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Full-Fat Soybean Meal Utilization by Fish

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Abstract

Full-fat soybean meal (FFSBM) is made from heat-treating whole soybeans. FFSBM contains slightly lower crude protein but much higher oil than defatted soybean meal. Like defatted soybean meal, FFSBM has one of the best amino acid profiles among vegetable proteins in meeting the essential amino acid requirements of fish. FFSBM is also a good source of linoleic and linolenic acids and phospholipids. There is little phosphorus present in FFSBM and it is mostly in the form of phytic acid which is not highly available for fish and hampers the utilization of other minerals. Raw soybeans also contain several anti-nutritional factors known to affect the growth and health of fish. However, several methods of heat treatment have been successfully used to inactivate or eliminate anti-nutritional factors that improve the nutritive value of FFSBM. The degree to which soybeans must be heat treated could vary among fish species. Nonetheless, available research information shows that the nutritive value of properly heated FFSBM for fish is comparable to, if not better than, defatted soybean meal reconstituted with soybean oil.

Introduction

From the standpoint of economics, market availability and nutritional value, soybeans are universally regarded as the most attractive vegetable protein source for animal feeds. Soybeans are available in many parts of the world at a lower cost than animal proteins. Among plant proteins, soybeans have the best amino acid profile for meeting the essential amino acid requirements of aquatic species. In addition to high quality protein, whole soybeans also contain a high level of oil, which is a concentrated source of highly digestible energy. The energy content of soybeans is approximately 50% higher than that of commercial soybean meal for poultry (Latshaw and Clayton 1976) and trout (Lovell 1989).

The utilization of soybeans, both raw and heated, as a feed material for terrestrial animals has been intensively studied for many years. Raw soybeans contain several anti-nutritional factors and other toxic substances which adversely affect the growth and well-being of animals. Properly heated soybeans ground to full-fat soybean meal (FFSBM) have been used successfully in diets of poultry, swine and cattle. Research on the utilization of FFSBM by fish has begun relatively recently. Most of the early work on this subject was done with trout and salmon. It was not until the 1980s that studies with other species were conducted.

This paper assesses the nutritional value of FFSBM as a feed ingredient for aquaculture diets. Information presented includes nutrient content, anti-nutritional factors, effect of processing on nutritional quality and utilization of FFSBM by various aquaculture species.

Nutrient Content

The chemical composition of soybeans varies depending on the variety of plant and growing conditions. The average nutrient content of various soybean products is presented in Table 1.

Protein and Amino Acids

Protein is the major nutrient of soybeans but is ranked second after oil in terms of economic value. Whole soybeans contain approximately 40% crude protein on a dry matter basis. Some strains of soybeans have as high as 48% crude protein (Pryde 1983a). These varieties, however, produce lower yields.

The essential amino acid content of roasted soybeans, dehulled solvent-extracted soybean meal, peanut meal (groundnut), cottonseed meal, sunflowerseed meal and rapeseed meal is given in Table 2.

Roasted soybeans and dehulled solvent-extracted soybean meal contain approximately the same essential amino acid composition when expressed in percentage of crude protein.

Table 1. Nutrient composition of soybean products.[1]

	Per cent nutrient				
	Seeds	Seeds, heat process (FFSBM)	Meal, mech. extd. (Soybean cake)	Meal, solv. extd. with hulls	Meal, solv. extd. without hulls
International feed #	5-04-610	5-04-597	5-04-600	5-04-637	5-04-612
Dry matter	92.0	90.0	90.0	89.0	90.0
Crude protein	39.2	38.0	42.9	44.6	49.7
Ether extract	17.2	18.0	4.8	1.4	0.9
Crude fiber	5.3	5.0	5.9	6.2	3.4
Ash	5.1	4.6	6.0	6.5	5.8

[1]NRC (1982).

Table 2. Essential amino acid composition of some plant seed meals.[1]

	Amino acid content (per cent protein)					
	Roasted full-fat soybean	Dehulled solv. extd. soybean meal	Peanut meal	Cotton seed meal	Sunflower seed meal	Rapeseed meal
International feed #	5-04-597	5-04-612	5-03-650	5-01-621	5-03-871	5-04-739
Arginine	7.4	7.4	9.5	10.2	9.6	5.6
Histidine	2.7	2.5	2.0	2.7	2.7	2.7
Isoleucine	5.7	5.0	3.7	3.7	4.9	3.7
Leucine	6.8	7.5	5.6	5.7	8.3	6.8
Lysine	6.3	6.4	3.7	4.1	4.2	5.4
Methionine	1.4	1.4	0.9	1.4	2.5	1.9
(+ cystine)	2.8	2.9	2.4	3.3	4.1	2.7
Phenylalanine	5.5	4.9	4.2	5.9	5.1	3.8
(+ tyrosine)	8.7	8.3	7.4	7.9	8.1	6.0
Threonine	4.4	3.9	2.4	3.4	4.2	4.2
Tryptophan	1.4	1.4	1.0	1.4	1.3	1.2
Valine	5.3	5.1	3.9	4.6	5.6	4.8

[1]NRC (1982).

As noted earlier, soybean protein is particularly valuable because it has one of the best amino acid compositions among plant proteins for meeting the essential amino acid requirements of fish. However, soybean meal is deficient in the sulfur amino acids (methionine and cystine) for most species. Rapeseed meal has an amino acid composition similar to that of soybean but has a lower lysine content. The first limiting amino acid in cottonseed meal and sunflowerseed meal is lysine, but in peanut meal, the sulfur amino acids are the most deficient, followed by lysine (Lim and Dominy 1989).

Lipid

The most economically valuable component of soybean is oil, which is approximately 20% of its dry weight (Table 1). The average composition of crude and refined soybean oil is shown in Table 3. Triglycerides, esters of fatty acids and glycerol are the major constituents of both crude and refined soybean oil. The fatty acid composition of the triglyceride fraction of soybean oil and some commonly used plant oils is given in Table 4. Coconut oil contains a high level of saturated fatty acids. In other oils the predominant fatty acids are unsaturated. The major polyunsaturated fatty acid in plant oils is linoleic acid. However, soybean and rapeseed oils are unique in that they also contain high levels of linolenic acid.

Table 3. Composition of crude and refined soybean oils.[1]

	Crude oil	Refined oil
Triglycerides (%)	96	> 99
Phospholipids (%)	1-3	0.03
Unsaponifiable matter (%)	0.6	0.3
Plant sterols (%)	0.33	0.13
Tocopherols (%)	0.15-0.21	0.11-0.18
Hydrocarbons (Squalene) (%)	0.014	0.01
Free fatty acid	0.5	< 0.05
Iron (ppm)	1-3	0.1-0.3
Copper (ppm)	0.4	0.4

[1]Mounts (1983); Snyder and Kwon (1987).

Table 4. Fatty acid composition of the triglyceride fraction of some plant oils.[1]

	Per cent fatty acid						
	Soybean	Rapeseed	Corn	Cottonseed	Sunflower	Peanut	Coconut
Saturated	14.0	4.5	9.4	30.0	17.0	14.5	91.5
Monosaturated	23.2	55.5	45.6	18.5	29.0	53.0	6.0
Polyunsaturated	62.8	39.5	45.0	51.5	52.0	27.5	2.5
Linoleic (18:2n-6)	54.5	29.5	45.0	51.5	52.0	27.5	2.5
Linolenic (18:3n-3)	8.3	10.0	-	-	-	-	-

[1]Pryde (1983b); Snyder and Kwon (1987); Lovell (1989).

The oil in FFSBM, despite its high content of polyunsaturated fatty acids, is relatively stable to oxidation. FFSBM that is properly processed to insure destruction of lipoxidases has a remarkably long shelflife due to the presence of high levels of natural antioxidants, tocopherol or vitamin E (Holmes 1988). Mustakas et al. (1964) reported that the free fatty acid level and peroxide value of FFSBM stored at 35°C and 45% humidity for 39 weeks without additional antioxidant increased only slightly.

Crude soybean oil also contains 1-3% phospholipids. This value is high in relation to other seed oils, which usually have less than 1% (Snyder and Kwon 1987). The term "soybean lecithin" is often used as a common name for the entire phospholipid fraction of soybean oil, although it is the common name of phosphatidyl choline. The major phospholipids found in soybean oil are shown in Table 5.

FFSBM, due to its high fat content, nature of its fatty acids and presence of phospholipids, could play a major role in the nutrition of aquatic animals. Fats are a concentrated source of energy and have a sparing effect on protein utilization. Lipids also contribute to the flavor of the diets, thus improving their palatability when included at the optimum level. However, if the fat content is too high, it may decrease the binding properties of the pellets and reduce

Table 5. Major phospholipids in soybean oil.[1]

Phospholipid	Per cent
Phosphatidyl choline (lecithin)	35
Phosphatidyl ethanolamine (cephalin)	25
Phosphatidyl inositol (lipositol)	15
Phosphatidic acid	5-10
Minor phospholipid compounds	15-20

[1]Snyder and Kwon (1987).

feed consumption due to the excess of dietary energy. FFSBM is also an important source of 18:2n-6 and 18:3n-3 which are dietary essentials for most fish. Tilapia have been reported to require fatty acids of the linoleic (n-6) family (Lim 1989), whereas rainbow trout have been shown to require n-3 rather than n-6 fatty acids (NRC 1982). Marine shrimp appear to have a requirement for both linoleic and linolenic fatty acids. However, long-chain polyunsaturated fatty acids, eicosapentanoic (20:5n-3) and docosahexaenoic (22:6n-3) acids promoted better growth in shrimp than linolenic acid (Lim and Persyn 1989). The ratio of n-6/n-3 must also be considered since it has been reported that a high ratio of these fatty acids represses growth. In addition FFSBM is a rich source of phospholipids, which have been shown to be dietary essentials for crustaceans.

Carbohydrates

Although oil and protein are components of major interest, FFSBM contains substantial amounts of carbohydrates, approximately 30% on a dry weight basis (Table 1). The carbohydrate fraction of soybeans is usually classified in two categories, the soluble carbohydrates or oligosaccharides and the insoluble carbohydrates or polysaccharides. Sucrose, raffinose and stachyose are the major soluble carbohydrates in soybeans. Mature soybean seeds contain about 10% soluble carbohydrates which comprise approximately 5% sucrose, 1% raffinose and 4% stachyose (Snyder and Kwon 1987). Raffinose and stachyose are not digested and absorbed by monogastric animals due to the lack of alpha-galactosidase. These sugars then pass into the large intestine where microbial fermentation converts them into CO_2 and H_2 causing flatulence (Wolff 1983; Snyder and Kwon 1987).

The insoluble carbohydrates of soybeans are mostly structural, high molecular-weight carbohydrates, namely cellulose, hemicellulose and pectins, and contain usually less than 1% starch (Snyder and Kwon 1987; Fulmer 1989). These polysaccharides, especially cellulose, hemicellulose and pectins, are considered unavailable for monogastric animals.

Inclusion of a high level of FFSBM or defatted soybean meal may reduce the binding properties of the diets. It has been observed at our laboratory that the pellet water stability was significantly reduced when defatted soybean meal was incorporated in the diets at levels of 42% or higher. Inclusion of 17.9, 35.7 and 53.6% FFSBM in the diets provided water stability similar to diets containing 14, 28 and 42% defatted soybean meal reconstituted with soybean oil. Therefore, FFSBM has a lesser effect on the binding properties of diets than defatted soybean meal reconstituted with soybean oil.

Minerals

The mineral composition of dry roasted soybeans is shown in Table 6. Phosphorus is the mineral of major concern in soybeans because aquatic species have a high requirement for this mineral and the available phosphorus in soybeans is low. Approximately 70% of the total phosphorus in soybeans is in the form of phytic acid which is unavailable to monogastric animals (Wolff 1983). Only the nonphytic acid fraction of phosphorus is considered available for fish. Moreover, phytic acid readily chelates di- and trivalent metal ions such as calcium, magnesium, zinc, copper and iron, thus reducing the availability of these minerals (Liener 1981). Adverse effects of phytate on zinc bioavailability have also been reported for fish (Gatlin and Wilson 1984; Richardson et al. 1985; McClain and Gatlin 1988). Therefore, if FFSBM is to be used as a major protein source, it is advisable to supplement phosphorus, zinc and other trace minerals.

Table 6. Mineral composition of roasted full-fat soybeans (90% dry matter).[1]

Macrominerals	(Per cent)
Calcium	0.25
Magnesium	0.21
Phosphorus	0.59
Potassium	1.70
Sodium	0.03
Sulfur	0.22
Microminerals	**($mg \cdot kg^{-1}$)**
Copper	16.0
Iron	80.0
Manganese	30.0
Selenium	0.11
Zinc	54.0

[1]NRC (1982).

Vitamins

FFSBM contains ample amounts of water-soluble vitamins, especially choline and inositol (Table 7). The fat-soluble vitamins present in soybeans are vitamins A and E with essentially no vitamin D and K (Snyder and Kwon 1987). However, like other protein sources, soybeans are not generally regarded as a major source of vitamins and vitamin mixtures are usually included in feed formulation.

Table 7. Water-soluble vitamin content of mature whole soybeans.[1]

Vitamin	$mg \cdot 100g^{-1}$
Ascorbic acid	20
Biotin	0.06
Choline	340
Folic acid	0.23
Inositol	190-260
Niacin	2.0-2.6
Panthothenic acid	1.2
Pyroxidine	0.64
Riboflavin	0.23
Thiamin	1.1-1.7

[1]Snyder and Kwon (1987).

Anti-Nutritional Factors in Soybeans

Raw soybeans contain a number of heat-labile anti-nutritional factors or toxic substances which must be inactivated or removed before they are suitable for monogastric animals and fish. The most commonly known and studied anti-nutritional factors are the inhibitors of trypsin and chymotrypsin, enzymes involved in the digestion of proteins. These inhibitors, known as trypsin inhibitors, are widely distributed among plants which are important sources of protein (Liener and Kakade 1980).

However, soybean trypsin inhibitors have received the most attention due to soybeans' potential use in animal feeds and human foods. Trypsin inhibitors, which constitute approximately 6% of the total protein of soybeans (Kakade et al. 1973), have generally been known to cause growth depression and pancreatic hypertrophy in numerous experimental animals. Trypsin inhibitors increase the secretion of pancreatic enzymes into the intestine, which in turn causes hypertrophy of the pancreas and loss of undigested pancreatic enzymes into the feces. Pancreatic enzymes such as trypsin and chymotrypsin are rich in sulfur amino acids. Excessive loss of these enzymes through the feces is believed to be responsible for the growth depression due to a drain on the body tissue of sulfur-containing amino acids (Liener 1981; Wolff 1983; Snyder and Kwon 1987). Rackis (1965) estimated that trypsin inhibitors are responsible for 30-50% of the growth inhibitor effect of raw soybeans and for nearly all of the pancreatic hypertrophy in rats. On the other hand, Kakade et al. (1973) observed that about 40% of the growth-depressing as well as 40% of the pancreatic hypertrophic effects of raw soybean extract are attributed to trypsin inhibitors. The remaining 60% of the effects is believed to be due primarily to poor digestibility of the undenatured soy protein. Trypsin inhibitors have also been cited for poor growth, feed efficiency and survival of various species of fish (Smith 1977; Viola et al. 1983; Abel et al. 1984; Wilson and Poe 1985; Balogun and Ologhobo 1989).

Besides the trypsin inhibitors, soybeans and most other legume seeds and cereals contain hemagglutinins or lectins which have the ability to bind to the carbohydrate components of red blood cells as well as other types of cells (Liener 1979; Jaffe 1980). The relative binding activities of various plant hemagglutinins differed significantly when tested with red blood cells from different animals. Lectins from some raw legume seeds caused growth retardation and sometimes even death when incorporated into the diets. However, toxicity depends on the animal species and strain (Jaffe 1980).

Soybeans contain several hemagglutinins comprising 1-3% of the protein of defatted soybean flour (Liener 1979). Turner and Liener (1975) reported that soybean hemagglutinins appear to be a relatively minor factor contributing to the poor nutritive value of raw soybeans. Soybean hemagglutinins are readily inactivated by heat or by the digestion with pepsin (Liener 1958).

It has also been reported that rats and chickens fed raw soybeans had enlarged thyroid glands. This goitrogenic effect could be prevented by the addition of iodine to the diet but only partially eliminated by toasting (Liener 1979; 1981). Thyroid enlargement due to soybeans is completely reversible (Wolff 1983; Snyder and Kwon 1987). However, goitrogenic effect caused by glucosinates in rapeseed meal could not be prevented by additions of iodine to the diet (Liener 1979).

Raw soybeans also contain a number of other substances such as saponins, estrogens and allergens. However, the physiological effects of these compounds on aquatic animals are unknown.

Effect of Processing on Nutritional Quality of Soybean Meal

Several different types of heating processes have been developed for commercial or laboratory production of FFSBM. These include toasting, micronizing, autoclaving or steam cooking, jetsploding, dry extrusion and wet extrusion. Although the methods of processing vary, they are all designed to improve the nutritional value of FFSBM. However, it has been demonstrated that the type of heat, exposure time and moisture content of the soybean have considerable effect on the quality of the final product. Proper heat treatment greatly enhances the nutritional value of FFSBM.

Excessive heat or prolonged heating can lead to a decrease in the nutritional value of the products, primarily as a result of losing lysine in nonenzymatic browning reactions and destruction of sulfur amino acids (Snyder and Kwon 1987; Goihl 1987). The presence of some moisture during heating greatly enhances the inactivation of urease and trypsin inhibitor (Abel et al. 1984; Snyder and Kwon 1987). Moist heat treatment also causes lysine destruction and protein denaturation at a much faster rate than dry heat treatment (Fulmer 1989).

The optimum conditions of heat treatments to effectively destroy the anti-nutritional factors without damaging the nutritional quality of soybean products have not been well defined. However, many attempts have been made using both chemical and biological indicators to determine the adequacy of heat treatment. The most frequently used chemical criteria are urease activity, trypsin inhibitor value and protein solubility index. Soybean products with a trypsin inhibitor value of 1-3 $mg \cdot g^{-1}$ sample, urease activity value of 0.00-0.20 and protein solubility index 60-80% are considered suitable for aquaculture species (Akiyama 1988). A urease activity of 0.00 may also be an indication of overheating. Biological indicators such as digestibility values, nutrient availability, growth, survival, feed utilization efficiency and gross or subclinical abnormal signs, although very laborious and time consuming, are the most accurate means for assessing the nutritional values of feed materials.

Smith (1977) reported that FFSBM which was heated only enough to destroy the urease is not suitable for inclusion in trout diets. For maximum digestibility and metabolizable energy, the soybeans should be roasted with a soybean temperature of 175-195°C for 5-12 minutes. For steam cooking in an autoclave, exposing the soybeans to 0.70 $kg \cdot cm^{-2}$ or 10 PSI for 10 minutes gave the best results. The digestion coefficients and metabolizable energy values of FFSBM receiving different heat treatments for rainbow trout are presented in Table 8.

In a study with chinook salmon, Fowler (1980) observed that FFSBM processed by a jetsploder at 218°C for 1 minute seemed to be overheated because they produced smaller fish than the soybeans heated at 178 or 190°C. Abel et al. (1984) obtained good growth and body protein retention in common carp (*Cyprinus carpio*) with diets in which soybeans were dry-heated through infrared rays in a micronizer at 118°C for 2.5 minutes or hydrothermally treated at

Table 8. Digestion coefficients and metabolizable energy values (mean ±SE) of various full-fat soybean meals for rainbow trout held at 15°C.[1]

Ground full-fat soybean meal	Nutrient		Digestion coefficient		Metabolizable energy (Kcal·kg^{-1})
	Gross energy	Crude protein	Protein (%)	Energy (%)	
Oven roasted					
127°C, 10 min.	5,663	42.9	40.3 ± 3.9	51.3 ± 3.6	2,564 ± 203
175°C, 10 min.	5,694	43.7	69.9 ± 5.6	71.7 ± 3.6	3,641 ± 253
232°C, 10 min.	5,875	41.1	71.8 ± 2.5	70.0 ± 2.1	3,761 ± 88
232°C, 8 min.	5,830	38.5	77.5 ± 1.2	74.4 ± 2.4	3,928 ± 152
232°C, 5 min.	5,672	43.0	75.2 ± 1.6	75.5 ± 1.9	3,895 ± 89
204°C, 12 min.	5,808	43.1	73.8 ± 1.6	72.1 ± 2.1	3,839 ± 125
204°C, 10 min.	5,626	43.6	78.2 ± 1.1	77.3 ± 1.0	4,033 ± 47
204°C, 8 min.	5,820	40.6	74.1 ± 1.7	70.8 ± 1.7	3,872 ± 112
204°C, 5 min.	5,677	43.1	65.6 ± 4.0	80.9 ± 1.5	3,784 ± 162
Microwave					
4 min.	5,802	38.5	43.0 ± 4.8	55.9 ± 3.4	2,983 ± 185
5 min.	5,778	37.9	46.0 ± 6.1	71.5 ± 2.3	3,808 ± 134
Jetsploder					
176°C	5,604	38.3	76.7 ± 1.2	75.8 ± 1.8	3,926 ± 106
194°C	5,581	37.9	74.9 ± 1.8	72.3 ± 2.1	3,722 ± 125
204°C	5,640	37.9	74.5 ± 1.4	78.6 ± 1.0	4,091 ± 63
Double dry extruded	5,590	32.6	74.6 ± 2.4	82.9 ± 1.8	4,340 ± 98
Steam cooked in autoclave					
1.05 kg/cm^2, 10 min.	5,693	43.8	74.7 ± 3.0	68.8 ± 4.0	3,510 ± 240
0.70 kg/cm^2, 10 min.	5,665	42.9	79.5 ± 2.3	74.7 ± 3.4	3,929 ± 180
0.35 kg/cm^2, 5 min.	5,690	42.7	37.1 ± 3.9	42.1 ± 0.8	2,074 ± 56
0.35 kg/cm^2, 15 min.	5,623	43.1	79.5 ± 1.2	63.4 ± 0.6	3,248 ± 30

[1]Smith et al. (1980). Values are on a dry matter basis.

90°C-95°C for 15-30 minutes. Balogun and Ologhobo (1989) reported that FFSBM pressure cooked for 45 minutes had significantly improved nutritional value for *Clarias gariepinus*.

Utilization of Full-Fat Soybeans in Aquaculture Diets

Aquatic species, like monogastric terrestrial animals, utilize raw soybeans very poorly. In general, it has been observed that fish fed diets containing raw or under-heated soybeans had poor growth and survival and sometimes developed abnormalities in the kidney tissues due mainly to the presence of anti-nutritional factors and poor utilization of the undenatured protein. The weight gains of rainbow trout fed the untreated commercial soybean meal diet reconstituted with soybean oil was only 50% of those obtained with either dry-roasted or steam-heated full-fat soybean diets (Smith 1977). Growth retardation of common carp fed diets containing unheated or under-heated soybeans has also been reported (Viola et al. 1983; Abel et al. 1984). Balogun and Ologhobo (1989) observed considerable differences between the utilization of raw and cooked soybeans by *C. gariepinus*. Weight gains of fish fed cooked soybean diets were significantly superior to those of fish fed on raw soybean diets.

FFSBM, when properly heated, has been shown to be a good protein and energy source for rainbow trout (Smith 1977). Smith (1977) also reported that the nutritive value of well-cooked soybeans and steam-cooked solvent extracted soybean meal reconstituted with soybean oil was similar for rainbow trout. Reinitz et al. (1978) showed that rainbow trout fingerlings fed a diet containing 72.7% FFSBM had a significantly higher weight gain and better feed conversion than fish fed a standard diet containing 20% commercial soybean meal, 25% herring meal and 5% fish oil. Percentage body fat was higher in fish fed FFSBM diets than in those fed the standard diet. However, the overall acceptability of fish based on sensory evaluation was comparable for all treatments. Tacon et al. (1983a) reported that 75% of Peruvian fish meal in trout diet could be replaced by FFSBM with no adverse effect on growth performance and feed efficiency.

In contrast to the results obtained in rainbow trout by Smith (1977), Reinitz et al. (1978) and Tacon et al. (1983a), chinook salmon utilized heat-treated soybeans very poorly. Fish fed diets containing FFSBM had significantly lower weight gains and suffered higher mortality than those fed the fish meal control diet. The growth of fish decreased with increasing levels of FFSBM, regardless of the degree of heat treatment. A diet containing 80% FFSBM which has been used successfully in rainbow trout by Smith (1977), produced poor growth and heavy mortality in chinook salmon. The refusal of fish to consume diets containing FFSBM was considered as one of the factors contributing to the poor performance of chinook salmon (Fowler 1980).

Smith (1977) reported that FFSBM is deficient in sulfur-containing amino acids. Supplementation of diets containing 80%

FFSBM with 0.5% methionine, 0.5% cystine or 0.5% methionine and 0.5% cystine, improved the growth of trout. The addition of methionine resulted in better growth than the addition of cystine. The addition of both sulfur-containing amino acids yielded only slightly better growth than methionine alone.

However, Fowler (1980) observed that the growth of chinook salmon fed soybean diets was poor in spite of supplementation of methionine to meet its requirement.

Viola et al. (1983) reported that the nutritive value of properly heated FFSBM for mirror carp was essentially the same as that of commercial soybean meal or soybean protein concentrate reconstituted with soybean oil to the level found in the FFSBM. Abel et al. (1984) observed that mirror carp fed diets containing 50% heat-treated FFSBM as a replacement for half of the fishmeal, attained only 60-65% of the growth obtained with the fishmeal control diet. The better performance of the control diet was thought to be due to more available and/or better balance of essential amino acids. Viola et al. (1983) concluded that FFSBM is deficient in lysine and methionine for carp. Abel et al. (1984) reported that supplementation of lysine, methionine and threonine to a FFSBM diet substantially increased the growth of carp.

In a study with tilapia, *Oreochromis niloticus*, addition of 0.5% DL-methionine to a diet containing 50% FFSBM as a replacement for 75% of the brown fishmeal provided the same growth and feed conversion as the fishmeal diet (Tacon et al. 1983b). However, the per cent body fat was greater in fish fed the FFSBM diet. Shiau et al. (1990) reported no difference in per cent weight gain, feed conversion ratio, protein efficiency ratio, and protein digestibility in tilapia fed a fishmeal-based diet and a diet in which 30% of the fishmeal was replaced by FFSBM. No other fishmeal replacement levels were tested.

Saad (1979) fed channel catfish in ponds with diets in which 37.2 and 77.0% FFSBM replaced 50 and 100% of the soybean meal in a control diet containing 64% commercial soybean meal and 10% fishmeal. Fish fed the highest (77%) FFSBM diet had a numerically higher weight gain than those fed with the other diets. The amount of protein gain was essentially the same for all diets, but more fat was observed in fish fed the FFSBM diets. Newton et al. (1980) also reported an increased level of body fat in cage-cultured channel catfish fed the FFSBM diet. However, the growth performance and feed conversion obtained with the 50% FFSBM was significantly poorer than that obtained with the commercial trout ration containing the same level of crude protein.

Balogun and Ologhobo (1989) evaluated the nutritional value of FFSBM as a substitute for various levels of peanut meal in a diet of *C. gariepinus* containing 44.64% peanut meal and 22.85% fishmeal. They reported that peanut meal can be totally replaced by properly cooked FFSBM without loss of growth and feed utilization efficiency.

Lim and Dominy (1990) fed *Penaeus vannamei* with diets containing 0, 17.9, 35.7 and 53.6% double dry-extruded FFSBM as replacement of 0, 20, 40 and 50% of the animal protein mix which consisted of 53% anchovy fishmeal, 32% shrimp head meal and 15% squid meal. Weight gains of shrimp fed the 0, 17.9 and 35.7% FFSBM diets were similar. However, feed conversion obtained with the 35.7% soybean diet was significantly poorer than that of the diets containing lower levels of FFSBM. In another study, shrimp were fed diets in which 8.95, 17.90, 26.85 and 35.8% FFSBM replaced 25, 50, 75 and 100% of the soybean meal in a control diet containing 28% commercial soybean meal. Soybean oil was added to obtain the same dietary lipid level. No significant differences were observed among weight gain, feed conversion and survival of shrimp fed the various diets.

Discussion

Available research information clearly indicates that inclusion of raw soybeans in diets significantly depressed the growth performance of various species of fish. The nutritive value of properly processed FFSBM was at least equal, if not superior, to that of defatted soybean meal reconstituted with soybean oil. However, FFSBM is currently not routinely used as a major protein source in commercial aquaculture feeds.

FFSBM, because of the high oil content, is particularly important when high energy diets are desired. FFSBM is probably most useful for coldwater fish since these fish utilize oil as an energy source much more efficiently than carbohydrates. Soybean oil is a rich source of linoleic and linolenic acids which are essential for most aquatic species. FFSBM also contains phospholipids which are considered essential for crustaceans. Thus, there is no doubt that heat-treated FFSBM could play a major role in aquaculture nutrition. However, the extent of its utilization will depend on the economics and vary with species.

Despite the great potential of FFSBM, different heat processes have generally resulted in different product quality. Optimum processing conditions could vary for different species and by the age or size of fish. The high oil content of FFSBM could cause an imbalance of dietary protein to energy ratio which can reduce nutrient intake and produce fatty fish. FFSBM is deficient in methionine and lysine. The low content and availability of phosphorus and the chelating effect of phytates on other minerals such as zinc, copper and iron should also be an area of concern when high levels of FFSBM are used. Moreover, high levels of FFSBM may also lead to poor binding properties of the pellets and decreased palatability of the diets for some fish species. These factors should be taken into consideration when FFSBM is used in aquaculture diets.

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