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FEATURE

Aquaculture:
New markets for meals, fats and oils

Aquiculture-the production of aquatic animals in a controlled environment-is increasing as U.S. consumers eat more fish, and wild catch and imports are unable to keep up with demand. In fact, aquiculture is one of the nation's fastest-growing agricultural industries, according to the U.S. Department of Agriculture (USDA). As a result, new markets for meals, fats and oils are being created to provide aquiculture feeds.

In 1986, the U.S. aquiculture industry produced more than 600 million pounds of catfish, crawfish (also known as crayfish), salmon and other aquatic products, compared with 200 million pounds in 1980. U.S. aquiculture production currently is estimated at more than 790 million pounds, valued at approximately $700 million, and is expected to surpass 2 billion pounds by the year 2000. Almost 90% of U.S. aquacultural production is concentrated in four major species—catfish, crawfish, salmon and trout (Fig. 1).

Global aquiculture production totaled about 22 billion pounds in 1986. Currently, 102 species of finfish, 32 species of crustaceans, 42 species of mollusks and "uncounted" numbers of miscellaneous species are cultured worldwide, according to David' Aiken of the Invertebrate Fisheries Section of the Biological Station in St. Andrews and editor of *World Aquiculture,* the World Aquiculture Society's quarterly magazine. In 1980, aquiculture accounted for **13%** of global production of aquatic foods and goods, up from 7% in 1970. Industry sources predict that by the year 2010, aquiculture will account for **25%** of the worldwide aquatic harvest.

Meals, fats and oils and other oilseed byproducts provide protein, essential nutrients, and fatty acids in fish and crustacean feeds.

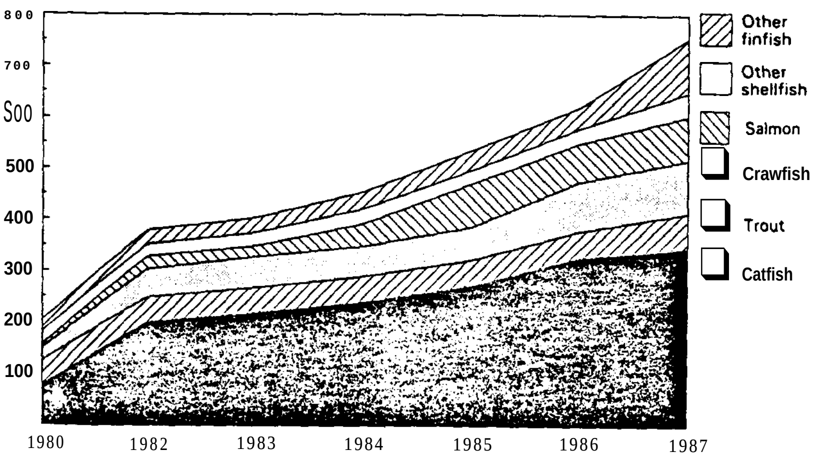

FIG. L **U.S. aquacultural production.** Source: U.S. Department of Agriculture, **Economic Research Service,** ***Aquaculture*** *Situation and* ***Outlook*** *Report* {October **1988).**

Market potential

Meals, fats and oils and other oilseed byproducts provide protein, essential nutrients, and fatty acids in fish and crustacean feeds.

According to **R.T. Lovell** of the Department of Fisheries and Allied Aquacultures at Auburn University, aquiculture's profitability is closely related to the world supply and cost of feed protein. "Intensively cultured fish require high protein feeds and feeds are usually the largest variable cost item in commercial production," Lovell told attendees at the 1989 AOCS annual meeting in Cincinnati this past May.

Fish are fed higher percentages of protein in their diets than land animals because fish have lower energy requirements. Commercially formulated fish feeds contain 25-*4590* crude protein. Consequently, high protein feedstuffs such as fish meal, animal byproducts and oilseed meals make up **60%** or more of the ingredient composition of the formula.

Fish meal conventionally is used in the diets of farm-raised fiah worldwide but high cost and limited supplies have encouraged the use of other meal sources, particu-

(Continued)

larly soybean meal, in shrimp and catfish feeds. In the U. S., aquiculture competes with livestock for domestic feed crops. Channel catfish feed, for instance, contains mostly soybean products and corn. Also, over 50% of the ingredients in salmon diets are byproducts of farm commodities—whey, wheat products, cottonseed meal and soybean oil.

Most diets developed for fish and crustaceans are based upon feeds for catfish (warm-water diets) or trout (cold-water diets), according to USDA Aquiculture Situation and Outlook. Warm-water diets rely more on feed grains; cold-water feed diets rely heavily upon fish meal. The catfish mix generally contains 50-5590 soybean meal, 25-35% corn and 15-25% other nutrients including wheat, barley, oats, fish meal, meat and bone meal, and fats and oils. Trout diets contain approximately 20-3090 fish meal and a variety of feeds such as whey products, wheat products, cottonseed meal, and soybean meal and oil. More fish meal is used in trout and salmon feeds because these fish find it more palatable. Fish oil and the residual fat in fish meal are the primary sources of the long-chain omega-3 polyunsaturated fatty acids (PUFA) required by cold-water fish and crustaceans.

The global use of fish meal in aquiculture during 1988 totaled over 1.4 billion pounds (644,000 metric tons), equalling approximately 107o of the total world fish meal production, Anthony P. Bimbo of Zapata Haynie Corp. said in a presentation at the 1989 AOCS annual meeting. Bimbo noted that shrimp, prawn and eels cultured in the Far East consumed almost 45% of the total, while salmon, trout and other species, including catfish, consumed 20%, 1870 and 1170, respectively.

The U.S. aquiculture industry uses between 1.2 and 1.3 billion pounds of domestic grain products, according to USDA. If current expansion continues, by the year 2000 the industry could consume nearly 4.5 billion pounds of soybean meal and 4.1 to 4.3 billion pounds of domestic grain products annually. USDA reported that the U.S. catfishindustrycurrently uses approximately 670 million pounds of soybean meal or approximately 1.570 of total U.S. production.

"Because plant proteins cost less than animal proteins, concentrated sources of plant protein should be used as much as possible in fish feeds," Lovell said, adding, "Considering quality, cost and world availability, soybean protein will probably be the key ingredient in aquiculture feeds."

'Soybean protein will probably be the key ingredient in aquaczdture feeds.

Trade promotion efforts

The American Soybean Association (ASA) has been actively promoting the use of soybean meal in fish feeds. One such effort has included demonstrations with feed producers in Southeast Asia on how to replace fish meal with soybean meal in shrimp feed. "Soybean meal is less expensive than fish meal, so using it makes good financial sense for feed manufacturers," according to Dean Akiyama, ASA's technical director of aquiculture in Singapore. He noted that ASA has reported soybean meal can be used in 40-50% of shrimp feed with no observed changes in weight gain performance. Akiyama said that for every 2.24 billion pounds (1 million metric tons) of feed produced, 18.5 million bushels of soybeans could be used.

Soybean farmers, through the soybean checkoff program, are funding four aquiculture research projects: use of soybean meal as a supplemental feed for pond-raised craw fish and redfish (at Louisiana State University); a soybean meal trout-feeding study in Idaho; effect of soy and soybean trypsin inhibitor on growth, survival, and protease enzymes of marine shrimp (Texas A&M University); and evaluation of a high-density recirculating aquiculture system for the commerical production of pure and hybrid striped bass (Virginia Polytechnic Institute and State University).

Speaking at the 1989 AOCS snnual meeting, Addison L. Lawrence of the Texas Agricultural Experiment Station, 'lkxas A&hI University, reported on the results of shrimp nutrition research funded in part by ASA. He noted that the growth and survival of shrimp in laboratory tanks were unaffected by levels of soybean mea! ranging from 20-50% of the feed. Data from experiments conducted in pens in ponds indicated that more than 50% of the feed could consist of soybean meal.

Jerry C. Weigel, vice president for nutrition at Archer Daniels Midland Co. (ADM), is excited about the potential markets for soybean products in aquiculture, particularly for lecithin. Species requiring omega-6 fatty acids in their diets also offer potential markets for soybean products, he added.

Meanwhile, the National Cottonseed Products Association (NCPA) estimates the U.S. catfish industry could use at least 224 million pounds (100,000 metric tons) of cottonseed meal annually if research could substantiate a higher level of usage in the catfish diet. Fish nutritionist Edwin Robinson at Mississippi State University's Delta Branch Experiment Station noted that current commercial catfish feed contains 15% cottonseed meal as a substitute (on a protein basis) for soybean meal. At this level, 300 pounds of cottonseed meal are used per ton of manufactured catfish feed. Robinson, who is conducting a research project on cottonseed meal levels in catfish feeds for NCPA and The Cotton Foundation, said preliminary results for substituting higher levels of cottonseed meal for soybean meal are very promising. "The only drawback we have found is that cottonseed meal doesn't have a sufficiently high level of **lysine.** However, this problem seems to be handled by adding synthetic lysine," he said, noting he is conducting trials to evaluate replacing 2590, 50% and **100%** of the soybean meal with cottonseed meal.

Shrimp research conducted by Lawrence at the Texas Agricultural Experiment Station has shown cottonseed meal can replace marine animal (fish and shrimp-head) meals at a level of 2070 in 30?0 protein feeds for young, post-larval white shrimp ***(Penaeus vannamei).*** Research also has shown that gossypol in cottonseed meal does not adversely affect this species. "Determining that surplus plant materials such as cottonseed and grain sorghum can be used in shrimp feeds would not only establish a very significant new market for these meals but also be significant in making shrimp culture more commercially feasible in the southern U.S. region," Lawrence said, noting that cottonseed meal is not used in shrimp feeds at present. Lawrence has submitted two research proposals to USDA to examine the feasibility of feeding cottonseed meal to other shrimp species and age groups.

If farm-raised shrimp in the U.S. were fed a diet containing 10Yo cottonseed meal, the shrimp industry could use 480,000,000 pounds (approximately 214,000 metric tons) of cottonseed meal per year in another ten years, according to Lawrence, basing his estimates on the assumption that 8,000 pounds of feed would be used per acre devoted to shrimp farming.

Meanwhile, the POS Pilot Plant in Canada, in conjunction with the University of British Columbia, is conducting research into canola meal processing techniques to produce an improved feed for salmon and trout, according to the *Canola Digest.* The project is being supported by the Agricultural Development Fund of Saskatchewan Agriculture, the Western Diversification Program, and three crushing companies—CSP Foods, United Oilseed Products Inc. and Canbra Foods. Canola meal already is starting to be incorporated into some fish feeds in Canada.

The National Renderers Association (NRA) also is promoting more use of animal byproducts such as meat and bone meal in fish feeds. Currently, it is collaborating with the Chinese on fish feeding trials using meat and bone meal. **During** 1990, NRA will sponsor a regional conference on aquiculture in coop. eration with the Aquiculture Department of Stirling University in Scotland. The conference will be geared for participants from Europe and Northern Africa.

Dietary requirements

Studies show lipid and essential fatty acid (EFA) requirements **dif·**fer from species to species. According to John D. Castell, a fish and crustacean nutritionist and **presi·**dent of the World **Aquacu!ture** Scciety, environmental factors such as salinity and water temperature have an effect on the lipid require ments of fish and crustaceans.

"Warm-water species tend to require omega-6 fatty acids, and marine cold-water species such as turbot require omega-3 and **specifi·**cally long-chain omega-3 PUFA **be·**cause they cannot chain-elongate and desaturate very effectively. Fresh-water, cold-water species such as trout best use linolenic fatty acid because they can elongate and desaturate," Castell said. Table 1 shows the fatty acid composition of the triglyceride fraction of ingredients used in fish feeds.

The balance of energy **compo·**

TABLE 1

Fatty Acid Composition of the Triglyceride Fraction of Ingredients Used in Fish Feeds

		Fatty acid composition of triglyceride (%)																			
Ingredient	**name**	C12 & **C14:0**	**C16:0**	**C16:1**	**C18:0**	**C18:1**	**C18:2**	**C18:3**	**C20:2**	**C20:3**	**C20:4**	**C20:5**	C22:4	C22:5	**C22:6**	**Sat** (9.)	**Mono-unsat.** (9.)	**POly-unsat.** (90)	□ 4 (90)	**n-3** (%)	**Satin n-3/n-6** (%)
Fish meal or oil																					
Menhaden		6.0	26.9	7.9	4.0	1s.4	1.1	0.9	0.5	–	1.2	10.2	0.7	1.6	12.6	40.9	21.3	2s.0	3.S	23.9	S.44
Herring		7.6	16.9	6.3	Z2	16.9	1.6	0.6	-	-	0.4	6.6	-	1.2	7.6	2S.1	25.2	**20.1**	3.2	16.8	5.03
Salmon-sea caught		3.7	10.2	6.7	4.7	16.6	1.2	0.6	0.4	0.1	0.9	12.0	0.6	2.9	13.6	16.6	25.3	32.5	5.0	26.4	5.2s
Channel catfish—cultured		1.0	14.1	2.2	4.6	41.1	25.5	2.5	-	1.1	0.6	0.7	-	0.5	1.7	19.7	43.3	33.6	26.3	6.4	0.24
Penaeid shrimp		1.1	15.5	7.5	8.2	12.6	4.3	1.0	-	–	8.7	11.2	-	1.9	11.0	24.6	20.3	2s.1	14.9	23.2	1.56
Animal by-product meal or fat																					
seer		**9.0**	27.0	–	21.0	40.0	2.0	0.5	–	-	-	–	-	-	-	51.0	40.0	2.5	2.0	0.5	0.25
Pork		1.5	32.2	3.0	7.8	48.0	11.0	0.6	-	-	-	-	-	-	-	41.5	51.0	11.6	11.0	0.6	0.05
Grain **and seed meal** or oil																					
Soybean	-	6.5	-	3.5	17.0	54.4	7.1	-	-	–	–	–	-	–		12.0	17.0	61.5	54.4	**7.1**	0.13
Corn			7.0	–	2.4	45.6	45.0	0.5	-	-	-	-	-	-	–	9.4	45.6	45.5	45.0	0.5	0.01
Coconut		65.5	6.0	-	2.8	5.6	1.6	-	-	-	–	-	-	-	-	26.6	5.6	**1.6**	1.6	0.0	0.00
Cottonseed		1.0	26.0	1.0	3.0	17.5	51.5	–	-	-	-	-	-	-	–	30.0	18.5	**51.5**	51.5	0.0	0.00
Linseed			6.0	–	3.5	m.o	14.5	56.0	-	–	–	-	—	-	-	9.5	20.0	70.5	14.5	56.0	3.ss
Canola			3.0	-	1.5	32.0	19.0	10.0	-	-	10.5	-	**23.5**[a]	-	–	4.5	55.5	39.5	29.5	10.0	0.34
Peanut			**11.5**	–	**3.0**	**53.0**	**26.0**	-	-	-	**1.5**	-	-	-	–	**14.5**	**53.0**	**27.5**	**27.5**	**0.0**	0.CO

[a]**22: I, n-9.**

Source: Nutrition ***and Feeding of Fish,*** by **Tom Lovell, an** AVI **Book published** by Vm **Nostrand Reinhold,** New York. NY. 1969, p. 253.

nents in the diet is important because a deficiency *or excess* can result in reduced growth. For instance, when excess energy is supplied, appetite may be satisfied before sufficient protein is ingested for growth. The level of dietary energy giving the maximum protein-sparing effect is influenced by temperature and the size of the fish, according to Allan J. Matty, Nutrition Unit, Institute of Aquiculture, University of Stirling, Scotland, in an article in Fish *Farming International*

Weigel of ADM noted that fish have a lower dietary energy requirement than land animals because fish don't have to maintain a constant body temperature and because they exert less energy to maintain their position or move in water. Also, they excrete most of their nitrogen wastes as ammonia instead of urea or uric acid.

Matty pointed out that dietary fats generally cost more than carbohydrates and an excess in the diet may increase the risk of rancidity. Also, high-fat diets increase body fat content, which may be undesirable in some species. Citing the use of full-fat soybean meal in fish feeds, Lovell said the additional fat is beneficial only if it improves the nutritional quality of the diet. "Too much fat can cause an imbslance of protein and energy in the feed, it can produce fatty fish, and it can adversely affect extrusion or pellet-processing of the feed," he said.

In general, fish meal is superior to animal protein, which, in turn, is superior to vegetable protein, in terms of protein content, essential amino acid composition, digestibility and palatability for fish feeding, according to John Grant in the July/August 1989 issue of *Canadian Aquiculture.* High-quality fish meal comes from very fresh or fresh-frozen whole fish, processed at fairly low temperatures to maintain the protein components. According to Grant, the best fish meal, particularly for shrimp and salmon farming, is processed from whole fish; he noted that if producers use waste fish products, the meal may contain excess ash, creating an imbalance in amino acid content.

According to Lovell, dehulled, solvent-extracted soybean meslcontsins approximately 49% crude protein which is approximately 85% digestible in channel catfish, rainbow trout and tilapia. "This digestion coefficient is equal to that for whole fish meal protein," he said, adding that soybean protein has one of the best amino acid profiles of all protein-rich plant feedstuffs for meeting the essential amino acid (EAA) requirements of fish. Table 2 shows the amino acid content for various protein sources; Table 3 shows the essential amino acid requirements for channel catfish and chinook salmon. "However, expen. ments with channel catfish have shown that diets containing 5-107o menhaden fish meal have produced faster growth than all-plant diets of similar protein content with most of the protein coming from soybean meal," he said.

The addition of fish meal, meat and bone meal, and meat, bone and blood meals to a soybean merd-corn basal feed seems to improve the palatability of the feed, Lovell said. "Increasing the level of the animal protein increases feed consumption," according to Lovell, noting that fish meal seems to be slightly superior to other animal **proteins.**"

"Other than palatability, the reasons for improved growth from replacing soybean meal with animal proteins are not clear," he added. Adding oil to the basal feed to increase the energy level of the feed, however, does not improve growth.

Researchers at the Texas Agricultural Experiment Station have examined the apparent dry matter digestibility (ADMD), apparent protein digestibility (APD) and apparent amino acid digestibility (AAAD) of 13 feedstuffs used for marine shrimp diets. Included were casein, cellulose, chitin, *ccrn* starch, diatomaceous sand, fish meal, gelatin, rice bran, shrimp meal, soy protein, soybean meal, squid meal and wheat gluten. Lawrence noted that

TABLE2

Essential Amino Acid Content of Some Protein Sources Commonly Used in Experimental and Commercial Diets of Fish

	Amino acid content (% protein) in:							
	Cseein	Gelatin	Menhaden fish meal	soybean mesd	Peanut meal	Cottonseed meal	Rapeseed mesf	SunflowerSeed meal
Arginine	4.2	8.0	6.1	7.4	9.5	10.2	5.6	9.6
Histidine	3.1	0.9	2.4	2.5	2.0	2.'7	2.7	2.7
Isoleucine	6.8	1.6	4.7	5.0	3.7	3.7	3.7	4.9
Leucine	10.5	3.3	7.3	7.5	5.6	5.7	6.8	8.3
Lysine	8.5	4.1	7.7	6.4	3.7	4.1	5.4	4.2
Methionine	3.3	0.8	2.9	1.4	0.9	1.4	1.9	2.5
(+ cystine)	3.7	1.0	3.8	3.1	2.4	3.3	2.7	4.1
Phenylsfanine	5.7	2.0	4.0	4.9	4.2	5.9	3.8	5.1
(+ tyrosine)	11.6	2.6	7.2	8.3	7.4	7.9	6.0	8.1
Threonine	4.7	2.0	4.1	3.9	2.4	3.4	4.2	4.2
Tryptophan	1.3	0.1	1.1	1.4	1.0	1.4	1.2	1.3
Valine	8.0	2.4	5.3	5.1	3.9	4.6	4.8	5.6

source: *Nutrient Requirements of Warm Water Fishes and Shellfishes, National Research Council,* **National Academy of Sciences Washington, D.C., 1983.**

the ADMD of the diets containing purified feedstuffs high in protein–casein, gelatin, soy protein and wheat gluten—were greater than the ADMD value of the high carbohydrate diet containing corn starch. Also, the ADMD of the diets containing these purified feedstuffs were higher than those containing fish meal, rice bran, shrimp meal, soybean meal and squid meal,

In studying the nutritional response of postlarval white shrimp to lard, tallow, and meat and bone meal, Lawrence and coworkers found that substituting 2070 and 4090 meat and bone meal for fish and shrimp-head meal in 40% protein feed resulted in reduced growth. Supplementing the feeds with menhaden oil did not change the results.

Lovell noted that when commercially processed soybean meal replaces fish meal or other animal byproduct proteins in fish diets, losses in energy, minerals and lipids should be considered. “Soybean meal (48% crude protein) contains 25% less metabolizable energy for rainbow trout, 8670 less available phosphorus for channel catfish and 90% less essential omega-3 fatty acids than anchovy fish meal.” Also, soybeans contain several antinutritional factors, but these can be eliminated through extrusion processing.

Fish nutritionist Robert R. Smith, manager of the U.S. Fish and Wildlife Service’s Hagerman, Idaho, field station, has reported good growth in rainbow trout fed full-fat roasted soybean meal as the predominant protein source and no fish meal. AMD’s Weigel reported that with adequate supplementation of energy, minerals and certain amino acids, commercially prepared soybean meal can replace much of the fish meal currently used in trout diets. He cited work in Austria with hydrothermally treated soybeans that made soy protein 80% digestible for rainbow trout. “Raw soybeans contain powerful protease inhibitors, which reduce the protein disgestibility of the bean. Present technology in soy processing, however, has enabled us to offer optimum processing techniques to provide a quality protein source to the trout industry, ” Weigel said.

TABLE 3

Essential Amino Acid Dietary Requirements of Channel Catfish and Chinook Salmon

	Dietary requirements (% protein)	
Essential amino acid	Channel catfish	Chinook salmon
Arginine	4.3	6.0
Histidine	1.5	1.8
Isoleucine	2.6	2.2
Leucine	3.5	3.9
Lysine	5.1	5.0
Methionine + cystine	2.3	4.0
Phenylalanine + tyrosine	5.0	5.1
Threonine	2.0	2.2
Tryptophan	0.5	0.5
Valine	3.0	3.2

Source: *Nutrient Requirements of Warm Water Fishes and Shellfishes,* National Research Council, National Academy of Sciences, Washington, D. C., 1983.

Matty cited work in Seattle, Washington, by Ron Hardy and colleagues, who replaced herring oil with a combination of menhaden oil, soybean oil and tallow in diets of Atlantic salmon raised in marine net-pens. Researchers noted no differences in growth or carcass quality. Fats used as energy sources in fish diets generally are oils that contain a high content of unsaturated fatty acids. However, Matty pointed out, research performed with channel catfish and coho salmon has shown saturated fat sources such as tallow, lard, cocoa butter and butterfat cars be used in moderation in fish feeds without modifying carcass composition or growth rates.

Although researchers have found crustaceans require dietary cholesterol, certain fatty acids and phospholipids, precise quantitative requirements generally remain undefined, according to crustacean nutritionist Louis R. D’Abramo of the Department of Wildlife and Fisheries at Mississippi State University. Nutritional crustacean studies have shown that dietary levels between 5-8% oil, preferably a mixture of animal and vegetable oils, achieve the best survival and growth rates, he said, pointing out that the optimum level is influenced by the quality and quantity of dietary protein, the source and amount of the oil, and the type and availability of other energy sources. ‘High dietary levels of oils are usually associated with significant growth retardation,” he added,

Diets containing marine derived lipids seem to yield superior growth in shrimp versus those containing exclusively vegetable oils; however, a marine and vegetable oil mixture generally achieves the best results, according to D’Abramo. He also cited findings that fatty acids of the linolenic (n-3) family have greater nutritive value than do those of the linoleic (n-6) family. For marine shrimp, the best responses seem to be achieved by incorporating I-z% linolenic acid in the diet.

Pointing out that “a quantitative requirement for any described essential fatty acid has yet to be established for any species of shrimp,” D’Abramo said, “Nevertheless, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are generally preferred to linolenic acid.” He said significant increases in weight gain have been achieved with relatively small additions of dietary PUFA and highly unsaturated fatty acids (HU FA, defined as omega-3 PUFA that contain five or more double bonds); levels as low as 0.075% of the diet may be sufficient to satisfy the requirements for particular essential fatty acids. D’Abramo also cited studies which indicate dietary PUFA may be necessary for successful ovarian maturation in shrimp. EPA and DHA also have

(Continued)

been associated with growth enhancement of lobsters.

Shrimp and other crustaceans are incapable of sterol synthesis from acetate, and thus require dietary sterols. Researchers at the Texas Agricultural Experimental Station, for instance, have found the minimum cholesterol require. ment for *Penaeus vannamei* appears to be 0.5%. Meanwhile, other research has shown that the marine prawn, juvenile lobsters and crayfish need dietary cholesterol for growth, with cited levels ranging from 0.12% to 5%. Plant sterols such as *beta*-sitosterol or stigmasterol maybe effective in satisfying the sterol requirement. D'Abramo pointed out that at least a portion–and possibly all-of the sterol requirement of juvenile lobsters must be met by dietary cholesterol. Findings also *reveal* the absorption rate of dietary cholesterol is improved by the presence of dietary palrnitic acid, tripalmitin or chicken-egg lecithin.

In addition, under certain dietary conditions, crustacean growth will be enhanced by the provision of dietary phospholipids. Lawrence and colleagues at Texas Agricultural Experiment Station have noted that *Penaeus vannamei* require between 2-8% lecithin. A *need* for dietary soy lecithin by juvenile lobsters for survival appears to be associated with the source of dietary protein. For instance, when casein or casein and egg albumin are the sole protein source in purified diets for lobsters, about 6-7% of lecithin is required to prevent "molt death" syndrome; however, when the casein is replaced with a crab protein concentrate (containing no lecithin), no dietary lecithin is required.

D'Abrarno and colleagues have identified the active component of the soy lecithin as phosphatidylcholine and demonstrated that phosphatidylcholine containing PUFA yielded the best survival. Insufficient dietary phospholipid has been associated with reduced serum cholesterol levels and reduced utilization of dietary lipids such as triglycerides and cholesterol, he added. Dietary carotenoids, meanwhile, are required for pigmentation, and have been associated with enhanced growth, reproductive rates and fecundity in cmstaceans.

"Lipid requirements of shrimp may be dependent upon other lipid or nonlipid constituents of the diet *or* age, and such interactions need to be considered," D'Abramo said, adding, "Larval stages of species of crustaceans most likely require higher levels of dietary lipid relative to juveniles and adults."

'Catfish, carp and tilapia do not require long-chain omega-3 fatty acids in their diets'

Citing research with salmon, R.G. Ackman, S.M. Polvi, R.L. Saunders and S.P. Lall have reported that salmonids lay down depot fat modified by dietary fats, and fatty acid composition of the fillets reflects fatty acid composition of the diets. Dietary linoleic acid, they said, appears to have no role in salmon nutrition. Studies also showed Atlantic salmon do not convert linolenic acid provided by canola oil to EPA and DHA if adequate levels of EPA and DHA are available in the diet. Citing Norwegian studies suggesting that overfeeding with fat is unnecessary, they recommended that the overall fat content of the fillet of farmed salmon not exceed 107o.

Human health benefits

Although some might argue it is enough to provide fish with their dietary requirements at the lowest cost, representatives of the World Aquiculture Society–which has 3.ooO members in 120 countries-point out another consideration: providing fish with a diet that will make the composition of the resulting fish products most beneficial for human consumption.

"By controlling what we feed the fish, we can alter the composition of the fish products that will be eaten by humans. In other words, we can provide the required EFA and then add long-chain omega-3 fatty acids to their diet to produce fish product's that will give consumers higher omega-3 PUFA, thus offering the potential to lower serum cholesterol," Castell said.

- Such species as catfish., cam and tilapia do not require long-chain omega-3 fatty acids in their diets, Castell said, "but in terms of human health, it would be heslthier if we added these as well."

William E.M. Lands, in a talk at the symposium, "Aquiculture Products: Implications for Human Health," in Honolulu in January 1988, asked, "Can aquiculture farms find ways to produce foods rich in n-3 that resemble those from the 'open range' rather than the feed lots?" He added, "Perhaps aquaculturists can provide us with a steadier intake of vitamins, min. erals and polyunsaturated fats by developing new and palatable forms of fish organs to accompany the lean source of protein already being marketed."

At the same conference, George M. Pigott of the Institute for Food Science and lkchnology, University of Washington in Seattle, noted, "Oil from wild fish is high in healthful omega-3 fatty acids. Unfortunately, many farmed freshwater fish are low in omega-3 content because their diets are formulated primarily from agriculture products. This deficiency could be eliminated by adding fish oil con" taining high levels of omega-3 to the.diet of farmed fish, thereby improving their public image and market value."

He added, "Fish get most of their HUFA from plants and anireals in the food chain. Since the diets of farmed fish often contain much less HUFA, the flesh of wild fish is normally much richer in these desirable fatty acids."

Noting that the fatty acid profile of farm-raised catfish is similar to that of grain-fed livestock, Lovell and T. Mohammed have reported on a study conducted at the Alabama Agricultural Station to determine if the amount of n-3 PUFA in catfish could be increased by manipulating the diet. Menhaden oil at 2, 4 and 6% levels was added to the basal diet and the corn ingredient was reduced accordingly. At the end of the feeding period, the fish were analyzed for fatty acid composition and evaluated for taste and chemical indicators of the potential for oxidative deterioration in flavor during frozen storage.

Results showed that when 2, 4 and 6'%0 fish oil were added, the n-3 PUFA content increased to 38, 56 and **67%** of the total fatty acids of the tissue of wild salmon. However, tests also revealed that the catfish consuming menhaden oil had a "fishy" flavor which intensified with the amount of fish oil in the feed.

"Thus, the advantages of increasing n-3 PUFA content of farm-raised catfish by adding fish oil to feeds must be compared with the adverse effects on the taste of the fish," Lovell and Mohammed wrote, recommending deferring feeding marine fish oil to cultured catfish "until it is determined whether the amount of n-3 PUFA that must be consumed to significantly reduce the risk of heart disease is great enough to adversely affect taste and quality of catfish."

Protein Products Inc., which operates a fish meal reduction plant in the Mississippi Delta region, uses the inedible byproducts from catfish processing plants to produce fish meal and catfish oil. Most of the catfish oil is incorporated at low levels (about 1.5510) into catfish feeds, according to Dallas Gay, president of Protein Products. "It is preferable to other feeding 'fats because it is produced and consumed locally, it is very clean and of known origin and it is readily assimilated by the catfish. Perhaps most important, catfish oil has very little fishy odor. Other fish oils have the potential to give a strong fishy taste and smell. The catfish industry, however, goes to great lengths to ,produce a mild-tasting, low-odor fish."

This and the accompanying article were written by Barbara Fitch Haumann, Senior Editor/Writer for JAOCS News.