Use of Soybean Meal in the Diets of Non-Salmonid Marine Fish

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UNITED SOYBEAN BOARD™

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Introduction

For several years, there has been continuing interest in identifying and developing ingredients as alternatives to fish meal for use within aquafeeds (Hardy, 1995; Tacon et al., 1998). Originally, the impetus for this was the often-variable nature of the price and supply of fish meal of suitably high quality for the aquafeed industry. Recently, however, the concern raised about the negative impact of fish meal production on global fish stocks has heightened this interest (Naylor et al., 2000). Among the ingredients being investigated as alternatives to fish meal, the products derived from soybeans (*Glycine max* L.) are some of the most promising (Lim et al., 1998; Hardy, 1999; Storebakken et al., 2000; Swick, 2002) because of the security of supply, price and protein/amino acid composition. According to Food and Agriculture Organization of the United Nations statistics, global soybean meal production has increased from about 15 million tons in 1961 to about 107 million tons in 2001, whereas fish meal production has remained fairly static at 5 to 7 million tons (Figure 1) and is expected to remain at these levels for the foreseeable future.

Soy products relevant to aquaculture feeds can be divided into three categories: protein products, oil and lecithin. In scientific literature, most attention has been paid to soy protein, although soy lecithin is used in commercial aquaculture feeds as a source of choline and as an emulsifier. Soy oil is used for marine fish only in limited amounts because of its fatty acid profile, but there is scope for expansion of its use, as fish oil availability becomes more limiting relative to its demand. This paper provides a review of research on the use of soy products, especially as protein sources, within feeds for non-salmonid marine fish.

For more information on the production and uses of soy products, refer to Lim et al., 1998; Hardy, 1999; Storebakken et al., 2000; and Swick, 2002; or visit www.soymeal.org, www.unitedsoybean.org, and www.soygrowers.com.

Soy Products and Their Manufacture

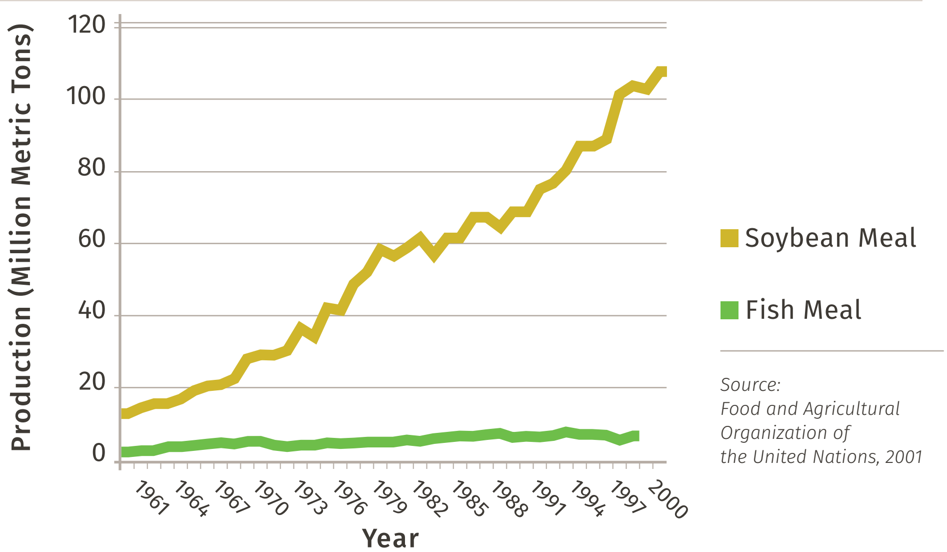
A number of processes go into the manufacture of products from soybeans. In general, the hulls are removed, and the beans are rolled into flakes, which are de-oiled by a solvent. The recovered crude oil is treated by hydration to precipitate the lecithin, leaving the oil in a more concentrated form. The de-oiled flakes, which contain the protein, are then toasted to remove the trypsin inhibitor. This product commonly is referred to as dehulled soybean meal, a low oil, high carbohydrate product with about 48% crude protein. It can be blended with ground soybean hulls to produce a meal with about 44% protein. Full-fat soya, produced without the fat extraction step, but treated to reduce anti-nutrient content, also is used in aquaculture feeds.

In addition to trypsin inhibitor, several anti-nutritional and/or allergenic compounds associated with the carbohydrate fraction exist in soybeans, such as glycinin, ß-conglycinin, oligosaccharides, lectins, and saponins (Liener, 1994). Some specific types of carbohydrates in soybean meal can impart a "beany" taste, and may influence its palatability. Many of theseanti-nutritional factors can be selectively

removed by solvent (aqueous alcohol) extraction or by isoelectric leaching, a method that produces a range of products with elevated protein content. These products include soy protein concentrate and soy isolate, which have protein contents of +/- 70% and +/- 90%, respectively.

The duration and temperature of the process, as well as the modification of the aqueous alcohol solvent used, combine to influence the characteristics of the final product, for example reduced antigen products. Texturized soy protein concentrate is produced by extrusion of traditional soy protein concentrate.

Figure 1 | ***Global Production of Soybean Meal and Fish Meal***



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The proximate composition, which estimates the moisture, lipid, protein, mineral and fiber content of feed ingredients, varies among the types of soy products, but is reasonably consistent for each type. The protein content of the products is increased by selectively removing the non-protein fraction. Thus, full-fat soybean meal has lower protein content than solvent extracted meal, which in turn has less protein than soy protein concentrate (Table 1). The specifics of the type of extraction used during manufacture (type of solvent, duration of extraction, etc.) are variable, especially for the protein concentrates, and consequently, there are differences in the proximate composition. It is important to note that the amino acid composition of the proteins does not change appreciably. Therefore, in situations where there is a need for other sources of methionine (which is low in soybean protein) for feeds made with low protein soy products, the same is likely for high protein products.

A number of studies have demonstrated the usefulness of soy protein products, especially soybean meal, in animal feeds, and this ingredient routinely is added to commercial formulations for many species of fish.

Table 1 | Typical Proximate Composition of Soybean Protein Products

INGREDIENT	MOISTURE	PROTEIN	LIPIDS
Soybean meal	11.0%	45.0%	1.2%
Full-fat soybean meal	10.0%	38.0%	18.0%
Soy protein concentrate	8.0%	84.0%*	0.5%

INGREDIENT	FIBER	ASH
Soybean meal	6.1%	6.1%
Full-fat soybean meal	5.0%	4.1%
Soy protein concentrate	0.1%	3.5%

**Note that the protein level reported for soy protein concentrate is considerably higher than the commercially accepted definition of greater than 65% on a moisture free basis.*

Sources: NRC, 1983; Tacon, 1990

Soy protein concentrate shows good promise for aquatic feeds. Removal of specific carbohydrates may reduce the palatability issue that is sometimes encountered with plant products in feeds for some aquatic species. The protein content of soy protein concentrate is approximately 65% (as fed basis), with a lipid level of less than 1% and ash content of about 6% (low phosphorus). The level and balance of amino acids (Table 2) found in soy protein concentrate is considered to be among the most appropriate among plant proteins, although it is low in methionine (Storebakken et al., 2000).

Soy Protein Products in Aquaculture Feeds

In general, cultured marine fish tend to be carnivorous and require higher dietary protein content relative to freshwater species. Traditionally, the requirement for this protein content has been met by including high quality fish meal, which has high nutritional value and good palatability characteristics. Because of the high price and insecurity of supply and concerns arising from the inefficiency of harvesting marine protein for inclusion into animal feed, ingredient manufacturers increasingly are seeking suitable replacements. Soy products have received a high degree of attention as a protein source in feeds for fish of all types, including non-salmonid marine fish, primarily for their low price, predictability of supply and generally good nutritional value.

Examining the work that has been done with various fish species, it is apparent that there are a number of limitations to the use of soy protein products in feeds, despite its overall good nutritional qualities. Among these limitations, the most important are: amino acid imbalance (especially the deficiency of methionine); poor palatability in some fish; presence of phytic acid, a naturally occurring compound that reduces the bioavailability of phosphorus and some other minerals; and presence of trypsin (and other protease) inhibitor, which deactivates the digestive enzyme trypsin, with subsequent reduction in protein digestibility (for a review, see Francis et al., 2001). As can be seen from the work reported below, these problems are dealt with in a variety of ways. Amino acid balance is maintained by supplementation or by inclusion of other ingredients rich in the deficient amino acids; methionine in the case of soy protein. Poor palatability can be overcome by including attractants. The effect of phytic acid on mineral availability can be alleviated by treatment with an enzyme that destroys phytic acid or by supplementing higher levels of certain minerals. The heat applied during manufacture of soybean meal destroys trypsin inhibitor.

Table 2 | Typical Essential Amino Acid Levels of a Fish Meal and a Soy Protein Concentrate

AMINO ACID	FISH MEAL (% as fed)	SOY PROTEIN CONCENTRATE (% as fed)
Tryptophan	0.731	0.771
Lysine	5.752	4.278
Histidine	1.820	1.790
Arginine	4.763	5.004
Threonine	3.036	2.742
Cystine	0.593	1.030
Valine	3.795	3.353
Methionine	2.268	1.554
Isoleucine	3.062	3.145
Leucine	5.400	5.378
Tyrosine	2.283	2.472
Phenylalanine	2.705	3.392
Taurine	0.812	0.000
ESSENTIAL AMINO ACID SUM	37.017	34.908

Source: LT-94 SSF, Norway

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Japanese Flounder

Considerable research has focused on the use of soy products, especially soybean meal, to replace fish products (fish meal and whole fish) in aquaculture feeds. One of the most common methods used to estimate the nutritional value of feedstuffs, including soy products, relative to fish meal is to feed a series of diets containing graded levels of the product in replacement of fish meal and to measure a relevant response (usually growth, feed efficiency and/or health). For example, Kikuchi (1999) fed juvenile Japanese flounder ***Paralichthys olivaceus*** a series of diets containing defatted soybean meal in replacement of fish meal of unspecified origin. In this trial, smaller amounts of other protein sources also were included with the soybean meal. The author concluded that soybean meal could effectively replace up to 45% of fish meal, provided that other protein sources were present, along with a feeding attractant (blue mussel in this trial). Earlier work with this species (Kikuchi et al., 1994, cited in Kikuchi, 1999) had shown that soybean meal protein could replace up to 50% of fish meal in diets for this species, when suitable supplemental amino acids were included.

Phytic acid is a naturally occurring component of many plant materials, including soy products, and is an unavailable phosphorus source for monogastric animals, including fish. Masumoto et al. (2001) examined the effectiveness of phytase, an enzyme that hydrolyzes phytic acid, on soybean meal and soy protein concentrate phosphorus bioavailability. These researchers examined the relative effectiveness of either adding phytase as a supplement to the feed containing soybean meal, or of pretreating soybean meal with the enzyme and they concluded that both methods were effective in dramatically raising the bioavailability of dietary phosphorus. In a 50-day growth trial with soy protein concentrate, it was found that growth and feed efficiency were significantly improved by supplementing the diets with phytase, or by supplementing the diet with trace minerals.

Japanese Flounder

Turbot

Turb

Turbot ***Scophthalmus maximus*** is a highly valued marine flatfish that is farmed in northern waters in Europe, especially along the Atlantic coast and is known to have high protein requirements. A study was recently reported on the effectiveness of soy protein concentrate as a source for dietary protein (Day and Gonzalez, 2000). In this study soy protein concentrate replaced fish meal protein in diets at levels of 0, 25, 50, 75 and 100% and these diets were hand-fed to the animals (13 grams initial weight). The results of this study indicated that inclusion of soy protein concentrate up to 25% replacement of fish meal did not statistically reduce the final weight or feed efficiency. It was further noted that the apparent digestibility of protein was the same for all diets. A subsequent trial in this study indicated that supplemental dietary methionine and lysine improved the utilization of this ingredient, but this finding was not statistically significant.

Yellowtail

Possibly the non-salmonid fish species most extensively studied with respect to the dietary potential of soybean meal is yellowtail ***Seriola quinqueradiata,*** a high value fish that is cultured in many countries in Asia, especially in Japan. Traditionally, the primary aquaculture feed for this species has been the whole sardine directly fed to the fish. Over the past decade, there has been considerable effort to develop alternative, formulated feeds (Watanabe et al., 1991).

Early work demonstrated that commercial defatted soybean meal (Shimeno et al., 1992a, 1992b, 1993a) could substitute for fish meal in up to 20% of the diets for fingerling yellowtail, while soy protein concentrate has higher protein quality. Watanabe et al. (1992) fed diets containing 0, 10, 20 and 30% defatted soybean meal in replacement of fish meal. They found that the growth and feed efficiency of the fish fed soy protein up to the level of about 20% were very similar to those fed the fish meal control feed, while there was a slight reduction above this level. The apparent digestibility of the protein was the same for all feeds, irrespective of soybean meal level.

Viyakarn et al. (1992) extended this work to higher levels of inclusion and obtained similar results. In these two studies, no attempt was made to equalize the protein content of the diets, and those with higher soybean meal inclusion had lower protein content, which may have affected the ability of the feed to promote growth at the highest levels of soybean meal inclusion. Subsequent work with yellowtail has shown the higher nutritional quality of fermented versus non-fermented soybean meal (Shimeno et al., 1993c), the improvement of the nutritional quality of diets containing soybean meal when combined with other protein sources (corn gluten meal, malt protein flour and meat meal) (Shimeno et al., 1993a, 1996), improvement of protein digestibility in heat treated soybean meal relative to raw meal (Shimeno et al., 1994), and the ability of full fat soybean meal to be included at up to 30% in extruded feeds in replacement of fish meal without loss of dietary nutritional quality (Shimeno et al., 1997).

Yellowtail

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Atlantic Halibut

Atlantic Halibut

Although soy protein products have been useful as ingredients in marine fish diets, two factors that could limit the inclusion are the effect on palatability and the imbalance of amino acids (methionine in soy protein is generally low relative to the requirements of many species). To assess soy protein products in these cases, feed attractants or palatability enhancers are sometimes added to counter the effect of the product on palatability. In addition, methionine, usually in synthetic crystalline form, is sometimes supplemented. For example, Berge et al. (1999) fed four diets to Atlantic halibut ***Hippoglossus hippoglossus***. Two of the diets contained high quality fish meal as the principal source, while in the other two diets about 39% of the fish meal was replaced by soy protein concentrate. The latter two diets were supplemented with 0.5% crystalline synthetic methionine. One diet containing fish meal and one of the soy protein concentrate diets were formulated to contain 0.2% squid meal as an attractant.

The feeds were each fed to three groups of fish for 12 weeks and growth rate, feed efficiency and digestibility were determined. At the end of the trial, there was no effect of treatment on growth, indicating that inclusion of 28% of soy protein concentrate (supplying 44% of the total crude protein) can be achieved without reduction in growth. The feed efficiency of the fish fed diets containing soy protein was slightly poorer than those fed the fish meal diets, and the authors attribute this to the higher fiber content of the soy protein concentrate (normally about 3.5-5% of dry matter) (Lusas and Rhee, 1995). The apparent digestibility coefficients of protein and lipid, which measures the biological availability of these components, were the same for the fish meal and soy protein diets.

Asian Seabass

Asian seabass ***Lates calcarifer*** have been cultured in many Asian countries for the past few decades. The feeds for this fish commonly contain high levels of fish meal, which increases the price of culture. Boonyaratpalin et al. (1998) examined the suitability of a variety of soy protein products to replace fish meal in feeds for this species. In this study, 37.5% of fish meal in a seabass feed was replaced with an equivalent protein level from each of four products: solvent extracted soybean meal; extruded full-fat soybean meal; steamed full-fat soybean meal; and soaked raw full-fat soybean meal. These feeds were fed to juvenile seabass for a 10-week period and the growth, feed efficiency and apparent digestibility were calculated. After 10 weeks, the fish fed the solvent extracted soybean meal exhibited a growth rate and feed efficiency that was not significantly different than the control fish meal feed. The fish fed the extruded full-fat soybean meal and the steamed full-fat soybean meal grew 83.7% and 83.3%, as fast as the control fish. This difference was statistically significant.

The feed efficiency and protein digestibility data of these four feeds, however, were the same, indicating that the reduced growth in the feeds containing the extruded ingredients was due more to feed intake differences (i.e., palatability issues) than differences in nutritive quality. Soaked raw full-fat soybean meal was poorly utilized by seabass, as shown by a markedly reduced performance (growth, feed efficiency, digestibility, etc.). One of the likely causes of the poor nutritional value of this raw product is the presence of trypsin inhibitor.

Asian Seabass

European Seabass

European seabass ***Dicentrarchus labrax*** is the Mediterranean aquaculture industry. As with many aquaculture operations, feeds generally account for a considerable proportion of the cost of production. Lanari et al. (1998) reported on a growth trial in which 25 and 50% of animal protein (fish meal, blood meal and yeast) was replaced by soybean meal in diets for European seabass (initial weight 100 grams). Over 97 days, the growth performance of fish fed the 25% soybean diet were similar to those fed the control diet, while the growth and feed utilization of the animals fed the highest soybean meal content feed were significantly poorer than the control. The results of this study indicate that soybean meal can replace up to 25% of the fish meal in feeds for European seabass. In this study, the apparent digestibility of protein in soybean meal was 91%, while the control protein source was 92.2%.

Amerio et al. (1991) examined the nutritional value of diets for seabream (initial weight of 169 grams) containing defatted and full-fat soybean meals at 25 and 28% (with 0.8% methionine supplementation), respectively. After 246 days of feeding, the weight of the fish fed the full-fat soy containing feed were not significantly different than the commercial feed control, whereas the soybean meal fed fish grew to only 91% the weight of the control.

Tulli et al. (2000) conducted a 90-day trial to measure performance and cellular and humoral immune response of seabass (11.7 grams initial weight) fed diets containing 0, 20, 40 and 60% soybean meal (an additional diet had 60% replacement by soy protein concentrates) in replacement of fish meal protein. The performance of the fish indicated that soy protein could replace up to 40% of the fish meal in the diet

European Seabass

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without inducing meaningful changes in performance or other parameters.
In a subsequent trial, Tulli and Tibaldi (2001) reported that the apparent digestibility of protein and energy were somewhat lower in soybean meal (88.9 and 69.3%, respectively) than the fish meal control (97.3 and 87.9%, respectively), but the protein digestibility of soy protein concentrate was higher (97.3%).

Gomes et al. (1997) examined the use of soy protein concentrates with and without the presence of an attractant (a mixture of amino acids included at 2.5%) in diets for European seabass in comparison with fish meal. The fish fed the fish meal diet performed the best of all the groups in this trial, but including the attractant in the soy based diet significantly improved the feed consumption and subsequent growth of the fish.

Gilthead Seabream

The efficacy of soybean meal to replace fish meal in diets for gilthead seabream ***Sparus aurata*** was examined in a study conducted by Robaina et al. (1995). This work consisted of both a growth trial and a digestibility trial. In the growth trial, fish were fed for 60 days with feeds in which fish meal was replaced by 0, 10, 20 and 30% of soybean meal. It was found that the inclusion of soybean meal — up to 20% replacement of fish meal — resulted in growth, feed efficiency and protein efficiency ratio values that were at least as high as the fish meal control diet. At 30% soy inclusion, there was some reduction in these parameters, but this was not statistically significant. The apparent protein digestibility of the diets containing increasing soybean meal paralleled the pattern found for growth.

In a similar study, Nengas et al. (1996) examined the growth of gilthead seabream fed diets containing solvent extracted soybean meal at 0, 10, 20, 30 and 40% replacement of white fish meal. The results of this trial indicated that soybean meal could replace up to 20% of fish meal with no loss of growth potential and with feed efficiency at least as high as the fish meal control diet. In a complementary trial, these researchers fed diets containing soybean meal product which had been heated to 150°C and then cooked at 110°C for five, 20 or 45 minutes. The destruction of trypsin inhibitor,

Gilthead Seabream

as measured by reduction in its activity, was increased by exposure to the heat of cooking, increasing from 0 for uncooked soybean meal, to 67, 73 and 85% for 5, 20 and 40 minute cooking times, respectively. In the trial, the differently processed soybean meals replaced 35% of the protein in the fish meal of the soy free control diet.

The final weight of the animals fed the soybean containing feeds was related positively to the level of destruction of the trypsin inhibitor, with the longest cooked soybean meal producing growth and feed efficiency at least equivalent to the fish meal control. The authors concluded that soybean meal is a suitable ingredient for this species, as long as the level of trypsin inhibitor is reduced by at least 85%.

In contrast, a recent study by Kissil et al. (2000) examined the ability of soy protein concentrate to replace fish meal in diets for gilthead seabream. In this study, a Chilean fish meal was replaced by soy protein concentrate at 0, 30, 60 or 100%, on a digestible protein basis (Lupatsch et al., 1997). These diets were fed to the animals (initial weight 12.1 grams) until each group reached an average weight of 50 grams. There was an inverse relationship between dietary soy protein concentrate level and growth of the fish. The authors concluded that reduced feed intake, rather than nutritional considerations in all but the highest inclusion level, explained the decreased growth observed in the fish fed the different diets.

Silver Seabream

A study evaluating the efficacy of soybean meal and other ingredients as replacements of fish meal as dietary protein sources for silver seabream ***Rhabdosargus sarba*** fingerlings was conducted by El-Sayed (1994). In this work, fish were fed feeds in which fish meal was replaced by dehulled, defatted, toasted

Silver Seabream

soybean meal at 0, 25, 50, 75 and 100%. The soybean meal containing diets was supplemented with methionine. After feeding for 60 days, it was found that the diet with 25% replacement by soybean meal performed similarly in terms of growth and feed efficiency to the fish meal control feed. The acceptance by the fish of the feed containing the highest levels of soybean meal, however, was reduced, resulting in poorer performance.

Red Sea Bream

Red sea bream ***Pagrus major*** is one of the most important marine culture species in Japan. Takagi et al. (1999, 2001) and Aoki et al. (1996, 2000) examined the ability of soy protein products to replace fish meal in diets for this species. Aoki (1996) reported that, with large fish (730 grams), feeding a diet containing 40% soy protein concentrate, 10% soybean meal, 3% corn gluten meal and 12% meat meal as total replacement of fish meal (67% in a commercial feed) resulted in comparable growth and flesh quality (as measured by a sensory panel). Takagi et al. (2001) demonstrated that for juvenile (11 grams initial weight) fish, the nutritional quality of soy protein concentrate was improved by supplementation with the amino acid methionine and to some extent with lysine. On the other hand, the growth rate of yearling (179 grams initial weight) fish fed diets containing soy protein concentrate was not responsive to supplementation of amino acids.

Red Sea Bream

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Red Drum

Milkfish

Red Drum

Reigh and Ellis (1992) examined the nutritional quality of soybean meal relative to fish (menhaden) meal in feeds for red drum ***Sciaenops ocellatus***. They reported poor consumption of the feeds containing only soy protein or soy protein plus a methionine supplement. In a series of four, 56 or 49 day feeding trials with this species, Davis et al. (1995) evaluated soybean protein meals (a soybean meal and two soy protein isolates), with and without supplemental methionine, lysine and feed attractants, as replacements for menhaden meal in diets. These authors found that with suitable inclusion of amino acids (primarily methionine) and attractants, soy protein products are acceptable for inclusion in practical diet formulations for red drum in replacement of fish meal.

McGoogan and Gatlin (1997) demonstrated that red drum fed diets in which 90% of the protein from soybean meal gained as much weight as fish fed a diet with 100% of protein from fish meal, and that soybean meal inclusion could be extended to 95% with supplementation of 2% glycine.

Milkfish

Milkfish ***Chanos chanos*** is a popular and economically important food fish in Southeast Asia. Shiau et al. (1988) examined the feasibility of using soybean meal at the level of 0, 33, 67 and 100% replacement of fish meal as a protein source for milkfish feeds containing 30 and 40% protein. Methionine was added to the soybean meal containing diets to ensure adequate dietary levels of this amino acid. The diets were each fed to three groups of juvenile milkfish (initial size 4 grams) for eight weeks, at the end of which time the apparent digestibility coefficients for protein and dry matter were determined. After eight weeks, there was a trend to lower growth and poorer feed efficiency in diets containing more than 33% soybean meal replacement of fish meal, but there were no significant differences for growth or feed efficiency among the treatments containing 67% or less of soybean meal, at either 30 or 40% total dietary protein levels. The digestibility of the diets was unaffected by the level of soybean meal replacement of fish meal, indicating that these two ingredients have similar biological availability.

Soybean Oil

Although soy products generally are considered for their protein content in feeds for aquatic animals, soybeans contain appreciable levels of oil as well. In parallel with the concern of the declining ability of fish meal to meet the growing demands of the animal feed industry, especially for aquatic animals, the availability of marine oil is also declining. As soy protein products worldwide have increased dramatically over the past four decades, so has the availability of soybean oil. Relatively little research has been published, however, on the suitability of soybean oil inclusion in replacement of fish oil in aquatic feeds.

Dietary lipids are a source of biochemical energy and fatty acids. While soybean oil is a good source of energy, it does not contain a good balance of fatty acids for marine animals. Soybean oil contains high levels of mono- and di-unsaturated fatty acids (Table 3), but is deficient in some of the specific highly unsaturated fatty acids required by many species of marine fish, and high levels of inclusion will likely need to be accompanied by supplementation of essential fatty acid containing sources.

For example, Tucker et al. (1997) examined the relative efficacy of soybean and menhaden oils in feeds for juvenile red drum *Sciaenops ocellatus*. These researchers found that at low levels of inclusion, soybean oil performed as well as menhaden oil. At high levels, however, the growth rate of the fish was impaired, apparently because of the reduced level of the essential fatty acids. Interestingly, in this study, the survival of the fish fed the soybean oil diets was consistently higher than those fed the menhaden oil diets.

Many issues need to be addressed to improve the usefulness of soybean oil for use in feeds for marine fish. As mentioned, one of these issues is the fatty acid content of soybean oil. Other areas of research include the effect of soybean oil inclusion on feed consumption (fish oil is often superior to soybean oil in its effect on feed palatability) and on product quality (the type of dietary oil can have profound impacts on the texture, flavor and shelf-life characteristics of the final product).

Table 3 | **Typical Fatty Acid Profile of Soybean Oil**

FATTY ACID	LEVEL (% of oil)
SATURATED	
C12 (lauric acid)	Trace
C14 (myristic acid)	Trace
C16 (palmitic acid)	11.0
C18 (stearic acid)	4.1
C20 (arachidic acid)	Trace
UNSATURATED	
16:1 (palmitioleic acid)	Trace
18:1 (oleic acid)	22.0
18:2 (linoleic acid)	54.0
18:3 (linolenic acid)	7.5

Source: American Soybean Association

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Other Research Efforts to Advance Soy Products and Soy Product Use

The American Soybean Association (ASA) has sponsored a great deal of work, especially in East Asia, to establish the efficacy of inclusion of soybean protein products in feeds for commercial non-salmonid marine fish culture. The species that have been studied include: Japanese sea bass *(Lateolabrax japonicus)*; pompano *(Trachinotus ovatus)*; yellow croaker *(Pseudosciaena crocea)*; red drum *(Sciaenops ocellata)*; green grouper *(Epinephelus awoara)*; and blackfin seabream *(Acanthopagrus sp.)*. The ASA has developed feeds containing soy protein products for different applications (Table 4), including juvenile fish, growing fish and weaning fish from a fresh fish diet to a prepared feed. These feeds have been found to be acceptable under practical conditions for these species of fish, and some of this work is summarized in Table 5.

Table 4 | **Examples of Soy-Inclusion Feeds for Use in Field-Based Feeding Trials in China with Marine Fish**

All rations were formulated to be nutritionally the same, with 43% crude protein and 11% crude lipid. The number following the ingredient name refers to the protein content.

INGREDIENT	INCLUSION LEVEL		
	LOW PROTEIN SOYBEAN MEAL BASE RATION (43% Protein)	DEHULLED SOYBEAN MEAL BASE RATION (43% Protein)	FISH MEAL BASED RATION (43% Protein)
Fish meal (anchovy 65)	37.00%	34.00%	44.00%
Wheat flour (10)	14.20%	16.50%	25.00%
Dehulled soybean meal (47.5)		40.00%	18.50%
Soybean meal (43)	35.00%		
Wheat gluten	4.60%		
Corn gluten meal (60)		1.00%	5.00%
Fish oil, unspecified	8.40%	8.03%	7.03%
Mineral premix	0.25%	0.25%	0.25%
Vitamin premix Roche 2118	0.50%	0.50%	0.50%
Stable Vitamin C (35% active)	0.03%		
Ethoxyquin	0.02%	0.02%	0.02%
TOTAL	**100.00%**	**100.03%**	**100.30%**

Source: American Soybean Association

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Table 5 | **Summary of Feeding Trials in China to Examine the Suitability of Soybean Protein in Diets for Non-Salmonid Marine Fish Species**

SPECIES	FEED USED (% protein)	INITIAL FISH WEIGHT (grams)	DURATION (days)	RESULT
Japanese Sea Bass	dehulled soybean meal (SBM) (43) versus fish meal (43)	3	153	Final weight: SBM 297 grams, Feed Conversion Ratio (FCR) 1.53; fish meal 289 grams, FCR 1.54
	SBM (43) versus fresh fish	10.6	102	Final weight: SBM 178.3 grams; fresh fish 178.3 grams
	SBM (47) to 25 grams, followed by SBM (43)	2.1	124	Final weight 212 grams; FCR 1.01
	SBM (43)	25	90	Final weight 195 grams; FCR 1.43
Red Drum	SBM (47)	0.5	30	Final weight 5.6 grams; FCR 1.04
	SBM (43)	5.6	88	Final weight 97.5 grams; FCR 1.31
	Wean from trash fish to SBM (43) extruded feed	161	155	Fish were successfully weaned; final fish weight 834 grams; FCR 1.99; growth and FCR impacted by poor water quality
Yellow Croaker	SBM (43) versus fresh fish	3.2-3.4	103	Final weight: SBM 37.9 grams, FCR 1.69; Fresh fish 44 grams, FCR 9.92
	SBM (43) versus fresh fish	5.4-5.6	62	Final weight: SBM 23.4 grams; fresh fish 25.4 grams
	SBM (47)	2.2	30	Final weight 5.7 grams; FCR 1.20
	SBM (47) versus SBM (43)	5.8	93	Final weight 42 grams; FCR 1.67, same for both treatments
	Hi-Pro Starter (53) versus fresh fish	0.67	45	Final weight was the same for both treatments 3.2-3.4 grams; FCR 1.55 (Hi-Pro Starter) versus 8.14 (fish)
	SBM (47) versus fresh fish	3.2-3.4	103	Final weight: SBM 38 grams, FCR 1.69 Final weight: fresh fish 44 grams, FCR 9.92
Pompano, Ovate	SBM (47) to 50 grams, followed by SBM (43)	7	103	Final fish weight 349 grams, FCR 2.1

Source: American Soybean Association

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Conclusions

Products derived from soybeans have been shown to be excellent ingredients for practical feeds for many commercially important species of cultured non-salmonid marine fish. This is primarily because of the high level of protein containing a reasonably balanced amino acid profile, its low price, the ease of incorporation into feeds, and the low level of antinutritional elements (when properly prepared).

A number of important items need consideration when contemplating use of soy protein products as ingredients in feeds for fish, namely: the degree to which the anti-nutritional compounds have been eliminated; the palatability for some fish species; and the low methionine (and possibly lysine) level. These issues can be resolved by suitable manufacturing processes, by formulating with a balance of ingredients, or by adding appropriate supplements (attractants, amino acids, etc.). The high protein level, low cost and ready availability of soy products makes them ideal ingredients for inclusion in fish feeds in partial or complete replacement of fish meal.

Future Research Directions

In order for soy products to be more fully utilized in fish feeds, more research needs to be done to match the ingredient to the feed. Most cultured marine species are carnivorous, and generally have narrower nutritional and palatability tolerances for plant proteins than do herbivorous or omnivorous species. This makes the need for research even more compelling.

The problems can be addressed from two directions: 1) improving the utilization of existing products, and 2) development of new soy products that match the requirements of aquaculture. Development of new methodologies that reduce the cost of production of ingredients will, of course, increase their utilization. Examples of some research approaches that will result in increased utilization of soy products in fish feeds, with overall improvement in return on investment of aquaculture operations, include:

- Formulating species-specific feeds with balanced amino acid profiles. This requires more information about amino acid requirements for cultured marine fish species, especially those amino acids that are limiting in soy products, such as methionine.
- In cases where the binding of specific minerals by phytic acid limits utilization of soy products, developing feeds that counter the problems associated with phytic acid (supplementa minerals, addition of phytase, etc.).
- Developing novel soy protein products with low palatability problems, by selective removal of specific compounds.
- Developing new breeds of soybean with elevated methionine (or the related amino acid, cystine), and/or reduced phytic acid.

References

Amerio, M., Vignali, D., Castelli, L., Fiorentinin, L., Tibaldi, E. 1991. Soybean products in feeds for sea bass. Proceedings of the IX National ASPA Congress, ASA, 1099-1010.

Aoki, H., Shimazu, H., Fukushige, T., Akano, H., Yamagata, Y., Watanabe, T. 1996. quality in red sea bream fed with diet containing a combination of protein sources as total substitution for fish meal. *Bull. Fish. Res. Inst. Mie.* no 6, 47-54.

Aoki, H., Furuichi, M., Watanabe, K., Satoh, S., Yamagata, Y. Watanabe, T. 2000. Use of low or non-fish meal diets for red sea bream. *Suisanzoshoku* 48:65-72.

Berge, G.E., Grisdale-Helland, B., Helland, S.J. 1999. Soy protein concentrate in diets for Atlantic halibut. *(Hippoglossus hippoglossus). Aquaculture* 178: 139-148.

Boonyaratpalin, M., Suraneiranat, P., Tunpibal, T. 1998. Replacement of fish meal with various types of soybean products in diets for the Asian seabass, *Lates calcarifer. Aquaculture* 161: 67 – 78.

Davis, D.A., Jirsa, D., Arnold, C.R. 1995. Evaluation of soybean proteins as replacements for menhaden fish meal in practical diets for the red drum *Sciaenops ocellatus. J World Aquacult*. Soc. 26:48-58.

Day, O.J., Plascencia Gonzalez, H.G. 2000. Soybean protein concentrate as a protein source for turbot *Scophthalmus maximus* L. *Aquaculture Nutrition* 6:221-228.

El-Sayed, A-FM. 1994. Evaluation of soybean meal, Spirulina meal and chicken offal meal as protein sources for silver seabream *(Rhabdosargus sarba)* fingerlings. *Aquaculture* 127:169-176.

Francis, G., Makkar, H.P.S., Becker, K. 2001. Antinutritional factors present in plant derived alternate fish feed ingredients and their effects in fish. *Aquaculture* 199:197- 227.

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References

Gomes, E., Dias, J.; Kaushik, S.J. 1997. Improvement of feed intake through supplementation with an attractant mix in European seabass fed plant-protein rich diets. *Aquatic Living Resources* 10:385-389.

Hardy, R.W. 1995. Current issues in salmonid nutrition. Nutrition and Utilization Technology in Aquaculture, (ed. by Lim, C. and Sessa, D.J.), AOAC Press, Champaign, USA, 26-35.

Hardy, R.W. 1999. Alternate protein sources. Feed Management 50:25-28.

Kikuchi, K., Furuta, T., Honda, H. 1994. Utilization of soybean meal as a protein source in the diet of juvenile Japanese flounder *(Paralicthys oliveaceus)*. *Suisanzoshoku* 42:601-604.

Kikuchi, K. 1999. Use of defatted soybean meal as a substitute for fish meal in diets of Japanese flounder *(Paralicthys oliveaceus)*. *Aquaculture* 179: 3-11.

Kissil, G.W., Lupatsch, I., Higgs, D.A., Hardy, R.W. 2000. Dietary substitution of soy and rapeseed protein concentrates for fish meal, and their effects on growth and nutrient utilization in gilthead seabream *Sparus auata* L. *Aquacult. Res.* 31: 595-601.

Lanari, D., Yones, M., Ballestrazzi, R., E. D'Agro. 1998. Alternative dietary protein sources (soybean, rapeseed, and potato) in diets for seabream. 8th International Symposium on Nutrition and Feeding in Fish. Las Palmas De Gran Canaria, Spain. 145.

Liener, I.E. 1994. Implications of anti-nutritional components in soybean foods. *Critical Reviews of Food Science and Nutrition* 34:31 - 67.

Lim, C., Klesius, P.H., Dominy, W. 1998. Soyabean products. *International Aqua Feeds* 3:17-23.

Lupatsch, I, Kissil, G.W., Sklan, D., Pfeffer, E. 1997. Apparent digestibility coefficients of feed ingredients and their predictability in compound diets for gilthead seabream, *Sparus aurata*. L. *Aquacult. Nutr.* 3:81-89.

Lusas, E.W., Rhee, K.C. 1995. Soybean protein processing and utilization. *In:* Erickson, D.R. (Ed.), Practical Handbook of Soybean Processing and Utilization. AOCS Press, Champaign, IL, 117-160.

McGoogan, B.B., D.M. Gatlin III. 1997. Effects of replacing fish meal with soybean meal in diets for red drum *Sciaenops ocellatus* and potential for palatability enhancement. *J. World Aquac. Soc.* 28(4):374-385.

Masumoto, T., Tamura, B., Shimeno, S. 2001. Effects of phytase on bioavailability of phosphorus in soybean meal based diets for Japanese flounder *Paralichthys olivaceus*. *Fisheries Science* 67:1075-1080.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature* 405:1017-1024.

Nengas, I., Alexis, M.N., Davies, S.J. 1996. Partial substitution of fish meal with soybean meal products and derivatives in diets for the gilthead seabream *Sparus aurata* (L.). *Aquacult. Res.* 27:147-156.

NRC (National Research Council). 1983. Nutrient Requirements of Warmwater Fishes and Shellfishes, Revised Edition. National Academy Press, Washington, USA.

Reigh, R.C., Ellis, S.C. 1992. Effects of dietary soybean and fish-protein ratios on growth and body composition of red drum *(Sciaenops ocellatus)* fed isonitrogenous diets. *Aquaculture* 104:279-292.

Robaina, L., Izquierdo, M.S., Moyano, F.J., Socorro, J., Vergara, J.M., Montero, D., Fernandez-Palacios, H. 1995. Soybean and lupin seed meals as protein sources in diets for gilthead seabream *(Sparus aurata)*: nutritional and histological implications. *Aquaculture* 130:219-233.

Shiau, S-Y., Pan, B.S., Chen, S., Yu, H-L., Lin, S-L. 1988. Successful use of soybean meal with a methionine supplement in diets for milkfish *Chanos chanos* Forskal. *J. World Aquacult.* Soc. 19: 14-19.

Shimeno, S., Hosokawa, H., Kunon, M., Masumoto, T., Ukawa, M. 1992a. Inclusion of defatted soybean meal in diet fo fingerling yellowtail. *Nippon Suisan Gakkaishi* 58:1319-1325.

Shimeno, S., Hosokawa, H., Yamane, R., Masumoto, T., Ueno, S-I. 1992b. Change in nutritive value of defatted soybean meal with duration of heating time for young yellowtail. *Nippon Suisan Gakkaishi* 58:1351-1359.

Shimeno, S., Kumon, M., Ando, H., Ukawa, M. 1993a. The growth performance and body composition of young yellowtail fed with diets containing defatted soybean meal for a long period. *Nippon Suisan Gakkaishi* 59:821-825, 1993.

Shimeno, S., Mima, T., Imanaga, T., Tomaru, K. 1993b. Inclusion of combination of defatted soybean meal, meat meal, and corn gluten meal to yellowtail diets. *Nippon Suisan Gakkaishi* 59:1889-1895.

Shimeno, S., Mima, T., Yamamoto, O., Ando, Y. 1993c. Effects of fermented defatted soybean meal in diet on the growth, feed conversion, and body composition of juvenile yellowtail. *Nippon Suisan Gakkaishi* 59:1883-1888.

Shimeno, S., Seki, S-I., Masumoto, T., Hosokawa, H. 1994. Post-feeding changes in digestion and serum constituent in juvenile yellowtail force-fed with raw and heated defatted soybean meals. *Nippon Suisan Gakkaishi* 60:95-99.

Shimeno, S., Hosokawa, H., Masumoto, T., Ruchimat, T., Kishi, S. 1996. Addition of combined defatted soybean meal, malt protein flour, and meat meal to yellowtail diet. *Nippon Suisan Gakkaishi* 62:243-247.

Shimeno, Sadao; Ruchimat, T; Matsumoto, Masaya; Ukawa, Masaharu. 1997. Inclusion of full-fat soybean meal in diet for fingerling yellowtail. *Nippon Suisan Gakkaishi* 63:70-76.

Storebakken, T., Refstie, S., Ruyter, B. 2000. Soy products as fat and protein sources in fish feeds for intensive aquaculture. *Soy in Animal Nutrition* (ed. by Drackley, J.K), Fed. Anim. Sci. Soc., Savoy, IL, USA, 127-170.

Swick, R.A. 2002. Soybean meal quality: assessing the characteristics of a major aquatic feed ingredient. *Global Aquaculture Advocate* 5:46-49.

Tacon, A.G.J. 1990. Standard methods for the nutrition and feeding of farmed fish and shrimp. Argent Laboratories Press, Redmond, Washington, USA 450.

Tacon, A.G.J., Dominy, W.G., Pruder, G.D. 1998. Global trends and challenges in aquafeeds for marine shrimp. *AquaFeed International* 4:28 - 35.

Takagi S., Hosokawa, H., Shimeno, S., H., Maita, M., Ukawa, M., Ueno, S. 1999. Utilization of soy protein concentrate in a diet for red sea bream *Pagrus major*. *Suisanzoshoku* 47:77-87.

Takagi, S., Shimeno, S., Hosokawa, H., Ukawa, M. 2001. Effect of lysine and methionine supplementation to a soy protein concentrate diet for red sea bream *Pagrus major*. *Fisheries Science* 67:1088-1096.

Tucker Jr., J.W., Lellis, W.A., Vermeer, G.K., Roberts Jr., D.E., Woodward, P.N. 1997. The effects of experimental starter diets with different levels of soybean or menhaden oil on red drum *(Sciaenops ocellatus)*. *Aquaculture* 149: 323 - 339.

Tulli, F, Ramelli, M, Tibaldi, E, Manetti, F, Volpatti, D, Galeotti, M. 2000. Feeding seabass *(Dicentrarchus labrax)* juveniles with soybean products: effects on growth, feed utilization, serological response and non-specific defense. *Bollettino Societa Italiana di Patologia Ittica* [Boll. Soc. Ital. Patol. Ittica]. 12:3-9.

Tulli, F., Tibaldi, E. 2001. Apparent nutrient digestibility of different protein sources for sea bass *(D. labrax)*. In: Recent Progress in Animal Production Science .2. Proceedings of the ASPA ZIV Congress, Florence, Italy, June 12-15, 2001. University of Florence, Italia, 697-699.

Viyakarn, V., Watanabe, T., Aoki, H., Tsuda, H., Sakamoto, H., Okamoto, N., Iso, N., Satoh, S., Takeuchi, T. 1992. Use of soybean meal as a substitute for fish meal in a newly developed soft-dry pellet for yellowtail. *Nippon Suisan Gakkaishi* 58: 1991 – 2000.

Watanabe, T., Sakamoto, H., Abiru, M., Yamashita, J. 1991. Development of a new type of dry pellet for yellowtail. *Nippon Suisan Gakkaishi* 57:891 – 897.

Watanabe, T., Viyakarn, V., Kimura, H, Ogawa, K., Okamoto, N., Iso, N. 1992 Utilization of soybean meal as a protein source in a newly developed soft-dry pellet for yellowtail. *Nippon Suisan Gakkaishi* 58:1761 – 1773.