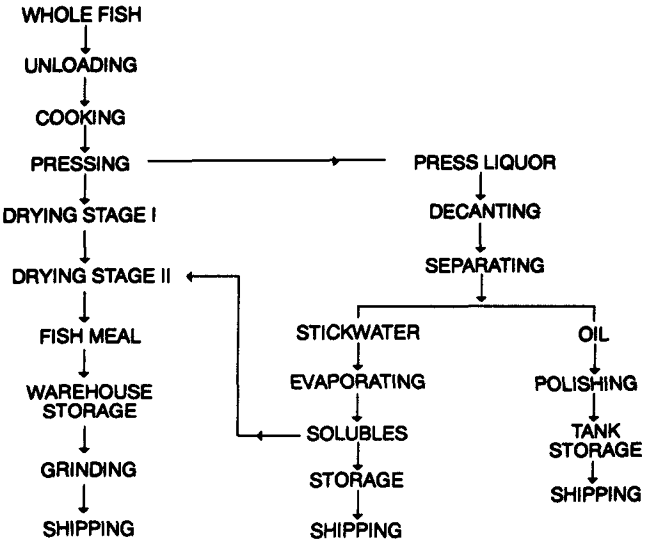

FIG. 1. Production scheme for fish meal and fish oil.

TABLE 2

Forecast of World Production of Oilseed Meals and Fish Meal for the Crop Year Oct./Sept. 1991–1992, in MMT[a]

Soybean	70.42
Cottonseed	15.31
Sunflower	9.25
Corn germ	2.30
Groundnut	5.67
Palm kernel	1.96
Copra	1.77
Rapeseed	14.21
Sesame	0.83
Linseed	1.40
Fish	6.50
Corn gluten	10.30
Totals	139.92

[a]Reference 6.

TABLE 3

World Fishmeal Situation in 1000 Metric Tons, Five Year Average[a]

	Production	Imports	Exports
EEC 12	496	1078	536
Eastern Europe	88	347	0
U.S.	349	155	48
South Africa	171	82	0
Pacific Basin	1227	1034	235
South America	2344	35	2103
USSR	769	36	11
Scandinavia	382	145	317
Others	560	516	155
Totals	6386	3428	3405

[a]References 7 and 8.

TABLE 4

World Fish Meal Consumption by Species Expressed as Percentage of Total Consumption[a]

Poultry	58.0
Ruminants	2.5
Pigs	20.0
Fur	1.5
Fish	14.0
Others	4.0

[a]Reference 9.

a unique balance of essential amino acids, energy, vitamins, minerals and trace elements, which complement other feed ingredients by correcting their deficiencies. Fish meal also is a good source of the amino acid taurine and arachidonic acid, which are essential for cat nutrition. In addition to being a major source of energy, the residual fat in fish meal is a rich source of omega (ω)3 fatty acids, which represent over 30% of the total fatty acids present. Table 5 gives typical composition data for a number of fish meal types currently available on the market (10–15).

The introduction of new equipment and processing techniques in the production of fish meal continues to give the industry the flexibility to produce feed proteins that are tailored for particular animals. Special quality fish meals are now available for ruminants, farmed fish and early-weaned pigs. Freshness of raw material is an extremely important criterion for all special meals because the profitability of feed use can vary with the freshness of the raw material used. In Denmark, a penalty payment system, in which Danish fishing vessels are paid according to the quality of the raw material landed at the factory, was initiated in 1986. Originally designed to reduce plant odors from poor-quality fish, the system soon demonstrated that a higher quality finished product with higher yields could be produced for less cost (16).

Apart from freshness, monogastrics and ruminants have quite different requirements for feed ingredients. Some producers now make a special quality fish meal from very fresh raw material, processed through cookers and dryers at 10–20°C below normal processing temperatures. Trials in Norway have demonstrated that the processing temperature affects the digestibility of fish meal when young minks are used as test animals. In other experiments in Norway with Atlantic salmon, drying temperature affected weight gain over 18 weeks of feeding (17).

Collaborative studies, sponsored by the International Association of Fish Meal Manufacturers (IAFMM), are currently underway to find chemical parameters that can be related to biological activity. Such tests are currently being evaluated on fish meals that were processed from fish of known quality under commercial conditions in both conventional and low-temperature (LT) plants. Meals produced from different species of fish are currently being fed to a wide range of test animals to determine which species are sensitive to raw material freshness or to processing temperatures.

In the U.S., Zapata Haynie Corporation has been producing a special quality menhaden meal processed from very fresh raw material at moderate processing temperatures. The program is now going into its sixth season, and the product has found acceptability in the early-weaned pig market. A product suitable for high-yielding dairy cows has recently passed the experimental stage and is

TABLE 5

Nutrient Composition of Various Fish Meals

	Herring type	White fish	Anchovy type	Menhaden
Proximate analysis, %[a, b]				
Crude protein	71.9	64.5	66.4	61.25
Ether fat	7.5	4.9	9.7	9.13
Moisture	8.4	10	8.6	7.99
Ash	10.1	20	15.4	18.77
Protein characteristics, % of crude protein[c]				
Rumen Degrad.	48.8	53.3	48.5	50.5
Water Soluble	19.8	8.9	18.3	15.5
Energy content, Mj/Kg[d]				
Poultry, M.E.	13.7	11.6	13.5	12.8
Pigs, D.E.	18.1	15.6	16.9	16.5
Ruminants, M.E.	16.4	13.4	13.1	12.8
Fish, M.E.[e]	17.0	16.5	16.5	16.0
Amino acids, % of protein[a, b]				
Lysine	7.73	6.90	7.75	7.43
Methionine	2.86	2.60	2.95	2.63
Cystine	0.97	0.93	0.94	0.90
Tryptophan	1.15	0.94	1.20	0.78
Arginine	5.84	6.37	5.82	6.01
Phenylalanine	3.91	3.29	4.21	3.55
Threonine	4.26	3.85	4.31	3.98
Taurine	NA[g]	NA	NA	0.69
Minerals[a, b]				
Calcium	1.95	8.00	3.95	4.87
Phosphorous	1.50	4.80	2.60	2.93
Sodium	0.42	0.77	0.87	0.61
Magnesium	0.11	0.15	0.25	0.20
Potassium	1.20	0.90	0.65	0.81
Iron, ppm	150.00	300.00	246.00	1019.00
Copper	5.40	7.00	10.60	5.50
Zinc	120.00	100.00	111.00	84.00
Manganese	2.40	10.00	9.70	41.00
Selenium	2.78	1.50	1.39	2.21
Vitamins, ppm[a]				
Panth. Acid	30.60	15.00	9.30	8.80
Riboflavin	7.30	6.50	2.50	4.80
Niacin	126.00	50.00	95.00	55.00
Choline	4396.00	4396.00	4396.00	4396.00
B12	0.25	0.07	0.18	0.06
Biotin	0.42	0.08	0.26	0.26
Essential fatty acids, % of fat[f]				
C18:2n-6	2	1	1	1
C18:3n-3	1	1	1	1
C18:4n-3	2	2	2	2
C20:4n-6	1	NA	1	1
C20:5n-3	6	12	16	12
C22:5n-3	1	2	2	3
C22:6n-3	13	19	14	9
Total n-3	23	35	34	30

[a]Reference 10.
[b]Reference 11.
[c]Reference 12.
[d]Reference 13.
[e]Reference 14.
[f]Reference 15.
[g]NA, not available.

now in limited commercial production. A product suitable for the aquaculture market currently is in the research stage.

Poultry-broilers. USDA researchers evaluated U.S. food consumption data and reported that the decline in the amount of ω3 fatty acids in the diet contributed by fatty fish has been offset by increased consumption of these fatty acids from poultry. They evaluated data for random periods from 1935–1985 and concluded that the increased poultry ω3 content came from the use of fish meal in poultry feeds. Thus, low concentrations of ω3 fatty acids in foods consumed in large quantities can make an important contribution to ω3 intake (18).

Historically, the common broiler has been the major consumer of fish meal, but it has not been a food that people recommend or think of as a rich source of ω3 fatty acids in the diet. Recent research, both in the U.S. and in Canada, indicates that chicken can be comparable to cod as a source of ω3 fatty acids (19–22). These researchers fed high levels of herring, white fish and red fish meals to broilers over extended periods of time and then evaluated the carcass meat for flavor and fatty acid composition by gas chromatography. Their results indicate that significant levels of ω3 fatty acids can be incorporated into poultry meat without affecting meat flavor.

Canadian researchers suggest that the consumption of fatty fish in North America has dropped significantly and that current fish consumption is of the white fish variety (cod, haddock, etc.). White fish typically contains 0.7 g of lipid/100 gm and 0.1–0.2 g ω3/100 gm. Based on their calculations, about half of the ω3 fatty acids in the North American diet comes from chicken. Therefore, ω3 enhancement of chicken could make it the main source of these fatty acids for humans. The studies indicated that broiler chickens fed a diet with 5% fish meal have substantial amounts of fish ω3 fatty acids deposited in the total carcass and edible meat lipids, and all ω3 PUFA were significantly increased by feeding higher levels of red fish meal (15–30%) or red fish oil (2–4%). Taste panel tests in an unpublished report found off-flavors in the meat of birds fed 15 or 30% red fish meal or 4.2% red fish oil, but the flavors detected were not described as fishy or objectionable. In a more recent study, lower levels of red fish meal (12%) were fed and it was calculated that an average meal of 100 g of chicken without skin would contain 10.7% lipid and would contribute a total of 196.6 mg of ω3 fatty acids. Cod flesh would deliver about 138 mg/100 gm ω3 fatty acids (23).

According to a leading nutritionist, we need ω3 fatty acids on a regular basis, not just occasionally. We can increase the availability of these fatty acids in foods by feeding fish meal to livestock and by incorporating fish oils into widely consumed foods, such as mayonnaise, margarine and salad dressings (24).

Ruminants. Ruminants' nutrition is greatly affected by the microflora that exists in their fore-stomach or rumen. Ruminants cannot efficiently utilize nutrients with a low fiber content, such as grain and oilseed meals. The microorganisms allow the ruminant to utilize materials with a high crude fiber content that cannot be used by monogastric animals. The microorganisms convert a substantial part of the fiber in the feed to volatile carboxylic acids. Proteins are also broken down into ammonia, which is then used by the rumen microorganisms (25).

These products of microbial metabolism are absorbed directly through the rumen wall, while the remaining microbial biomass and feed are passed to the abomassum, where they are utilized in the same manner as in monogastric animals.

Fish meal has been fed to ruminants for some time in the U.K. and northern Europe, but it is a relatively new concept in the U.S. Cooked proteins tend to be relatively resistant to degradation by rumen microorganisms, thus permitting those proteins to escape the rumen and provide the animal with a source of high-quality protein. Because fish meal is cooked, it has a fairly high "by-pass" value. Where fish meal has been added to diets of high-producing animals, some dramatic responses have been seen. Cornell researchers (26) demonstrated significant increases in muscle size and in the lean/fat ratio when 2–3% fish meal was added to the diets of lambs. Other researchers (27) evaluated 3% menhaden fish meal in the diets of feedlot cattle and found that the cattle reached market weight 30 days sooner than usual.

Researchers in Scotland (28) recently reported that feeding lambs and heifers straw or straw supplemented with fish meal demonstrated that all animals would utilize body fat for maintenance. Those on straw lost weight as fat and lean tissue, but those on the fish meal supplement lost fat and gained lean tissue, thus maintaining body weight. The lambs were given 75 g/day of fish meal, while the heifers received 400 gms/day.

The dairy cow presents a unique problem for fish meal producers in the U.S. Fish meal initially appeared to depress butterfat production under some feeding circumstances. Recent studies (29–31), however, have demonstrated that fish meal can be used successfully with high-yielding dairy cows fed high alfalfa silage diets. Cows produced an additional 3 pounds or 1.4 quarts of milk daily when fed alfalfa silage mixed with 1 pound per day of fish meal protein. The fish meal cost 11 cents more per day than soybean meal, but tests showed that the cows were producing an additional 36 cents worth of milk per day. This equates to an additional profit of $12/day for the average farm with 48 cows. The cows also produced milk with 4% more protein (32). Fish meal has an excellent amino acid profile, close to that required for growth and milk production, according to a review of animal by-products as protein supplements for cattle (33).

British researchers (34) reported on trials in Israel and Northern Ireland, in which fish meal improved the fertility of dairy cows. Higher milk production, improved income from more calves and reduced veterinary charges were documented. In the Northern Ireland trial, conception rate improved from 44 to 64%. The authors calculated that the combined cost benefit of improved fertility and improved production efficiency was worth 160–165 £ per cow per lactation.

Pigs. Intensive production methods require pigs to be weaned early at 3–4 weeks of age. At this age, young pigs are sensitive to the form of protein in their diets. Many dietary proteins give an allergenic response, in which diarrhea, reduced growth and increased mortality can result. With proteins from fish, this response is low. Fish meal made from fresh raw material is tolerated well by these young animals because it is highly digestible and palatable.

Studies conducted in 1986 at Kansas State University evaluated the effect of a selected menhaden fish meal as a protein source in starter diets for pigs. Results from the study indicated that the addition of 8% specially selected menhaden meal to the diets of three-week-old weaned pigs resulted in an 11.5% increase in average daily gain by the end of the fifth week (35,36).

TABLE 6

Estimated Total Use of Fish Meal in Fish Diets, Expressed in 1000 Metric Tons[a]

Prawns	237
Sea Bream	30
Salmon	225
Carp/Tilapia	50
Trout	132
Catfish	29
Eels	135
Yellowtail	35
Totals	873

[a]Reference 9.

Aquaculture. Fish differ from domestic animals in several ways. Their body temperature varies according to water temperature. Therefore, they do not require energy to maintain a constant body temperature. They are efficient at eliminating waste through the gills in the form of soluble ammonium compounds. Thus, high-protein feeds are readily digested and have higher metabolizable energy values for fish than for warm-blooded animals (17).

The global use for fish meal in aquaculture in 1990 was 873,000 metric tons. Table 6 gives a breakdown of fish meal consumption by species (9). Aquaculture accounted for 12–14% of the world's fishery production in 1987. By the year 2000, that figure is expected to rise to 20%. In fact, there are predictions that the amount of fish harvested from aquaculture could someday surpass the yield from wild fish (37). Demand for fish meal in these feeds is expected to double, with farmed fish taking 20–25% of world fish meal production by the year 2000. There will not, however, be a shortage of fish meal for the traditional market as the increased production of edible fish naturally generates more cuttings and offal that can be converted back into fish meal.

Farmed fish, especially young, fast-growing cold-water species such as salmon and trout, are sensitive to dietary protein quality because they require high-protein diets (40–50%). Fish meal is used at high levels in these diets—50–60% for salmon and around 30% for trout. The quality of the fish meal is critical and it should be produced from very fresh fish. Because most fish, especially cold-water fish, need the long-chain ω3 polyunsaturated fatty acids present in fish oil and in the residual fat present in fish meal, these products also supply ω3's in the feeds of fish and crustaceans.

FISH OIL

The world will produce over 80 MMT of fats and oils in the 1990/91 crop year (38). Table 7 gives a breakdown by source. About 1.44 MMT of fish oil were produced in 1990. Table 8 gives a five-year average geographical breakdown of production, imports and exports for fish oil (39).

TABLE 7

World Supply of Fats and Oils in Million Metric Tons, Five-Year Average[a]

	Production	Imports	Exports
Soya	15.57	3.87	3.88
Cottonseed	3.67	0.32	0.32
Groundnut	3.73	0.36	0.36
Sunflower	7.45	2.28	2.29
Rapeseed	7.76	1.84	1.85
Sesame	0.65	0.02	0.02
Corn	1.29	0.40	0.40
Olive	1.83	0.59	0.59
Palm	9.57	7.22	7.19
Palm kernel	1.25	0.82	0.83
Coconut	3.01	1.44	1.44
Butter fat	6.39	1.30	1.30
Lard	5.42	0.52	0.52
Fish	1.50	0.85	0.84
Linseed	0.71	0.25	0.25
Castor	0.39	0.20	0.20
Tallow/grease	6.63	2.69	2.69
Totals	76.82	24.97	24.97

[a]Reference 38.

TABLE 8

World Fish Oil Situation in 1000 Metric Tons, Five-Year Average[a]

	Production	Imports	Exports
EEC 12	125	614	110
Other western European countries	185	107	197
USSR	110	0	18
South Africa	36	17	7
U.S.	115	11	89
Latin America	389	31	190
Eastern Europe	0	36	0
Pacific Basin	446	29	232
Others	137	28	27
Totals	1543	872	870

[a]Reference 39.

Fish oil is a versatile product and finds many applications in the food, feed and technical industries of the world. The largest use for fish oil is in the partially hydrogenated form in Europe in the baking industry. The recent Generally Recognized As Safe (GRAS) affirmation of partially hydrogenated menhaden oil (PHMO) has not yet resulted in a major market in the U.S. We still export over 80% of our production to Europe for edible use. The second part of the GRAS application for refined menhaden oil is still pending before the FDA, and approval is not expected until late 1992.

Layer hens. The consumption of shell eggs has decreased during the past decade because of recommendations by health professionals to reduce dietary cholesterol. Attempts over the last 30 years to reduce the cholesterol level in eggs has not been successful. A side effect of this work has been a change in the fatty acid composition of the yolk. In 1987, an interesting area of feed fat research emerged. This involved the production of low-cholesterol, high-ω3 fatty acid eggs (40–43). Some of these eggs are currently on the market. While the cholesterol issue remains controversial, feeding 1.5–3% highly refined menhaden oil in layer hen diets increases the ω3 levels in the egg yolk. Flavor is not affected until levels of 6% are used (43).

In a recent study in Texas, 3% menhaden oil was fed to layer hens over an 18-week period and compared to an isocaloric diet containing no added fat. The menhaden oil did not alter egg production, egg weight, total yolk fat or yolk cholesterol, but the content of ω6 and ω3 fatty acids was altered. After 1 week, the EPA level increased and the final ratio of ω6 to ω3 changed from 18 to 3. Further studies presently underway will evaluate consumer acceptance and include tests for functionality, compositional stability and sensory characteristics. A human clinical study with the eggs also is in progress (44).

Researchers at the University of Rhode Island (45) fed diets containing up to 3% menhaden oil to layer hens for four weeks. Feed consumption, weight gain and feed conversion of hens in four different groups were measured. They concluded that ω3 polyunsaturated fatty acids in the egg yolk can be increased without causing a fishy flavor by feeding up to 3% menhaden oil. They attributed the lack of fishy flavor in the eggs to the fact that the oil was stabilized with antioxidant.

Broilers. Some researchers are taking a different approach to animal nutrition. Dietary lipids are one class of nutrients that offer tremendous opportunity for modifying immune responses in animals. Research indicates that the prostaglandin E2 is immunosuppressive and that the ω3 fatty acids in menhaden oil reduce its biosynthesis. Commercial application of this modulation will require further research, especially with poultry, as this is a new area of work. Improvements in flock health and disease resistance may be realized by manipulating the amounts and types of fat in the diet (46). Infectious diseases cause serious economic losses to the poultry industry every year. Evidence suggests that current nutrient guidelines for poultry do not optimize immune responses or disease resistance. The immune response of chickens has been shown to be influenced by a number of nutrients. In addition to supplying energy, dietary fats are modulators of the immune response. A group in Missouri fed linseed, menhaden, lard, corn and canola oils to chicks and found that a diet containing 7% menhaden oil significantly enhances antibody production. Further work is underway, including plans for an evaluation under commercial conditions at a number of institutions (47).

Fish oil also affects the composition of broiler meat. Different dietary lipid sources, including fish oil, safflower oil and beef tallow, were fed to broilers for 18 weeks. The composition of breast, thigh and skin lipids were evaluated. Lipids in the meat reflected the lipid fed. Chickens fed the menhaden oil reflected the fish fatty acids not found in the chickens fed the other diets (48–50).

In another study (done in Virginia), researchers fed linseed, menhaden, soybean or chicken fat to chickens for 56 days. They found that linseed oil and menhaden oil resulted in similar levels of EPA in the tissue, chicken fat gave the highest level of saturates and soybean oil gave the highest levels of ω6 fatty acids in the tissue (51).

Ruminants. Because of bad publicity about red meats, several researchers have been attempting to decrease the saturated fatty acids and incorporate ω3 fatty acids into the flesh of red-meat animals. At Southern Illinois University, researchers infused 1–4% refined menhaden fish oil into the abomassum of beef cattle over a 60-day period. The results indicated that while there was no increase in carcass body fat, the ω3 fatty acids were extensively incorporated into the muscle tissue at the expense of saturated fatty acids. There were no taste studies done and further research with protected fats is underway (52,53).

A recent U.S. patent (54) describes "split feeding" as a way to regulate the content and composition of fats in milk. The cows are trained to activate their oesophageal groove reflex so that they can take liquid feed directly into the abomassum or concentrate into the rumen. In this way the unsaturated oils are not hydrogenated in the rumen, and even with fish oils there is no off-flavor in the milk.

Pigs. Supplementing practical sow diets (corn/soy) with menhaden oil at 3.5–7% of the diet late in gestation can significantly increase the content of ω3 fatty acids in the sow's serum, colostrum and milk (55). The fatty acid profile of serum and tissues of the piglets was significantly affected by the fat source provided to the sow. Substituting menhaden oil for lard in a sow's late gestation and lactation diet greatly elevates the content of ω3 fatty acids in the nursing pig and reduces PGE_2 production of its immune cells, but it had no effect on primary and secondary antibody responses of weanling piglets.

Aquaculture. Animals with all food provided under the management of a farmer have minimal choice of diet and will acquire a ratio of ω6/ω3 that is controlled by the farmer. Thus, farmers can indirectly influence the ω3/ω6 balance in the people who eat their farm products. This makes an aquaculturist's decisions about feeding fat to fish of more importance than just meeting the growth needs of the farmed animal. The supplies of long-chain ω3 fats, which are currently obtained by hunting fish in the oceans, may not be adequate in the next century. But the marine food chain offers some unique ways to increase ω3's in the diet by the feeding of fish (56).

Lipids from wild fish, particularly marine fish, contain comparatively high levels of ω3 PUFA, which they obtain in the diet by consuming plankton, algae and other fish. Numerous investigators have demonstrated that fish are what they eat. The composition and flavor of the fat in the fish can be adjusted easily by the type of fat fed. Louisiana State University (LSU) researchers (57) reported on the difference in fat composition of fresh-water prawn and marine shrimp. Canadian researchers (58) have indicated that consumers are confused about whether to consume more high-fat fish, in order to increase their intake of ω3 fatty acids, or to avoid the extra fat and eat only lean white-fleshed fish. They go on to say that farm-raised salmon should provide at least 5 grams of fat containing 400 mg of DHA and 200 mg of EPA per 100-gram serving in order to mimic wild salmon.

Many farm-raised fish are low in ω3 fatty acids because their diets are formulated primarily from agriculture products. This deficiency can be eliminated by adding fish oil containing high levels of ω3 to their diet. The compositions of shrimp, crayfish, catfish, eel, trout and carp lipids have been reviewed, and it is apparent that ω3's are going to have an effect on the future of all commercial aquaculture (59). The public image of aquaculture could suffer if these ω3 fatty acids are not controlled in the fish diet. It is important for the aquaculture industry to investigate the possibility of economically altering fish feeding programs to insure that the ω3's are available in their products.

An in-depth study of the nutrients and chemical residues in Mississippi farm-raised channel catfish was recently reported. The total ω3 content of these fish, 100 mg/100 g, makes them an extremely poor source of these fatty acids, somewhat less than lean fish (60). In a 12-week trial in Texas, catfish were fed menhaden oil at levels ranging from 1.5% to 6%. A practical diet supplemented with 3% menhaden oil is suitable for achieving maximum growth. At 6% menhaden oil and in the control treatments, fish did not grow as well as the 3% treatment. A trained taste panel said that the catfish on 3% menhaden oil tasted more fishy, but the flavor was not objectionable (61).

The consumption of fish and the oil it contains is believed to be beneficial to health. Some of the fatty acids in fish, in particular the EPA and DHA, would appear to be of particular value. By using good-quality fish oils that are adequately protected against oxidation it should be possible to increase the content of these fatty acids in the lipids of farmed fish to similar or even higher concentrations than are found in the wild species (62).

The use of fish meal and oil in the feeding of livestock, pets and farmed fish has taken on a new aspect in recent years. Formerly utilized as a source of protein and energy, fish meal is now recognized as a unique balance of amino acids, vitamins, essential fatty acids and trace elements. Fish oils, formerly used as a source of cheap energy, are now utilized in a variety of feeds, not only as a source of essential fatty acids but as a source of nutrients with positive health benefits for the animals and the people who eat them.

REFERENCES

1. *Fisheries of the United States 1989 Supplemental*, U.S. Dept of Commerce, May, 1990.
2. *Fisheries of the United States 1989; Current Fishery Statistics*, U.S. Dept of Commerce, No. 8900, 1990.
3. *The Production of Fish Meal and Oil*, Fisheries Food and Agriculture Organization of the United Nations, Technical Paper 142, Revision 1, 1986.
4. Griffin, N., *Seafood Supplier*, Nov/Dec., pp. 53–60 (1990).
5. Fosbol, P., *Infofish International 88(5)*:26 (1988).
6. Mielke, T. (ed.), *Oil World 34*:17 (1991).
7. *Ibid. 34*:1 (1991).
8. *Ibid. 32*:46 (1989).
9. Pike, I.H., *Increasing Importance of Aquaculture to the Fish Meal Industry*, International Association of Fish Meal Manufacturers, Technical Market Report, April, 1991.
10. Barlow, S., and M. Windsor, *Fishery By-Products*, International Association of Fish Meal Manufacturers, Technical Bulletin No. 19, 1984.
11. Collette, R.G., *Fish Meal Notes, Menhaden Meal Composition Data*, National Fish Meal and Oil Association, Washington, D.C., 1991.
12. Mantysaari, P., and C. Sniffen, *Feedstuffs 61*:18 (1989).
13. Pike, I.H., *The Feed Compounder*, February, 13 (1987).
14. Rumsey, G., in *Proceedings of the 43rd Minnesota Nutrition Conference*, September, 1982, University of Minnesota, p. 46.
15. Opstvedt, J., *Fish Lipids in Animal Nutrition*, International Association of Fish Meal Manufacturers, Technical Bulletin No. 22, 1985.
16. Madsen, H.B., *Feed International 7-7*:16 (1986).

17. Pike, I.H., *The Role of Fish Meal in Diets for Salmonids*, International Association of Fish Meal Manufacturers, Technical Bulletin No. 24, 1990.
18. Raper, N.R., and J. Exler, in *Proceedings of the 2nd International Conference on the Health Effects of Omega-3 Polyunsaturated Fatty Acids in Seafoods*, Washington, D.C., June 20–23, 1990.
19. Ackman, R., F. Lamothe, H. Hulan and F. Proudfoot, *N-3 News Unsaturated Fatty Acids and Health 3*:1 (1988).
20. Hulan, H., R. Ackman, W. Ratnayake and F. Proudfoot, *Can. J. Anim. Sci. 68*:533 (1988).
21. Hulan, H., R. Ackman, W. Ratnayake and F. Proudfoot, *Poultry Sci. 68*:153 (1989).
22. Hulan, H.W., F.G. Proudfoot and D.M. Nash, *Ibid. 63*:324 (1984).
23. Hulan, H.W., and R.G. Ackman, *Proceedings of the Eleventh Western Nutrition Conference*, University of Alberta, Calgary, Canada, September 13–14, 1990.
24. Nettleton, J.A., *J. Amer. Dietetic Assoc. 91*:331 (1991).
25. Pike, I., *The Feed Compounder*, January, 1 (1981).
26. Beermann, D., D. Hogue, V. Fishell, R. Dalrymple and C. Ricks, *J. Anim. Sci. 62*:370 (1986).
27. Thonney, M., and D. Hogue, *J. Dairy Sci. 69*:1648 (1986).
28. Orskov, E.R., *Feedstuffs 63*:67 (1991).
29. Broderick, G., *U.S. Dairy Forage Research Center Summaries*, 1989, p. 59.
30. Dhiman, T., and L. Satter, Abstract of paper presented at the American Dairy Science Association and American Society of Animal Science, Lexington, Kentucky, 1989.
31. Broderick, G.A., and L.D. Satter, *Feedstuffs 62*:38 (1990).
32. Anonymous, *Food Business*, September (1989).
33. Stern, M.D., and H.R. Mansfield, *Feedstuffs 61*:16 (1989).
34. Pike, I.H., and R.J. Esslemont, International Association of Fish Meal Manufacturers, Fish Meal Flyer No. 19, March, 1991.
35. Stoner, G., G. Allee, J. Nelssen and M. Johnston, *Kansas State University Swine Day Progress Report No. 507*, 1986.
36. *Effect of a Selected Menhaden Fish Meal in Starter Diets for Early Weaned Pigs*, International Association of Fish Meal Manufacturers, Kansas State University, Fish Meal Flyer No. 15, 1987).
37. Weddig, L., *Meat and Poultry March*, 25 (1991).
38. *Oil World 34(3)*:1 (1991).
39. *Ibid. 34(30)*:12 (1990).
40. Stadelman, W., Paper presented at the 30th Annual Fisheries Symposium, National Fish Meal and Oil Association, March 15, 1989, Baltimore, MD.
41. Yu, M., and J. Sim, *Poultry Science 66*:195 (1987).
42. Hulan, H., *Ibid. 67*:99 (1988).
43. Oh, S., T. Hsieh, J. Ryue and D. Bell, FASEB Meeting, May 1988, Las Vegas, NV.
44. Hargis, P.S., M.E. Van Elswyk and B.M. Hargis, *Poultry Science 70*:874 (1991).
45. Huang, Z.B., H. Leibovitz, C.M. Lee and R. Millar, *J. Agric. Food Chem. 38*:743 (1990).
46. Watkins, B.A., Speech presented at the 32nd Annual National Fish Meal and Oil Association Fisheries Symposium, March 20, 1991, Baltimore, MD.
47. Hall, K.N., Speech presented at the 31st Annual National Fish Meal and Oil Association Fisheries Symposium, March 21, 1990, Baltimore, MD.
48. Adams, M.H., M. Colberg, M.A. Reiber and A.L. Izat, *Poultry Science 68*:166 (1989).
49. Nir, I., *Ibid. 69*:99 (1990).
50. Phetteplace, H.W., and B.A. Watkins, *Journal of Food Composition and Analysis 2*:104 (1989).
51. Fritsche, K.L., N.A. Cassity and S.C. Huang, *Poultry Science 70*:611 (1991).
52. Barry, M., M.S. Thesis, Southern Illinois University, 1988.
53. Young, A.W., Speech presented at the 31st Annual National Fish Meal and Oil Association Fisheries Symposium, March 21, 1990, Baltimore, MD.
54. Christensen, B., and E. Storm, U.S. Patent No. 459-119-9 (1989).
55. Fritsche, K.L., Speech presented at the 32nd Annual National Fish Meal and Oil Association Fisheries Symposium, March 20, 1991, Baltimore, MD.
56. Lands, W.E.M., *World Aquaculture 20*:1 59 (1989).
57. Chanmugam, P., J. Donovan, C.J. Wheeler and D.H. Hwang, *J. Food Science 48*:1440 (1983).
58. Ackman, R.G., S.M. Polvi, R.L. Saunders and S.P. Lall, *Bull. Aquacul. Assoc. Canada 90(4)*:45 (1990).
59. Pigott, G.M., *World Aquaculture 20*:63 (1989).
60. Nettleton, J.A., W.H. Allen, Jr., L.V. Klatt, W.M.N. Ratnayake and R.G. Ackman, *J. Food Sci. 55*:954 (1990).
61. Brown, R.H., *Feedstuffs 62*:11 (1990).
62. *The Role of Fish Oil in Feeds for Farmed Fish—Estimated Current and Potential Use*, International Association of Fish Meal Manufacturers, Technical Bulletin No. 25, 1990.

[Received August 30, 1991; accepted November 28, 1991]