The Use of Soy Protein in Aquafeeds

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ABSTRACT

Traditionally, fish meal is the main dietary protein source in fish feed formulation, especially for carnivorous fish species such as salmon and eel. In general, fish feed contains 5 to 50% of fish meal and shrimp feed contains marine animal protein at a level between 30-50%. The rapid development of aquaculture will result in a high demand and a shortage of supply for fish meal. Besides of the limited availability, fishmeal is also a relatively expensive ingredient in aquafeed. Furthermore, the quality of fishmeal can vary to a large extent, concerning to nutritional composition, pathogen and contamination of biogenic amines. Many researches, therefore, have been conducted to search alternative protein sources as replacement of fishmeal in aquafeeds.

In shrimp and carnivorous fish species, the replacement of fishmeal by plant protein sources has only achieved limited success. Fish, compared with pigs and poultry, can not utilize carbohydrates as an energy source efficiently. Carnivorous fish species and young animals require good quality and highly digestible protein source in their feed.

Among plant protein ingredients, soybean meal is considered as the most nutritive plant protein source. However, the high concentration of anti nutritional factors limited the inclusion levels of soybean meal in aquafeed. In soy protein concentrate, the anti nutritional components are eliminated. Compared to fishmeal, soy protein concentrate has advantage of high protein and amino acids digestibility co-efficiency, readily available and consistent quality.

Literature studies demonstrate that soy protein concentrate is a good alternative to fishmeal in shrimp and fish diets. In shrimp diet, 40% of fish meal can be replaced by soy protein concentrate without negative influence on growth performance. In fish, 40-100% of fishmeal can be replaced by soy protein concentrate. In conclusion, soy protein concentrate is a good protein source for aquafeeds.

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INTRODUCTION

Demand for fish meal

Fish meal is an excellent protein source in fish feed due to it's balanced amino acid profile and high digestibility. Traditionally, fish meal is the main dietary protein source in fish feed formulation, especially for carnivorous fish species such as salmon and eel. In general, fish feed contains 5 to 50% of fish meal.

In commercially manufactured feeds for shrimp culture, marine animal protein sources such as fish, shrimp and squid meals are the primary protein sources being included in the feed, at a level between 30-50%.

The statistical data from Food and Agriculture Organization of the United Nations (FAO) indicated that aquaculture is continuously increasing and the supplies from fisheries stabilized and even tend to decrease. However, the demand of fish production for human consumption is increasing and leading to a reduced fish meal and fish oil production. For example, fish meal production was 6.83, 6.86, 6.70, 5.28 and 6.06 million metric tones in 1995, 1996, 1997, 1998 and 1999 respectively. Fishmeal Information Network estimated that about 35% of fish meal is consumed by fish feed industry, while 29% of fish meal is consumed by pig feed industry. For land farming animals, such as pig, poultry and ruminants, up to 10% (maximum) of fish meal is included in the diets. In contrast, up to 55% of fish meal is included in fish feed. In fact, aquaculture has become the fastest growing food production sector of the world, with an average annual increase of about 10% since 1984 as compared to 3% increase for livestock meat and 1.6% increase for capture fisheries (FAO, 1997). The rapid development of aquaculture will result in a high demand and a shortage of supply for fish meal. Furthermore, the contamination of certain fish meal with dioxins has reduced the quality of fish meal as a raw material to be included in fish feed. Those factors are forcing feed industries and scientists to search for alternative protein sources in fish feed.

Table 1 Estimated production (thousand metric tons) of aquaculture feeds and the use of fish meal in aquaculture feed.

	1994			2010		
	Feed produced	Fish meal used		Feed produced	Fish meal used	
			%			%
Salmon	685	351	51	1600	480	30
Trout	446	171	38	560	140	25
Shrimp	922	241	26	2940	588	20
Eels	186	93	50	155	47	30
Bream/bass	97	58	60	240	72	30
Carp	300	45	15	1040	52	5
Yellow tail	70	42	60	90	27	30
Catfish	530	22	4	1218	12	1
Others	337	61	18	820	88	11
Total	3573	1084	30	8663	1506	17

Source: Dudley-Cash (1998)

Table 1 shows the use of fish meal by species in 1994 and estimated fish meal use in 2010. It is predicted that, generally, aquaculture feeds will use lower levels of fish meal. To meet the high dietary protein requirement of fish, alternative protein sources will be used in fish feed as replacement of fish meal.

ALTERNATIVE PROTEIN SOURCES

Animal proteins such as poultry by-product, meat and bone meal has been used to replace fish meal in fish feed. Animal proteins are good protein sources with low price, which can be used to partially replace fish meal. However, due to the occurrence of BSE, consumers are questioning feeding practices based on the use of animal proteins as raw materials in animal feed. In some countries, animal proteins are banned in animal feed. Therefore, future development of animal feed goes towards a vegetable based formulation.

Plant ingredients which contain high protein content, such as oil seeds, are alternative protein sources for fish meal. These ingredients are readily available worldwide and with a low cost. However, plant proteins in general are low in some essential amino acids and containing anti nutritional factors (Table 2). Therefore the inclusion levels of raw or under processed plant materials are limited in fish feed. On the other hand, the proper processed plant ingredients, containing high protein content and with high digestibility of crude protein and low anti-nutritional components, are potential alternative protein sources for replacement of fish meal in fish and shrimp diets.

Table 2 Nutritional values of common protein ingredients in fish diets (data on as fed basis, NRC, 1998).

	Fish meal menhaden	Soy protein concentrate[1]	*Soybean meal*	*Potato protein*	*Sunflower meal*	*Corn gluten meal*	*Cottonseed meal*
Composition %							
Dry matter	92	93	89	91	93	90	90
Crude protein	62.9	65	44	73.8	42.2	60.2	41.4
AA composition %							
Lysine	4.81	4.23	2.83	5.83	1.17	1.02	1.72
Methionine	1.77	0.91	0.61	1.68	0.66	1.43	0.67
Met & Cys	2.34	1.89	1.31	2.88	1.35	2.52	1.37
Threonine	2.64	2.73	1.73	4.3	1.28	2.08	1.36
Isoleucine	2.57	3.19	1.99	4.09	1.69	2.48	1.3
Tryptophan	0.66	0.78	0.61	1.02	0.54	0.31	0.48
Arginine	3.66	4.94	3.23	3.8	3.59	1.93	4.55
Phenylalanine	2.51	3.45	2.18	4.89	2	3.84	2.2
Valine	3.03	3.38	2.06	4.89	2.33	2.79	1.78
Histidine	1.78	1.82	1.17	1.71	1.07	1.28	1.17
Leucine	4.54	5.2	3.42	*7.61*	2.57	10.19	2.47
Anti nutritional factors							
	Biogenic amine dioxin	Very low	Protease inhibitors, allergens, oligosacch arides, lectins, saponin	Solanidine glyco alkaloids (solanine, chaconin), sulfite	Chlorogenic acid, fiber	Mycotoxins (high xanthophylls)	Gossypol, cyclopropenoid fatty acids, tannins

1, Using Soycomil FG as an example, a soy protein concentrate produced by ADM Europoort B.V, Rotterdam, The Netherlands.

Among oil seeds produced, soybean meal contributes more than 50% of the production (see Figure 1).

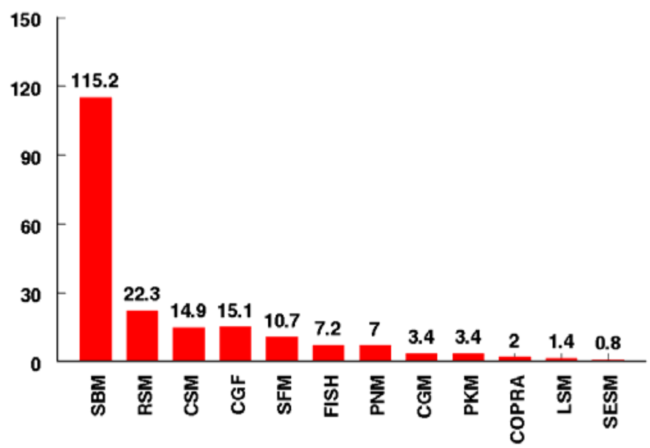

Figure 1. World production of protein meals in 2000, million metric tones. SBM - Soybean meal; RSM – Rapeseed meal; CSM – Cottonseed meal; CGF – Corn gluten feed; SFM – Sunflower meal; Fish – Fish meal; PNM – Peanut meal; CGM – corn gluten meal; PKM – Palm kernel meal; LSM – lupin seed meal; SESM – Sesame meal. Source: Oilwords Statistics, 2000.

NUTRITIONAL VALUE OF SOYBEAN MEAL (SBM)

Soybean meal (SBM) is considered as the most nutritive plant ingredients widely used in pig, poultry and fish feed. Among plant protein ingredients, soybean meal has well balanced amino acid profile. Furthermore, SBM has the advantage of being resistant to oxidation and spoilage and is naturally clean from organisms such as fungi, viruses and bacteria that are harmful to shrimp and fish (Swick et al. 1995). SBM can be used to partially replace fish meal or animal protein in fish and shrimp diets. In general, however, at high replacement levels the growth rates of fish and shrimp are reduced. The growth depression effect of soybean meal at high inclusion levels may be related to the anti-nutritional components presented in SBM, as illustrated in Table 2.

It has been observed in many fish species that anti-nutritional components in SBM, such as trypsin inhibitor, antigens, lectins, saponins and oligosaccharides, can have negative effect on digestibility of nutrients and performance of fish.

1.- Trypsin inhibitor

Literature studies showed that soybean trypsin inhibitor activity is negatively correlated with digestibility of protein and lipid and growth rate in salmon (Olli et al. 1989), rainbow trout (Sandholm *et al*., 1976), carps (Viola *et al*., 1983, Abel *et al*., 1984), Nile tilapia (Wee & Shu, 1989) and channel catfish (Wilson & Poe, 1985). Alarcon *et al*. (1999) observed that sea bream alkaline digestive proteases was inhibited by 42.6% after incubation of extract with solution containing raw soybean meal. Wilson & Poe (1985) observed that best growth of channel catfish occurred when 83% (e.g. 3.2 g TI/g diet) of the trypsin inhibitor activity in the soybean meal had been destroyed (see Figure 2).

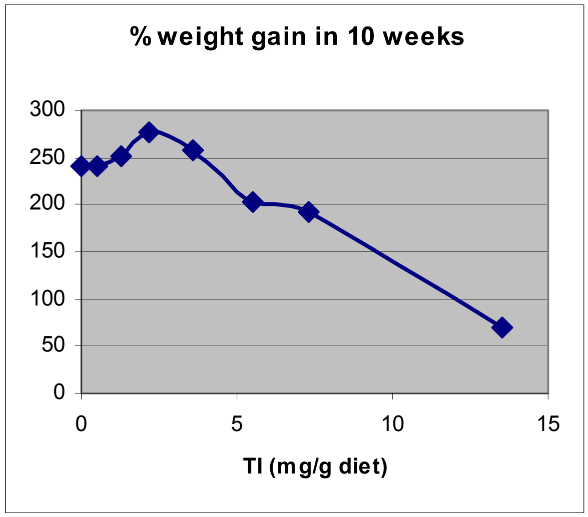

Figure 2, The relationship between trypsin inhibitor activity (TI) and growth performance of channel catfish (Wilson & Poe, 1985).

2).- Lectins

Letcins can cause morphology changes in the intestine and therefore reduce the absorption of nutrients. Hendriks *et al*. (1990) demonstrated the high sensitivity of the distal small intestine to the toxic effect of soybean lectin in Atlantic salmon.

3).- Oligosaccharides

Soybean meal contains approximately 15% of oligosaccharides (sucrose, raffinose and stachyose). Oligosaccharides can have a negative effect on nutrient utilization in fish. It was reported removing of oligosaccharides from SBM significantly improved the utilization efficiency of nutrients in salmon and rainbow trout (Murai *et al*., 1987; 1989, cited by Krogdahl, 1989). Arnesen *et al*. (1989) found that alcohol soluble carbohydrate from SBM had a negative influence on digestibility of protein and lipid in salmon and in trout (tendency). For both species, alcohol soluble carbohydrate showed a negative effect on fecal dry matter content.

4).- Soy antigens

Soy antigens can cause allergic response of animals and lead to intestinal damage. Rumsey *et al*. (1994) found that trout fed diet containing high levels of the globular antigenic proteins glycinin and β-conglycinin from SBM had inferior growth performance, impaired utilization of dietary protein and intestinal pathology.

Figure 3 illustrates that fish fed full-fat SBM based diet showed damaged epithelium, with an increased number of goblet cells and a marked decrease or even absence of absorptive vacuoles. The microvilli of the enterocytes were shortened, with increased microvillar vesicle formation (van den Ingh *et al*., *1991)*. Whereas fish received soy protein concentrate based diet have normal, healthy intestinal structure, which is comparable to the fish received fish meal diet. The authors suggested that these changes might be due to the presence of anti nutritional factors in full-fat soybean meal diet. It was observed that fish fed soybean meal based diet caused enteritis-like changes in the distal intestine in Atlantic salmon (Baeverfjord & Krogdahl, 1996; Krogdahl *et al*., 2000; Refstie *et al*., 2001) and in rainbow trout (Bureau *et al*., 1998) and caused an altered immune response (Rumsey *et al*., 1994; Bakke-McKellep *et al*., 2000) and might lead to increased susceptibility to furunculosis (Krogdahl *et al*., 2000).

The alcohol-extract of SBM (soybean molasses) has been found to cause the enteritis-like changes (van den Ingh *et al*., 1996; Krogdahl *et al*., 2000) and correspondingly alcohol-extracted soy protein concentrate has been found to be of high nutritional value in salmonid diets (Olli & Krogdahl, 1994).

5).- Saponins

Soyasaponins can contribute an undesirable taste and may alter intestinal functions. The presence of soyasaponins in soy products is highly dependent on the mode of preparation. Soybean meal and soy flour contain between 0.43-0.67% soyasaponins (Ireland *et al*., 1986). Saponins can be carried over with the protein during extraction in water, therefore, soy protein concentrate and isolate produced by extraction with water alone may contain high levels of saponins. It was found that a soy isolate (90% cp) contained 0.8% of saponins (Ireland *et al*., 1986). Soy protein concentrates produced by alcohol extraction are devoid of saponins since alcohol is a 'bond-breaker' and helps to remove saponin from proteins (Bureau *et al*., 1998). It was reported that a purified alcohol extracts from soybean meal and soy protein isolate (prepared by an extraction process aiming at the isolation of soyasaponins) depressed feed intake and growth dramatically in Chinook salmon and depressed growth of rainbow trout (Bureau *et al*., 1998). The authors suggested that soyasaponins was responsible for the effect of the extract used in this study. Saponins in water are highly toxic to fish because of the damage caused to the respiratory epithelium of the gills by the detergent action of the saponins (Francis *et al*., 2001).

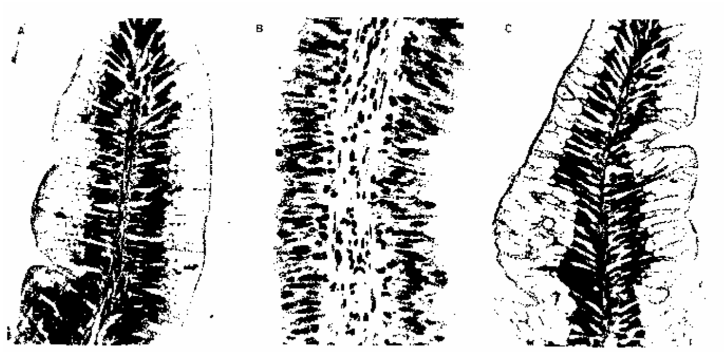

Figure 3. Simple fold from distal intestine of Atlantic salmon. a, fish received fish meal diet; b, fish received full-fat soybean meal diet; c, fish received soy protein concentrate diet. (van den Ingh et al., 1991)

It was observed that soy protein isolate, which is produces by aqueous solubilization and isoelectric precipitation of protein from soy flakes, appears to depress feed intake in similar manner as soybean meal in Chinook salmon (Hajen *et al*., 1993). Since soy protein isolate contains very low levels of antitrypsin factors, lectins and oligosaccharides, it indicated that heat stable, alcohol-soluble factors appear to be responsible for the depression of feed intake in salmon and may be also in other fishes.

NUTRITIONAL VALUE OF SOY PROTEIN CONCENTRATE (SPC)

The amino acid profile in fish meal in general reflects dietary amino acids requirement of fish. Compared to fish meal, soy protein concentrate (SPC) has balanced amino acids profile (see Table 2).

Table 3 presents an example of amino acids provided by SPC at a dietary protein level of 30%. Assuming using SPC as sole protein source in fish feed, the essential amino acids provided by SPC meet very well the dietary requirement of channel catfish, common carp and tilapia. For rainbow trout, methionine concentration in the diet may need to be balanced by other protein ingredients or synthetic amino acid.

Table 3, Essential amino acids composition of SPC and requirement of fish (% of diet)

	SPC[1] (cp 65%) % as is	SPC % at 30% protein level	Requirement[2] Channel catfish	Rainbow trout	Common carp	Tilapia
Arginine	4.94	2.3	1.2	1.5	1.31	1.18
Histidine	1.82	0.8	0.42	0.7	0.64	0.48
Isoleucine	3.19	1.5	0.73	0.9	0.76	0.87
Leucine	5.2	2.4	0.98	1.4	1	0.95
Lysine	4.23	2.0	1.43	1.8	1.74	1.43
Met + Cys	1.89	0.9	0.64	1.0	0.94	0.9
Phe + tyr	3.45*	1.6*	1.4	1.8	1.98	1.55
Threonine	2.73	1.3	0.56	0.8	1.19	1.05
Tryptophan	0.78	0.4	0.14	0.2	0.24	0.28
Valine	3.38	1.6	0.84	1.2	1.10	0.78

1, Soycomil FG, ADM Europoort bv, Rotterdam, The Netherlands; 2, NRC, 1993
*, Only phenylalanine

Mambrini *et al*. (1999) showed that supplementation of 75% of dietary protein by a soy protein concentrate (Soycomil) as replacement of fish meal resulted in similar amino acids digestibility compared to using pure fish meal as protein source in fish feed. Berge *et al*. (1999) reported that partially replacement of fish meal by Soycomil in fish feed resulted in similar digestibility in nitrogen, fat and organic matter as shown in Table 4.

Table 4, Apparent digestibility coefficients (%) in Atlantic halibut fed a feed containing fish meal (fish meal diet) or a feed with 44% of dietary protein supplied by SPC (Soycomil diet). (Berge *et al*. 1999).

	Fishmeal diet	Soycomil diet
Nitrogen	83.7	85.5
Fat	96.8	96.9
Organic matter	80	78.4

Digestibility of dry matter, crude protein and energy for SPC is improved compared to soy flour and soybean meal (Refstie *et al*., 1999; Kaushik *et al*., 1995, Figure 4).

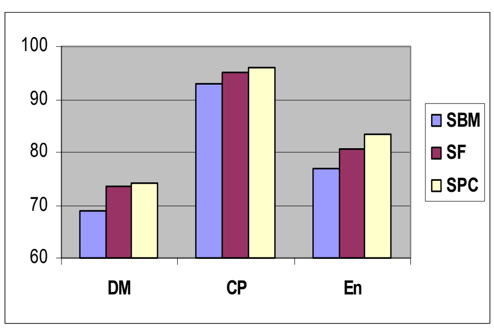

Figure 4 apparent digestibility coefficients (%) of dry matter (DM), crude protein (CP) and energy (En) for SBM, soyflour (SF) and SPC in rainbow trout. (Kaushik et al., 1995).

The anti-nutritional components have been removed during the processing procedure of SPC (see Table 5). Consequently using SPC as protein source will assure a healthier animal and better growth performance of fish compared to using soybean meal as protein source in fish and shrimp diets.

Table 5, Anti-nutritional components in SBM and SPC (Peisker, 2001).

	Soybeans	Soybean meal	Soy protein concentrate[1]
Trypsin inhibitor (mg/g)	45-50	1-8	**2**
Glycinin antigen (ppm)	180.000	66000	**<3**
Lectin (ppm)	3.500	10-200	**<1**
Oligosaccharides%	14	15	**2**
Saponin	0.5	0.6	**0**

1, Using Soycomil as an example.

PERFORMANCE DATA WITH SBM AND SPC

Literature studies showed that 40-100% of dietary protein from fish meal could be replaced by soy protein concentrate (SPC) without negative influence on growth performance. Whereas replacing fishmeal by soybean meal (SBM) or soy flour at high inclusion levels, in general, reduced growth rate.

Bureau *et al*. (1998) reviewed studies from Murai *et al*., 1989; Shimeno *et al*., 1992; Olli *et al*., 1994 and Kaushik *et al*., 1995 on soy protein and indicated that the soy protein concentrate, produced mostly through aqueous ethanol extraction of defatted soy flakes, are more acceptable or support better growth than soy flour or soybean meal for salmonids and other fishes.

The effect of SBM and SPC on growth performance of shrimp and fish are demonstrated by the following examples.

In shrimp*:* it was observed that 40% of fish meal could be replaced by a soy protein concentrate without negative influence on growth rate (Hamlet protein, 1997 as cited by Peisker, 2001). Liu *et a*l. (2000) showed that inclusion of 8% of a soy protein concentrate (Soycomil) as replacement of 22% of fish meal in shrimp diet increased weight gain by 17% during 60 days testing period in tiger shrimp (*Penaeus monodon*). Fenucci *et al*. (cited by Swick *et al*., 1995) replaced 50% of squid meal with a purified soy protein and obtained better growth, survival and feed conversion ratio in *P. setiferus* and *P. stylirostris*. However, Lim & Dominy (1990) observed that more than 40% of replacement of animal protein by SBM (> 28% of inclusion) reduced growth rate of shrimp (*P. vannamei*) significantly. Studies showed that there were species differences and size differences in the ability of marine shrimp to nutritionally utilize soybean protein (Akiyama, 1988a). *Penaeus vannamei* had good growth performance with a diet containing 75% of soybean meal, whereas *P. duorarum* had lower tolerance level to soybean meal (30%). In general, small shrimps were more sensitive to the level of soybean meal in the diets as compared to larger shrimps (Akiyama, 1988a). It was suggested that a 25-30% of dietary level of SBM as replacement of 40-50% of the marine animal protein in shrimp feeds appear optimum (Swick *et al*., 1995).

In rainbow trout: Mambrini *et al*. (1999) demonstrated that a soy protein concentrate (*Soycomil)* could replace 50% of dietary protein from fish meal in rainbow trout (106 g), during a 90 days testing period. The mean final body weight of fish was 441.8 and 453.4 g in fish groups fed fish meal and SPC based diet respectively. Kaushik *et al*. (1995) reported that replacement of fish meal with SPC (33 to 100% replacement) did not affect growth performance or nutrient utilization. However, replacement of fish meal with soyflour (up to 50%) reduced final body weight by 8% (see Figure 5). In this study, rainbow trout with initial body weight of 83g were tested for a 12 weeks feeding period. Médale *et al*. (1998) observed that up to 75% of dietary protein from fish meal could be replaced by SPC without negative influence on voluntary feed intake and growth of trout fed with demand feeders. However, 100% replacement of fish meal by SPC reduced growth rate of fish. Similar results were obtained by Stickney et al. (1996), trout fed a diet with 50% of protein from SPC as replacement of fish meal grew as well as the fish fed fish meal diet (weight increase of 604 and 607% respectively). However, 70 to 100% replacement reduced growth rate of trout.

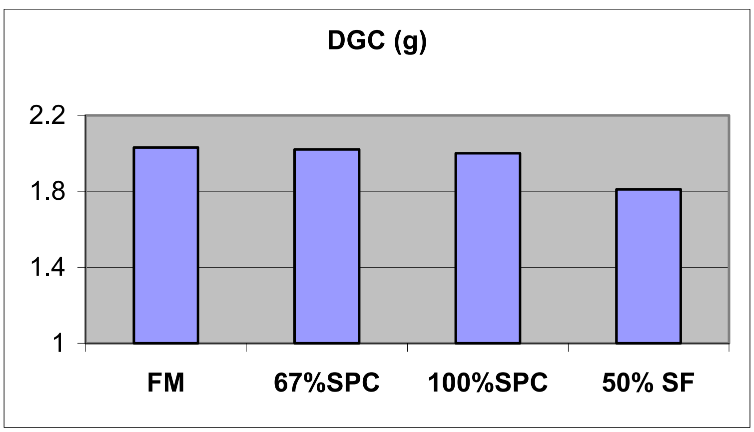

Figure 5 Daily growth coefficient (DGC = 100* ($FBW^{0.3333}$-$IBW^{0.3333}$)/duration) in rainbow trout (83 g) fed experimental diets with 1, fish meal (FM), 2, 67% of dietary protein from SPC (67% SPC), 3, 100% of dietary protein from SPC and 4, 50% of dietary protein from soy flour (SF). From Kaushik *et al*. (1995)

Vielma *et al*. (2000) reported that in a feeding trial with trout from 0.25 to an average body weight of 2.02 kg, fish fed a diet containing 69% of the protein from soy ingredients (55.6% from SPC and 13.8% from SBM) grew significantly faster than fish fed fish meal based diet. Whereas Olli & Krogdahl (1994) and Pfeffer & Henrichfreise (1994) reported no growth reduction by fish meal replacement for SPC, at a replacement level of 100% and 56% respectively. With soybean meal, however, Dabrowski *et al*. (1989) reported that the growth rate of rainbow trout fry was reduced significantly when 50% of the fish meal was replaced by soybean meal, and 100% replacement resulted in severe growth depression and mortality.

In Channel catfish**:** Wilson & Poe (1985) reported that during a 10 weeks feeding trial, the growth rate of channel catfish was reduced in fish fed raw or inadequently heated soybean meal. Reducing trypsin inhibitor activity improved the growth performance of the fish. However, the growth rate of catfish fed proper heated soybean meal was lower compared to the growth rate of the fish fed a purified diet at a similar dietary protein level. The authors indicated that the diets were not deficient in any of the 10 essential amino acids, implying that the reduced growth rate might be related to heat stable anti-nutritional factors. Similar results were observed by Andrews and Page (1974), when soybean meal was substituted on an isonitrogenous basis for menhaden meal, growth and feed efficiency in channel catfish were reduced.

In Atlantic halibut**:** Berge *et al.* (1999) observed that replacement of 44% of dietary protein from fish meal by a soy protein concentrate (Soycomil) numerically increased feed intake and growth rate in Atlantic halibut during 12 weeks testing period. The final body weight was 864 and 877 g in fish fed fish meal and SPC based diets respectively.

In Atlantic salmon: Refstie *et al*. (1998) examined three dietary protein sources (e.g. fish meal, 40% of dietary protein from SPC or SBM) on growth performance of Atlantic salmon (107g) for 55 days. The specific growth rate (SGR) was 1.69, 1.59 and 1.31 during first 28 days and 1.16, 1.19 and 1.00 during day 29 to 55 for salmon fed fish meal, SPC and SBM diets respectively. Feed intake followed same pattern. Feed conversion (g feed intake/g weight gain) was significantly higher in SBM diet compared to fish meal and SPC diets. The authors suggested that SBM contained some heat stable anti-nutritional factors that depressed feed intake and growth of Salmon. Apparently, these factors were eliminated in SPC. Brown *et al*. (1997) reported that inclusion of 30% of a soy protein concentrate as replacement of fish meal in salmon diet resulted in a similar growth rate of salmon compared with the group fed fish meal based diet (381.1 vs 386.2 g of weight gain respectively in 56 days period). At 10% soy protein concentrate inclusion level, the growth rate of salmon was higher than the group fed fish meal based diet (444.7 vs 386.2 g of weight gain respectively in 56 days period). Storebakken *et al*. (1998, 2000) replaced 75% of dietary protein from fish meal by a soy protein concentrate (Soycomil) in salmon diet. They concluded that SPC was equivalent to fish meal as a source of dietary protein for Atlantic salmon, based on performance results during a 84 days testing period. Similarly, on comparison of four soybean products (solvent-extracted soybean meal, dehulled and solvent-extracted soybean meal, dehulled full-fat soybean meal and soy protein concentrate), Olli *et al*. (1994) concluded that nutritive value of the SPC appeared comparable to that of fish meal. Whereas the three other soybean products impaired performance of salmon increasingly with increasing levels of inclusion, indicating lower nutritive value than for the fish meal. Through improved processing, soy protein can be used as an important protein source for salmon diet. Similarly, Fowler (1980) reported that inclusion of full-fat soybeans (17.5-48.9%) in the diets fed to chinook salmon markedly reduced weight gain and increased mortality.

***In seabream*:** Kissil *et al*. (2000) reported that 30% of dietary protein from fish meal replaced by a soy protein concentrate did not significantly influence feed intake in seabream. However, 60% and 100% replacement reduced feed intake significantly. In this study, the lipid content was higher in 60% and 100% SPC replacement diets, this may explain the reduced feed intake. Furthermore, methionine was not balanced between treatment diets. The study of Robaina *et al.* (1995) showed a general reduction of weight gain with increasing inclusion levels of soybean meal from 10 to 30%. The authors suggested that some other anti-nutritional factors such as oligosaccharides other than trypsin inhibitors might limit the use of high level of soybean meal in the diet.

In carps: With first-feeding common carp larvae, Escaffre *et al*. (1997) reported that incorporation of SPC up to 40% in the diet did not adversely affect survival or growth of carp larvae. However, Dabrowski & Kozak (1979) found that the growth of grass carp fry was depressed when the content of soybean meal in the diet was increased, despite the addition of deficient amino acids.

Viola *et al*. (1983) observed that soybean meal containing high level of trypsin inhibitor activity reduced growth rate of fish fingerlings (25-40g). The authors concluded that the limiting factor for the growth of carp in properly processed commercial soybean meals was not the residual antitrypsin, but inadequente lysine. Viola *et al*. (1982) showed a linear decrease in relative weight gain of carp in cages with increasing soybean meal inclusion levels. With supplementation of methionine, lysine and oil in soybean meal based diets, the same growth rate as in control group was obtained. Addition of essential amino acid supplementation to the diets containing soy flour significantly improved growth of carp (Murai *et al*. 1986). However, the authors reported that treatment of soy flour with methanol did not significantly affect the performance of fish. The authors suggested that carp might be less sensitive to the appetite-suppressing factors in soybean products than other fish species.

***In tilapia*:** Jackson *et al*. (1982) showed that 25% of dietary protein from fish meal could be replaced by soybean meal without significantly influence growth performance of tilapia during 7 weeks feeding trial. At higher SBM inclusion levels, however, the growth rate of fish was lower (up to 33% decrease at 100% replacement) compared to control group. The authors indicated that the low methionine level as well as the incomplete denaturing of the trypsin inhibitor and haemagglutinins during treatment of the meal might contribute to the inferior growth rate of fish fed a diet with high soybean meal inclusion level. The similar depression in growth of T. *aurea* by replacement of fishmeal with SBM was also observed by Davis & Stickney (1978) and Wu & Yan (1977), as cited by Jackson *et al*. (1982). Shiau *et al*. (1987) observed that without methionine supplementation, fish meal could be partially (30%) replaced by SBM when the dietary protein level was sub-optimal (24%) for tilapia growth. However, at an optimal dietary protein level (32%), partial replacement (30%) of fish meal protein with SBM depressed growth of tilapia.

The replacement of fish meal by SPC can have also positive effect on environment. It was observed that inclusion of SPC in the diet reduced P losses and improved P retention in trout (Médale *et al*., 1998) and in salmon (Storebakken *et al*., 2000). Trout fed soybean meal diet had reduced fecal dry matter content, indicating diarrhoea. Whereas the trout fed SPC diet had constantly high fecal dry matter content (Olli & Krogdahl, 1994).

These studies demonstrate that soy protein concentrate can be used as a good alternative protein source as replacement of fish meal in fish feed and as replacement of marine animal protein in shrimp feed.

DISCUSSION AND IMPLICATION

Regarding to the use of soy protein in fish feed, different results were obtained in different studies, this may be related to the following aspects: 1), the quality of soy products: the nutritional values of soy products are closely related to the processing procedures. In most of the studies, the anti nutritional components were not analyzed, leading to a difficulty in evaluating the relationship between the quality of soy products and growth performance of animals. 2), the nutritional balance in the diets: different studies using different diet formulation, this will lead to a difference in AA profile and essential fatty acids composition. The reduced performance observed in some studies may be related to nutrients imbalance. For example, at high SPC inclusion level, methionine requirement should be considered and met by addition of methionine rich ingredient or synthetic methionine. The limiting of methionine may partially explain the reduced growth at high soy protein inclusion levels as observed in some studies. 3), the age of fish. Young animals are more vulnerable to dietary anti nutritional components those can have negative influence on digestion than older animals. Therefore, only the best ingredients with low anti-nutrients should be used in starter diets, assuring healthier and higher growth rate.

In fish, SBM may be used to partially replace fish meal in the diets. However, high inclusion level (>30%) of SBM could cause intestinal damage and in general reduce growth performance in different fish species. It appears that carnivorous fish species such as salmon and trout are more sensitive to the anti-nutritional components in SBM than herbivorous or omnivorous species such as carp. In general, however, soy protein concentrate has been proved to have better nutritional value and produced better growth performance in fish compared to soybean meal. Partial replacement of fish meal by SPC can be expected to have economical benefit due to the better growth performance as illustrated by the literature studies. Furthermore, using SPC in fish feed can assure a healthy status of fish whereas using SBM in fish feed may cause altered immune response and susceptible to pathogens. In addition, it was reported that application of SPC in extruded salmon feed pellets improved pellet durability, fat absorption, fat leakage, sinking rate and water holding capacity (Herzog Møller *et al*., 2002).

In shrimp, partial replacement of fish meal or marine animal protein by SPC resulted in better growth performance, indicating an economical profit. Small size shrimps are more sensitive to anti-nutritional components in SBM than large size shrimps. For small size shrimps, therefore, SPC can be a good alternative protein source for marine animal protein due to the high nutritional values of SPC as characterized by high digestibility of amino acids and low anti-nutritional components. For large size shrimps, it can be expected that a combination of SPC and SBM can be used to replace higher amount of marine animal protein in the diets. More researches are needed to ascertain these aspects.

When using soy protein to replace fish meal or marine animal protein, the nutritional balance in the diet should be considered, including amino acids, fatty acids, energy and minerals. Fish meal and marine animal protein meals generally contain more fat and minerals than soy protein. At high soy protein inclusion levels, a mineral supplementation is recommended. Phosphorous is the most critical mineral when formulating fish feeds which contain a high level of soy protein (Akiyama, 1988b). Soy protein concentrate contains 0.8% of phosphorous, however, a considerable amount of phosphorous is bound in phytic acid and unavailable in fish. The supplementation of inorganic P in fish diet is recommended at high SPC inclusion levels. Furthermore the amino acid and energy requirement should be considered. For instance, methionine concentration in the high SPC inclusion diet should be balanced.

To achieve a balanced nutritional composition in fish feed, a more divers choice should be made in selecting feed ingredients. A mixture of feed ingredients will provide more balanced nutrients than only use limited feed ingredients to formulate fish feed.

In conclusion, soy protein concentrate can be used as an excellent protein source for fish and shrimp diets, as alternative to fish meal and marine animal protein meal.

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