THE USE OF SOY PRODUCTS AND OTHER PLANT PROTEIN SUPPLEMENTS IN AQUACULTURE FEEDS

by
DEAN M. AKIYAMA
American Soybean Association
541 Orchard Road, # 11-03
Liat Towers
Singapore

Aquaculture feed production worldwide is expanding rapidly. In Asia alone, this feed sector has increased from 980,000 MT to 2,500,000 MT from 1986 to 1989. This relatively new, immature, and highly profitable market is the fastest growing of all animal feed markets.

Traditionally, animal protein supplements were the foundation of any aquaculture feed formulation. However, given the limited world supplies and the increasing price of these animal protein supplements aquatic nutritionists are considering alternative protein sources. This trend will be further emphasized as these aquaculture feed markets mature, thereby increasing competition and decreasing profit margins. Plant protein supplements are generally cheaper per unit of nutrient as compared to the animal protein supplements. The increased use of plant protein supplements in aquaculture feeds will be dependent on reliable nutrition research.

There are limitations in our knowledge of nutrition of aquatic species. The comparison of various nutritional studies are complicated by differences in research methodology such as size and physiological state of the animal, diet composition and processing environmental conditions, and experimental facilities. The reliability of data is also dependent on growth rate, survival rate, and feed conversion ratios.

Current aquaculture feed formulations are based on intuition and "unknown growth factors", rather than nutritional science. Animals do not require feed ingredients or formulas, but rather the nutrients which are part of the chemical composition of these ingredients and feed formulas. Therefore, a feed formula is meaningless if we don't understand the nutritional principles involved in formulating the feed. In general, plant protein supplements are lower in some essential amino acids, energy, and minerals such as phosphorous as compared to animal protein supplements. These parameters need to be considered in feed formulations based on plant proteins.

The purpose of this paper is to discuss the nutritional value of plant protein supplements.

AVAILABILITY OF NUTRIENTS

The availability of nutrients from a feed ingredient is essential in determining the nutritional value of the feed ingredient. A nutrient may be present, however, if it is unavailable to the animal, its presence is nutritionally meaningless. A major limitation in aquaculture nutrition is the lack of nutritional availability data for feed ingredients for the different aquatic species.

Protein and essential amino acids:

Protein and essential amino acid digestibility by marine shrimp and channel catfish for common feed ingredients are presented in Table 1 (Akiyama et al., 1988; Robinson and Wilson, 1985). Protein digestibility of these ingredients range from 74.6% to 89.9% and 74.0% to 87.0% for shrimp and catfish, respectively. In shrimp, soybean meal had a higher protein digestibility value as compared to fish meal, squid meal, and shrimp meal. The protein digestibility was higher by 10%, 11%, and 17% as compared to fish meal, squid meal, and shrimp meal, respectively. A misconception of many nutritionists is that animal proteins are more digestible than plant proteins.

Protein digestibility does not always reflect essential amino acid digestibility. In marine shrimp, shrimp meal had a protein digestibility of 74.6% (Table 1). However, all of the essential amino acids had higher digestibility values which ranged from 75.4% to 85.7%. Lysine, arginine, and threonine had digestibility values of 85.7%, 81.8%, and 83.7%, respectively. The lower protein digestibility was related to the analytical methods for determining protein digestibility and its relationship to chitin which is relatively undigestible. In channel catfish, this contention is most evident in soybean meal and peanut meal. Soybean meal had a protein digestibility of 77.0% with essential amino acid digestibilities ranging from 78.7% to 96.7%. Lysine, arginine, threonine, and methionine had digestibility values of 94.0%, 96.7%, 81.9%, and 84.6%, respectively. Peanut meal had a protein digestibility of 74.0% with essential amino acid digestibilities ranging from 89.5% to 97.8%. Lysine, arginine, threonine, and methionine had digestibility values of 94.4%, 97.8%, 93.1%, and 90.5%, respectively. Therefore, in feed formulations, available amino acid values should be utilized rather than total or digestible protein.

In catfish, lysine, arginine, and methionine availability were higher in soybean meal and peanut meal as compared to fish meal (Table 1). In shrimp, all of the essential amino acids measured were higher in availability in soybean meal as compared to fish meal, squid meal, and shrimp meal. Plant protein utilization in aquaculture feeds would be enhanced if feeds were formulated on available rather than total amino acid values.

Energy:

Plant protein supplements are considerably lower in energy as compared to fish meal (Table 2). The balance of protein and energy is essential in the formulation of efficient feeds. As plant protein supplements replace animal protein supplements in feed formulation, energy values need to be monitored.

A plant protein supplement high in available energy is fullfat soybean meal (FFSBM). FFSBM has a metabolizable energy value of 96% than that of fish meal in rainbow trout (Table 2). The oil content of FFSBM is relatively stable due to the high levels of naturally occurring tocopherols (Holmes, 1988). Raw soybeans contain several antinutritional factors which affect animal growth and performance (Rackis, 1972; Liener, 1975). However, it is well documented that the heat treatment of raw soybeans improves its utilization. Smith (1988) reported that for maximum metabolizable energy in rainbow trout, soybeans should be processed at a minimum of 175° C.

Phosphorous :

A common oversight of aquaculture feeds formulated with high levels of plant protein supplements is available phosphorous content. It is generally believed that phosphorous availability is considerably less in plant versus animal products and differs significantly by species. Phytic acid found in plant products binds phosphorous as well as other minerals lowering their availability (National Research Council, 1983). Phytate bound phosphorous has availability values in channel catfish, red seabream, rainbow trout, and common carp of 0%, 0%, 0-19%, and 8-38%, respectively (Andrews et al., 1973; Ogino et al., 1979; Sakamoto and Yone, 1979). However, phosphorous availability, considering all forms of phosphorous in soybean meal for channel catfish and marine shrimp are 50% and 40%, respectively (Table 3). Phosphorous availability values for other plant protein supplements are unavailable.

In aquaculture. feed formulations, cost per unit of available phosphorous should be considered. For example, total phosphorous in a Kg of mono-basic and dibasic forms of calcium phosphate are similar at 210 gm and 190 gin, respectively. Given the availability values for common carp of 94% and 46%, available phosphorous in the mono-basic and dibasic forms would be 197 gin and 87 gin, respectively. Di-calcium phosphate is cheaper per Kg than mono-calcium phosphate, however, the available phosphorous content is only 44% of the latter. In feed formulations containing high levels of plant protein supplements, available phosphorous needs to be considered and phosphorous supplements are usually added.

FEED FORMULATIONS AND CHEMICAL COMPOSITIONS WITH COMMERCIAL APPLICABILITY

Good quality feeds are dependent on the chemical composition (nutrients), ingredient quality, and processing technology. The chemical composition of feeds is in turn dependent on the formulation. All of these factors are essential and interdependent. Little is known about ingredient quality standards while most published information is on chemical composition or nutrition.

This lack of information is reflected in the feed industry where ingredient quality is the major limitation on the consistent production of good quality feeds. Feed Processing limitations restrict efficient feed production and formulation flexibilities. Approximate nutritional requirements of aquatic species are readily available however, the nutritional composition of commercial feeds usually exceed the animals' requirements. If greater emphasis was placed on nutritional principles rather than formulations, feeds would cost less without sacrificing animal performance.

Channel catfish:

Channel catfish feed formulations are fairly consistent in the U.S. Model channel catfish feed formulations and chemical compositions are presented in Tables 4-5 (Robinette, 1984). Plant proteins comprise 82.4%, 84.9%, and 76.6%, of the total protein of the starter feed and both grower feeds, respectively. These plant proteins were supplemented primarily from soybean meal and peanut meal with animal protein being supplemented by fish meal and meat & bone meal. Feed cost, production levels, and feed conversion ratios of commercial channel catfish farms are approximately US$350.00/MT, 5 MT/ha, and 1.6, respectively. Therefore, feed cost per kg of channel catfish produced is US$0.56.

Common carp:

Two common carp feed formulations and chemical compositions are presented in Tables 6 - 7 (Akiyama, unpublished data). Plant proteins comprised 78.3% and 56.4% of the total protein of feeds A and B, respectively. These plant proteins were supplemented primarily from soybean meal with animal proteins being supplemented by fish meal.

These feeds were fed to common carp in floating cages at stocking densities of 5 kg/m^3 and 10 kg/m^3. After 59 days, there were no differences in growth rates, survival rates, and feed conversion ratios between the plant protein and animal protein based feeds (Table 8). These measured parameters were well within acceptable standards.

Rainbow trout:

Two rainbow trout feed formulations and chemical compositions are presented in Tables 9 - 10 (Smith et al., 1988). Plant proteins comprised 74.8% and 33.1% of the total protein of feeds A and B, respectively. These plant proteins were supplemented primarily from full-fat soybean meal, cottonseed meal, and corn gluten meal with animal proteins being supplemented by fish meal and blood flour.

These feeds were fed to 10 different strains of rainbow trout. In experiment I, the high plant protein feed took longer to reach final weight and had a higher feed conversion ratio as compared to the animal protein feed (Table 11). In experiment II, there were no differences between feeds for these parameters.

The primary consideration of any farmer is profitability. A simple economic comparison of these feeds is presented (Table 12). In experiment I, though feed conversion ratio of the plant protein feed was higher, the feed cost per kg of fish produced was lower by 8.5%. In experiment ii with similar feed conversion ratios, the feed cost benefit was improved by 16.7%. Therefore, the cost effectiveness of the plant protein feed was better than the animal protein feed for the production of rainbow trout.

Marine shrimp:

Two marine shrimp feed formulations and chemical compositions are presented in Tables 13-14 (Akiyama and FSGP Aquaculture Research, 1990). Plant proteins comprised 72.2% and 50.3% of the total protein of the feeds, A and B, respectively. These plant proteins were supplemented primarily from soybean meal and wheat products with animal proteins being supplemented by fish meal, squid meal, and shrimp meal.

These feeds were fed to Penaeus monodon in outdoor concrete tanks at a stocking density of $30/m^2$ (Table 15). After 42 days, there were no differences in growth rates, survival rates, and feed conversion ratios between the plant protein and animal protein based feeds. These measured parameters were well within acceptable standards.

SUMMARY

The commercialization of aquaculture is growing, thereby increasing the demand for aquaculture feeds. Traditionally, these feeds have been based on animal protein. However, due to cost and availability considerations, it is inevitable that more plant protein supplements will be utilized in the feeds. Plant protein supplements are a more cost effective source of nutrients as compared to animal protein supplements. The increased acceptability and utilization by the feed industry will be dependent on reliable nutrition research.

All plant protein supplements are being used to some extent in aquaculture feeds. Of all plant protein supplements, soybean meal has been the most extensively evaluated and most commonly used in commercial aquaculture feeds.

REFERENCES

Akiyama, D.M.7S.R. Coelho, A.L. Lawrence, and E.H. Robinson. 1988. Apparent digestibility of feedstuffs by the marine shrimp Penaeus vannamei Boone. Bull. Japan. Soc. Sci. Fish. 55(1) :91.

Akiyama, D.M. and FSGP Aquaculture Research. 1990. The use of soybean meal to replace white fish meal in commercially processed Penaeus monodon Fabricus feeds in Taiwan, R.O.C. In: M. Takeda and T. Watanabe (Editors), The Current Status of' Fish Nutrition in Aquaculture: The Proceedings of the Third International Symposium on Feeding and Nutrition in Fish, August 28-September 1, 1989, Toba, Japan.

Andrews, J.W., T. Murai, and C. Campbell. 1973. Effects of dietary calcium and phosphorus on growth, food conversion, bone ash and hematocrit levels of catfish. J. Nutr. 103:766.

Holmes, B. 1988. Quality control of raw material and finished product in full-fat soya production. ASA Technical Bulletin, Vol. 2, AQ 9.

Liener, I.E. 1975. Effects of anti-nutritional and toxic factors on the quality and utilization of legume proteins. In: M. Friedman (Editor) Protein Nutritional Quality of Foods and Feeds. Marcel Deckker, New York.

National Research Council, 1983. Nutrient requirements of warmwater fishes and shellfishes. National Academy Press, Washington, DC.

Ogino, C, L. Takeuchi, H. Takeda, and T. Watanabe. 1979. Availability of dietary phosphorus in carp and rainbow trout. Bull. Japan. Soc. Sci. Fish. 45:1527.

Rackis, J.J. 1972. Biologically' active components. In: A.K. Smith and S.J. Circle (Editors), Soybeans: Chemical and Technology. AVI Publishing Co., Westport, Connecticut.

Robinette, H.R. 1984. Feed formulation and processing. In: E.H. Robinson and R.T. Lovell (Editors), Nutrition and Feeding of Channel Catfish (Revised). Southern Cooperative Series Bull. 296, Texas A&M University, College Station, Texas.

Robinson, E.H. and R.P. Wilson. 1985. Nutrition and feeding. In: C.S. Tucker (Editor), Channel Catfish Culture. Elsevier Science Publishers B.V., Amsterdam.

Sakamoto, S., and Y. Yone. 1979b. Availabilities of phosphorus compounds as dietary phosphorus sources for red sea bream. J. Fac. Agric. Kyushu Univ. 23:177.

Smith, R.R. 1988. Soybean and wheat flour by-products in trout feeds. American Soybean Association Technical Bulletin. American Soybean Association, Singapore.

Smith, R.R., H.L. Kincaid, J.M. Regenstein and G.L. Rumsey. 1988. Growth, carcass composition, and taste of rainbow trout of different strains fed diets containing primarily plant or animal protein. Aquaculture (70):309.

Table 1. Protein and amino acid digestibility values for various feed ingredients [a]

	Protein	ARG	LYS	LEU	ILE	THR	VAL	HIS	PHE	MET
Marine shrimp [b]										
Soybean meal	89.9	91.4	91.5	88.4	90.2	89.3	87.9	86.3	89.6	--
Fish meal	80.7	81.0	83.1	80.7	80.4	80.6	79.4	79.0	71.1	--
Squid meal	79.7	79.4	78.6	79.4	77.2	79.7	79.3	73.6	74.1	--
Shrimp meal	74.6	81.8	85.7	82.1	81.6	83.7	79.0	75.4	75.6	--
Channel catfish [c]										
Fish meal	87.0	90.9	86.4	89.1	87.2	87.6	87.0	84.8	87.4	82.9
Cottonseed meal	81.0	90.5	71.0	76.4	71.7	76.8	.76.1	82.0	83.5	76.3
Soybean meal	77.0	96.7	94.0	83.5	79.8	81.9	78.7	87.9	84.4	84.6
Peanut meal	74.0	97.8	94.4	95.2	93.2	93.1	93.1	89.5	96.1	.90.5

[a] Values in percent digestibility of total content.
[b] Akiyama et al., 1988.
[c] Robinson and Wilson, 1985.

Table 2. Energy values for various feed ingredients [a]

Ingredient	Rainbow trout (ME, Kcal/g)	Channel catfish (DE, Kcal/g)	Tilapia (DE, Kcal/g)
Fishmeal [b]	3.80	3.90	4.04
Cottonseed meal	2.08	2.55	-
Rapeseed meal	2.47	-	-
Soybean meal			
solvent extracted	-	2.58	3.34
dehulled solvent extracted	2.89	-	-
full-fat	3.64	-	-

[a] National Research Council, 1983.
[b] Varies with type of fish meal.

Table 3. Phosphorous availability values for various sources and ingredients [a]

	Rainbow trout [b]	Channel catfish [b]	Common carp [b]	Marine shrimp [c]
Sodium phosphate, mono	98	90	94	-
Potassium phosphate, mono	98	-	94	-
Calcium phosphate				
mono-basic	94	94	94	-
dibasic	71	65	46	-
tribasic	64	-	13	-
Fish meal	74	40	24	47
Yeast	91	-	93	-
Soybean meal	-	50	-	40
Shrimp meal	-	-	-	30
Squid meal	-	-	-	77

[a] Values in percent availability.

[b] National Research Council, 1983.

[c] Akiyama (unpublished data).

Table 4. Ingredient composition of channel catfish feeds [a]

Ingredient	Starter	Grower A	Grower B
Fish meal	10	8	-
Soybean meal (48%)	37	48.25	-
Soybean meal (44%)	-	-	47.5
Meat and bone meal	-	-	15
Peanut meal	18	-	-
Distillers dry solubles	7.5	-	-
Corn	23.5	29.1	33
Rice bran	-	10	-
Wheat middlings	-	-	1.75
Di-Ca-P	1.5	1	0.25
Whey	-	-	2.4
Pellet binder[b]	2.5	2	-
Fat	-	1.5	-
Vitamin/Minerals	0.18	0.14	0.14

[a] Robinette, 1984. Percent as fed basis.
[b] Not required if feeds are extruded.

Table 5. Estimated chemical composition of channel catfish feeds [a]

Nutrient	Starter	Grower A	Grower B
Protein	35.4	32.0	31.1
plant protein (% of total)	82.4	84.9	76.6
animal protein (% of total)	17.6	16.1	23.4
Fat	4.8	5.0	4.3
Fiber	5.3	3.3	4.0
Ash	6.6	6.5	8.2
Calcium	1.0	*0.6*	1.5
Phosphorous (available)	0.5	0.4	0.5

[a] percent as fed basis.

Table 6. Ingredient composition of common carp feeds [a]

Ingredient	A	B
Fish meal	10.8	21.6
Soybean meal	45.0	25.0
Wheat pollards	12.6	24.4
Rice bran	20.0	20.0
Di-Ca-P	4.6	3.3
Fish oil	1.8	0.7
Methionine	0.2	0.1
Limestone	2.4	2.3
Vitamin/Mineral premix	2.6	2.6

[a] percent as fed basis.

Table 7. Estimated chemical composition of common carp feeds [a]

Nutrient	A	B
Protein	30.1	29.9
plant protein (% of total)	78.3	56.4
animal protein (% of total)	21.7	43.5
Fat	6.5	6.4
Fiber	6.4	6.2
Ash	12.5	12.4
Calcium	2.8	3.0
Phosphorous (available)	0.7	0.7

[a] As fed basis.

Table 8. Results of the common carp feeding trial conducted in floating cages[a]

	Experiment I		Experiment II	
	A	B	A	B
Initial weight (gm)	57	57	73	73
Stocking density (kg/m^3)	5.0	5.0	10.0	10.0
Experimental time (days)	59	59	59	59
Final weight (gin)	163.5[b]	175.8[b]	232.7[b]	249.4[b]
Weight gain (%)	186	207	220	242
Survival rate (%)	94.8[b]	94.6[b]	99.4[b]	99.3[b]
Final density (kg/m^3)	13.5	14.2	31.8	33.9
Feed conversion ratio	2.3[b]	2.2[b]	1.9[b]	1.8[b]

[a] Values are means for 3 replicates.
[b] Means within an experiment and in the same row with different superscripts differ ($P<0.05$).

Table 9. Ingredient composition of rainbow trout feeds[a]

Ingredient	A	B
Fish meal, anchovy	7.5	30.0
Soybean meal, full-fat	40.0	7.5
Cottonseed meal	15.0	10.0
Corn gluten meal	7.0	7.5
Blood flour	5.0	5.0
Yeast, brewers dry	5.0	5.0
Wheat middlings	-	20.0
Whey, dried	6.0	-
Fish oil	3.0	3.0
Soybean oil	-	6.0
Molasses (sugar beet) 30% moisture	10.0	3.0
Vitamin/Mineral premix	5.0	5.0

[a] Smith et al., 1988; Percent as fed basis.

Table 10. Estimated chemical composition of rainbow trout feeds [a]

Nutrient	A	B
Protein	42.4	45.0
plant protein (% of total)	74.8	33.1
animal protein (% of total)	25.2	66.9
Fat	11.0	13.0
Fiber	2.1	0.7
Ash	9.2	9.7
Energy (ME, Kcal/kg)	3529	3430
Calcium [b]	0.4	1.0
Phosphorous (available)[b]	0.4	0.8

[a] As fed basis.
[b] Not including premix.

Table 11. Days required for rainbow trout to increase in average weight from 2 to 200 g and feed conversion ratios [a]

	Days to final weight		FCR	
Experiment	A	B	A	B
I	207[b]	203[c]	159[b]	1.49[c]
II	187[b]	185[b]	113[b]	113[b]

[a] Smith et al., 1988; Values are means for 4 replicates by 5 rainbow trout strains.
[b, c] Means in same row with different superscript differ ($P<0.05$).

Table 12. Cost advantages of high plant protein rainbow trout feeds[a]

	FCR	Feed cost (US$/Kg)	Feed cost (US$/Kg) per Kg fish produced
Experiment I			
Diet A	1.59	0.37	0.59
Diet B	1.49	0.43	0.64
Experiment II			
Diet A	1.13	0.37	0.42
Diet B	1.13	0.43	0.49

[a] Smith et al., 1988.

Table 13. Ingredient composition of marine shrimp feeds[a]

Ingredient	A	B
Soybean meal	40.0	20.0
White fish meal	6.0	18.0
Wheat bran	4.1	12.5
Limes tone	0.7	-
Di-Ca-P	3.0	1.0
Fish oil	0.7	-
Wheat flour	14.6	16.8
Potassium bicarbonate	0.4	1.2
Soy lecithin	0.5	0.5
Wheat gluten	5.0	5.0
Shrimp meal	7.0	7.0
Squid meal	7.0	7.0
Vitamin/Mineral premix	3.0	3.0
Yeast	2.0	2.0
Sodium phosphate	2.0	2.0
Zeolite	2.0	2.0
Dehydrated fish solub les	1.0	1.0
Squid oil	1.0	1.0

[a] Akiyama 1990; Percent as fed basis.

Table 14. Estimated chemical composition of marine shrimp feeds [a]

Nutrient	A	B
Protein	37.8	38.0
plant protein (% of total)	72.2	50.3
animal protein (% of total)	27.8	49.7
Fat	5.3	5.3
Fiber	3.2	3.6
Ash	17.9	18.2
Calcium	2.4	2.6
Phosphorous (total)	2.0	2.0

[a] Percent as fed basis.

Table 15. Results of the Penaeus monodon feeding trial conducted in outdoor concrete tanks [a]

Diets	A	B
Initial weight (g)	3.6	3.8
Stocking density (#/m^2)	30.0	30.0
Experimental time (days)	42	42
Final weight (g)	12.8	12.3
Weight gain (%)	256[b]	224[b]
Survival rate (%)	91.3[b]	92.8[b]
Final biomass (g/m^2)	351.1	343.5
Feed conversion ratio	1.3b	1.2[b]

[a] Akiyama, 1990. Values are means for 4 replicates.
[b] Means in the same row with different superscripts differ ($P<0.05$).