THE UTILIZATION OF SOYBEAN PRODUCTS IN TILAPIA FEED – A REVIEW

TRI NHU NGUYEN

Faculty of Fisheries, Nong Lam University, Thu Duc district, Ho Chi Minh city, Vietnam
Email: nguyennhutri@yahoo.com

Abstract

Tilapia is one of the most important groups of fish for aquaculture with an annual production exceeds two million metric tons. They have been cultured for quite a long time ago. However, their aquaculture production has been developed remarkably during the last few decades due to the increased level of intensification and cultured area. In the past, fish meal was used as a main protein source in tilapia feed. Due to the escalating price and unstable supply of this ingredient, many studies have been conducted to replace fish meal by the less expensive plant and animal protein sources. Among these alternative protein sources, soybean meal appears to be an excellent substitution and its utilization in tilapia feed has been increased at a past rate recently. In order to effectively use soybean meal to replace fish meal and other protein sources, the nutrient requirement of tilapia, especially protein and amino acid should be known. These requirements as well as studies related to the replacement of soybean meal for fish meal and future research direction have been reviewed in this paper.

INTRODUCTION

Aquaculture continues to grow more rapidly than all other animal food-producing sectors, with an average annual growth rate for the world of 8.8 percent per year since 1970, compared with only 1.2 percent for capture fisheries and 2.8 percent for terrestrial farmed meat production systems over the same period. Aquaculture production in 2004 was reported to be 45.5 million metric tons (MT) with a value of US$ 63.3 billion or, if aquatic plants are included, 59.4 million MT with a value of US$ 70.3 billion. Production from aquaculture has greatly outpaced population growth, with per capita supply from aquaculture increasing from 0.7 kg in 1970 to 7.1 kg in 2004, representing an average annual growth rate of 7.1 percent (FAO, 2007).

Tilapia are important freshwater fish species for aquaculture. They are native to Africa, but were introduced into many different regions of the world during the second half of the 20th century (Pillay, 1990). Tilapia are currently known as "aquatic chicken" due to their fast growth, adaptability to a wide range of environmental conditions, disease resistance, high flesh quality, ability to grow and reproduce in captivity and feed on low trophic levels. Thus, they have become excellent candidates for aquaculture, especially in tropical and subtropical regions. Tilapia culture is believed to start more than 4,000 years ago, but very little information is available on their culture during those ancient times. The first trials of tilapia culture were recorded in Kenya in the 1920s (El-Sayed, 2006). Since then, tilapia culture has been established in many tropical and subtropical regions, and even in areas beyond their native ranges. Considerable attention has been paid to tilapia culture during the last three decades. Tilapia is currently cultured in more than 100 countries in the world (El-Sayed, 2006). Global landing of tilapia from capture fisheries increased progressively during the 1950s to the 1980s. During the 1990s and early 2000s, the landings were almost stable, fluctuating around 585,000-600,000 MT per year. Africa is the most important tilapia producer from capture fisheries, contributing about 70% of global landing in 2002, followed by Asia (18%), North America (9%) and South America (3%). Therefore, it is no surprise that, among the world's top ten tilapia producers from capture fisheries, six are African countries (Egypt, Uganda, Tanzania, Kenya, Mali and Malawi). The top ten producers included three Asian countries (Thailand, Philippines and Sri Lanka) and one North American country (Mexico) (El-Sayed, 2006).

In intensive fish production models, the utilization of nutritionally completed feeds is critical to the success of the industry. Traditionally, these feeds were formulated using fish meal (FM) as primary protein source. Supply and price considerations make the use of high levels of FM economically unjustified in grow-out diets for many freshwater fish species in general and tilapia in particular. A number of studies have been conducted to evaluate the potential of alternative plant and animal protein sources to replace FM in practical diet for tilapia. Among these protein sources, soybean has become one of the best candidates and its utilization has been rapidly increased in tilapia feeds. Based on data from the American Soybean Association statistics, global soybean production in 2006 was 228.4 million MT. The most widely used soybean products in aquaculture diets are the meals resulting from the removal of oil from the soybean. Solvent-extraction of the oil results in products that typically contain 44% crude protein if the soybean hulls are included or 48% crude protein without the hulls (NRC, 1993). The amino acid composition of these soybean meals represents the most balanced profile of all plant protein sources. As aquaculture production continues to increase globally to meet the growing demand for aquatic animal products, soybean products will play an even more important role in providing high-quality protein for tilapia and other fish species.

An overview of global tilapia culture

Tilapia aquaculture production has expanded very fast during the past decade. The production of farmed tilapia has increased from 383,654 MT in 1990 to 1,505,804 MT in 2002, representing 2.28% and 2.93% of total aquaculture production, respectively. The average annual growth of tilapia production during this period approached 12.2% (El-Sayed, 2006). In 2004, world production of farmed tilapia exceeded 2,002,087 metric tons, trailed behind that of the carps and exceeded that of the salmonids. Tilapia have been domesticated more quickly and to a greater extent than any other group of fish. The rapid improvements in domestication and wider consumption patterns may mean that tilapia may eventually overtake the carps to become the most important farmed fish. Tilapia have already become one of the most important farm-raised fish and have an increasing role in the international seafood trade (Fitzsimmons, 2006). There are about ten species of tilapia have been used for aquaculture. Nile tilapia (*O. niloticus*) is, by far, the most important farmed tilapia species in the world. It represented more than 80% of total tilapia production during 1970-2002. Nile tilapia also ranked sixth in terms of global farmed fish production in 2002, after silver carp, grass carp, common carp, crucian carp and big head carp (El-Sayed, 2006).

Traditionally, tilapia have been cultured in extensive systems. As the industry expands and the technology development continues, traditional extensive culture of tilapia is being replaced by semi-intensive and intensive production systems. In semi-intensive farming systems, supplemental feeds that consist of locally available, low-cost single feedstuffs such as rice bran, copra meal, coffee pulp, brewery by-products and/or their combination are generally used as supplements to natural food (Lim, 1989). As stocking rate increases, the contribution of natural food decreases and more nutritionally complete feeds are needed. In intensive culture systems such as in ponds, raceways, cages and tanks, feed is the most expensive item, often ranging from 30 to 60 percent of the total variable expenses, depending on the intensity of the culture operation (Lim and Webster, 2006). Therefore, the development of cost-effective feeds using cheap and locally available plant and animal protein sources has a great contribution to its sustainable aquaculture development in the future. In order to achieve this goal, the understanding of protein and essential amino acid requirements of juvenile tilapia is very important.

Protein requirement

Protein requirement at different life stages of various tilapia species have been studied extensively. These values have generally been determined by measuring growth response of tilapia fed test diets containing graded levels of protein. Generally, semi-purified diets containing casein, casein/gelatin mixtures or casein/crystalline amino acid mixtures as protein sources or practical diets formulated using conventional feedstuffs such as fish meal (FM) or soybean meal as protein sources, have been used to determine protein requirements.

Protein requirement of tilapia is depended on many factors such as species, size, protein source and quality, non-protein energy level in the test diets, feeding rate, water quality variables (temperature, dissolved oxygen, salinity, etc.), the presence and density of natural food (NRC, 1993). For example, casein was traditionally used as the only dietary protein source in many studies. It contains adequate levels of most essential amino acids (EAA) but is deficient in arginine. When casein is used as a sole protein source, higher levels of protein are required to compensate for the arginine deficiency. Since the amino acid profile is imbalanced, the observed protein requirement for tilapia would be lower if arginine is supplemented to the diet (El-Sayed, 1989). Due to faster growth rates, smaller fish often have higher protein requirements than bigger ones. Insufficient non-protein energy in the diet will also lead to a higher dietary protein requirement because fish will utilize part of the protein as energy to meet their metabolic energy needs. Water quality variables such as temperature and dissolved oxygen (DO) have considerable effects on metabolic rate of fish and thus their dietary protein requirements. A higher dietary protein level is required at optimum water temperature and DO for growth than at lower temperature or DO. Tilapia are very efficient in utilizing natural food. At low stocking densities in earthen ponds, they obtain significant amount of protein from natural food and therefore lower protein level is required (Lim and Webster, 2006). Dietary protein requirements of some commercially important tilapia species vary from 25 to 56% diet (Table 1).

Quantitative amino acid requirement

Quantitative essential amino acid requirements of *O. niloticus* and *O. mossambicus* juveniles are shown in Table 2. The values determined by Jauncey *et al.* (1983) for *O. mossambicus* are lower than those of *O. niloticus* as reported by Santiago and Lovell (1988), except for leucine. Among all of the essential amino acids required by fish in general and tilapia in particular, methionine is often one of the most limiting EAA in feeds. Hence, the determination of methionine or total sulfur amino acid (TSAA, consists of methionine and cystine) requirements of juvenile tilapia is critical to the production of cost-effective feeds.

Table 1. Dietary protein requirements of some commercially important tilapia species.

Species	Protein source	Size (g)	Protein requirement (%)	Reference
O. niloticus	Fish meal	0.012	45	El-Sayed and Teshima, 1992.
	Casein, gelatin	0.56	35	Teshima *et al.,* 1985
	Casein	3.5	30	Wang *et al.,* 1985.
		9.0	25	
	Fish meal, soybean meal	Broodstock	40	El-Sayed *et al.,* 2003. Siddiqui *et al.,* 1998.
	Fish meal	Broodstock	45	
O. mossambicus	Fish meal	Fry	50	Jauncey and Ross, 1982.
		0.5-1.0	40	
		6.0-30.0	30-35	
O. aureus	Soybean meal or fish meal	0.3-0.5	36	Davis and Stickney, 1978.
	Casein, albumin	Fry-2.5	56	Winfree and Stickney, 1981.
		2.5-7.5	34	
Tilapia zillii	Casein	1.3-3.5	35	Mazid *et al.,* 1979.
	Casein, gelatin	1.4	35	El-Sayed, 1987.

Table 2. Quantitative essential amino acid requirements of *O. niloticus* and *O. mossambicus* juveniles.

Amino acid	Requirements (Percent of dietary protein)	
	O. niloticus[a]	*O. mossambicus*[b]
Arginine	4.20	2.82
Histidine	1.72	1.05
Isoleucine	3.11	2.01
Leucine	3.39	3.40
Lysine	5.12	3.78
Methionine	2.68[c]	0.99
Phenylalanine	3.75[d]	2.50
Threonine	3.75	2.93
Tryptophan	1.00	0.43
Valine	2.80	2.20

[a] Santiago and Lovell, 1988; [b] Jauncey et al., 1983; [c] In the presence of cystine at 0.54% of dietary protein; [d] In the presence of tyrosine at 1.79% of dietary protein.

Total sulfur amino acid requirement

Total sulfur amino acid requirement of tilapia can be met by methionine alone or a proper mixture of methionine and cystine (Shiau, 2002). This requirement, expressing as percentage of dietary protein, has been determined for Mozambique tilapia (3.2%: Jackson and Capper, 1982). In Nile tilapia, TSAA requirement in semi-purified diet has been determined by several investigators. However, the reports covered a wide range of values. For example, Santiago and Lovell (1988) determined that TSAA requirement of Nile tilapia fry was 0.9% of the diet (consisted of 0.75% methionine and 0.15% cystine) or 3.22% of dietary protein while Kasper et al. (2000) concluded that this requirement for the same species was only 0.5% of the diet or 1.56% of dietary protein. Since Nile tilapia is one of the most popular cultured fish species in the world, feed cost must be reduced as much as possible by using inexpensive and locally available plant and animal protein sources. Quite often, diets formulated from these protein sources are limited in methionine. Consequently we must re-determine TSAA requirement that may allow the use of the feed ingredients that have low levels of methionine. TSAA requirement in semi-purified diet for juvenile Nile tilapia has been re-determined to be 3.04% of dietary protein (Nguyen, 2007). When TSAA requirement in semi-purified diet for tilapia has been determined, it is also critical to confirm its requirement in practical diet in order to transfer the result to tilapia feed industry. Methionine requirement in practical diet (using soybean meal, cottonseed meal and gelatin as protein sources) of juvenile Nile tilapia was 0.49% of the diet or 1.75% of dietary protein, in the presence of cystine at 0.45% of the diet or 1.61% of dietary protein (Nguyen, 2007).

Cystine is a non-essential amino acid but required for protein synthesis. Since cystine can only be synthesized metabolically from methionine precursor, its presence in the diets can spare a portion of methionine requirement for maximum growth. Therefore, the determination of replacement value of cystine for methionine in tilapia is also important since we can minimize the incorporated level of methionine in practical diets without reducing biological performance and thus, minimize feed cost. The replacement value of cystine for methionine have been determined for blue tilapia (44%: Liou, 1989) and Nile tilapia (49%: Nguyen, 2007).

Overview of studies on evaluation of soybean products to replace fish meal in practical diets for tilapia.

The nutritional value of protein sources, commonly referred to as protein quality, is determined based on the EAA profile and their digestibility or bioavailability. A protein source with EAA profile that closely matches EAA requirements of fish is likely to have high nutritional value (Lim and Webster, 2006). As protein is the most expensive components of aquatic feeds, the utilization must be optimized and the cost minimized. The development of commercial feeds for aquatic animals in general and tilapia in particular has been traditionally based on the use of FM as the main protein source. This is due to its high protein content and balanced EAA profile. Fish meal is also an excellent source of essential fatty acids, digestible energy, minerals and vitamins. Because of its nutritive value, it is no surprise that fish meal is the most expensive protein source in animal feeds (Tacon, 1993).

The production of FM based on captured fisheries is at or beyond sustainable limits. The limited supply coupled with an increasing demand from the animal feed industry, results in a high price for this ingredient. Given the escalating cost of FM, it is critical that all animal production systems reduce their reliance on this ingredient. This is particularly important in feeds for aquatic animal species as they often contain high levels of FM (El-Sayed, 1999). Furthermore, there are growing environmental concerns with regards to the use of wild fish to produce FM. Hence, there is interest in replacing FM with less expensive protein sources. Replacement of FM in practical diets without reducing the performance would result in a more profitable production of tilapia. Many studies have been conducted to evaluate the replacement of FM by the low-cost, locally available plant and animal protein sources such as soybean meal, cottonseed meal, meat and bone meal, etc., in practical diets for tilapia.

Soybean meal (SBM), because of its availability, consistent quality, high protein content with good amino acid profile and low cost, is the most studied plant feedstuff in aquaculture diets (Lim and Dominy, 1989). However, it is considered limiting in methionine and contains some anti-nutrients such as trypsin inhibitor, hemagglutinin and anti-vitamins (Tacon, 1993). Useful information on nutritional values, apparent digestibility, the utilization, etc., of various soybean products can be found at following websites: www.soymeal.org, www.unitedsoybean.org, www.soygrowers.com, and www.centralsoya.com

Many studies have been conducted to evaluate the potential of using soybean products as a replacement for FM. Davis and Stickney (1978) evaluated the interaction between dietary protein levels (15, 22, 29, 36%) and the ratios of FM and SBM (0, 33, 67, 100% of dietary protein) in practical diets for juvenile blue tilapia (*Oreochromis aureus*). All test diets, except the 36% protein diet with 100% FM were supplemented with DL-methionine. At low-protein diets (15, 22 and 29%), SBM-based diet could not meet the EAA requirements and thus inferior growth rate was obtained as compared to a FM-based diet. However, when the protein level was increased to 36%, the performance of fish fed a SBM-based diet was adequate and comparable to that of the FM-based diet. Supplementation of 0.8% D,L-methionine to a test diet in which 75%

of brown FM was replaced by SBM improved the growth of Nile tilapia to a level comparable to that obtained from FM-based diet (Tacon *et al.*, 1983). Viola et al. (1988) found no significant difference in terms of weight gain and feed efficiency of hybrid tilapia fed diet containing 35% FM and SBM-based diet with a supplementation of if 3% dicalcium phosphate. Hybrid tilapia (*Oreochromis niloticus* x *O. aureus*) fed a diet in which 30% of the FM in the control diet was replaced by full-fat SBM had similar weight gain, feed efficiency, protein efficiency ratio and protein digestibility, compared to fish fed the control diet (Shiau *et al.*, 1990). Wee and Shu (1989) demonstrated that Nile tilapia (*Oreochromis niloticus*) fed boiled full-fat SBM at a level of 58.3% of diet had similar weight gain, feed efficiency, apparent protein digestibility and apparent net protein utilization as fish fed a diet with 52.4% solvent-extracted soybean meal.

Other studies in Nile tilapia also demonstrate that it is feasible to replace FM by SBM. Wu et al., (1995) and Tudor et al., (1996) found that Nile tilapia fed diets containing from 35 to 56% soybean flour and corn gluten as protein sources had similar weight gain and feed efficiency as fish fed diets containing as much as 6% FM. Nile tilapia fed a diet containing 55% SBM supplemented with 1% methionine and 0.5% lysine significantly improved weight gain and feed efficiency than fish fed the control diet containing 20% menhaden FM and 30% SBM (El-Saidy and Gaber, 2002). Another study was conducted to compare the performance of red tilapia (*Oreochromis* spp.) fed SBM-based diet and diet contains 6% FM, which was considered as a regular inclusion rate of FM in commercial diet for tilapia. The results showed that there were no significant difference ($P>0.05$) in final mean weight, survival and FCR of the experimental fish fed these two diets (Nguyen, 2007).

Results of studies mentioned above indicated that it is possible to eliminate FM from commercial tilapia diets with the utilization of SBM. Nguyen (2007) also conducted a study to compare the performance of red tilapia (*Oreochromis* spp.) fed SBM-based diet and organic expeller-pressed SBM-based diet and found no significant difference ($P>0.05$) in final mean weight, survival and FCR of the experimental fish. If organic expeller-pressed SBM has reasonable price as compared to regular SBM, it may be more profitable to produce organic tilapia since they often have higher prices than non-organic ones. To date, the demand for organic products from aquaculture has been increasing due to the growing awareness concerning environmental pollution and the safety of aquatic products for human consumption, as well as the state of global fishery resources and long-term sustainability of current aquatic food production systems (Tacon and Brister, 2002). Although no statistical data are available concerning the global production of certified organic aquaculture products, it is estimated that total production in the year 2000 was only about 5,000 MT, primarily from European countries. This modest quantity represents about 0.01% of total global aquaculture production or about 0.25% of European aquaculture production. Based on current estimates of certified organic aquaculture production and an anticipated annual growth rate of 30% from 2001 to 2010, 20% from 2011 to 2020 and 10% from 2021 to 2030, it is estimated that production will increase 240-fold, from 5,000 MT to 1.2 million MT by 2030. Such a production of certified organic aquatic products would be equivalent to 0.6% of the total estimated aquaculture production in 2030 (Yussefi, 2004). Since tilapia is one of the most popular aquaculture species in the world, attempts to produce them organically would have a great contribution toward sustainable aquaculture development in the future.

Future research direction

There is a great potential for increased use of SBM in aquaculture feeds due to its nutritional value and cost-effectiveness compared to other protein sources, especially FM. Future research should focus on overcoming the disadvantages of using SBM such as low methionine content, the presence of anti-nutritional substances. Increasing the availability of nutrients from SBM not only enhance its utilization in aquaculture industry but also reduce the potential of aquatic environment pollution. In SBM, phosphorus often appears as phytate form, comprising about 67% of total phosphorus in plant ingredients. Phytate is not readily available to monogastric animals including various fish species (NRC, 1993) because of their lack of phytase, the enzyme required to liberate phosphorus. Therefore, increasing the availability of phosphorus from SBM is desirable to reduce the amount of supplemental phosphorus in diet formulation and limit the phosphorus loading into the environment, as well as reduce feed cost. Considerable research has been conducted on the use of various forms of phytase to enhance phosphorus bioavailability from plants containing significant levels of phytate phosphorus. Such studies are becoming even more important as we move from animal protein sources, which are rich sources of minerals, towards plant-based diets that often do not contain adequate levels of minerals. The incorporation of phytase into fish feeds could effectively increase the availability of phosphorus to various fish species such as common carp (Schafer et al., 1995), channel catfish (Eya and Lovell, 1997; Li and Robinson, 1997; Yan et al., 2002). However, the instability of phytase to heat during extrusion process has restricted its use in fish feeds. The development of low-temperature feed manufacturing techniques or an application of phytase after extrusion will enhance its use in aquaculture feed industry.

Soybean meal also contains non-starch polysaccharides that are not efficiently digested by most fish species. Improving the digestion of these substances not only increase digestible energy of SBM, but also reduce the waste loading. The potential of incorporating exogenous enzymes such as xylanase, β-glucanase and endo-β-mannanase into fish feeds to enhance the digestibility of this fraction should be investigated. As the aquaculture industry moves towards increased cost efficiencies, feed formulations must become more precise thus making the need for digestibility values of SBM for many aquatic animal species even more critical. More information concerning amino acid availability of SBM to various fish species will help nutritionists to precisely formulate diets based on an available amino acid basis. Such diets will enhance amino acid utilization by the target fish species and thus reduce nitrogen loading into aquatic environment. The research focused on increasing levels of certain essential amino acids, improving amino acid balance and digestibility, reducing selected carbohydrates, improving phosphorus availability of SBM is being conducted by The United Soybean Board's Better Bean Initiative (BBI). These research findings will enhance the quality of SBM, make it becomes a more competitive protein feedstuff for aquaculture feed industry.

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