STRATEGIES FOR REDUCING AND/OR REPLACING FISH MEAL IN PRODUCTION DIETS FOR THE PACIFIC WHITE SHRIMP, *LITOPENAEUS VANNAMEI*

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ABSTRACT

In recent years, worldwide increases in marine shrimp production have been accompanied by decreases in shrimp value and reduced profitability for farmers. Facing this scenario, there has been considerable interest in evaluating alternatives to reduce shrimp production costs. Reducing the cost of feed by minimizing the inclusion of expensive ingredients of marine origin, mainly fish meal, is one alternative. Fish meal is the most important and costly protein source in most shrimp feeds, with commercial shrimp formulations commonly including from 25 to 50% fish meal in the diet. In addition to economic concerns, the use of marine ingredients has received considerable attention from the public in terms of perceived sustainability issues. Hence, the reduction and/or removal of fish meal and other marine ingredients are of considerable concern to the industry. With proper replacement strategies, a number of studies have demonstrated that fish meal and marine oil levels can be reduced or eliminated depending on the strategies used. It is clear that cheaper, high quality plant (e.g. combinations of solvent extracted soybean meal, corn gluten meal, distiller's grain solubles, and pea meal) or terrestrial animal protein sources (e.g. poultry meal) can be used to successfully replace fish meal in shrimp feeds without compromising shrimp growth. Economic returns on various dietary formulations are specific to a region. However, in most areas, the reduction of fish meal levels in production diets will result in reductions in feed costs and hence improved economic returns on the investment in feeds. Marine fish oils can also be removed from the feed by using a suitable combination of plant oils and highly unsaturated fatty acids (HUFAs). Such a technique has been demonstrated, but due to current prices for proprietary sources of HUFAs, this may not reduce overall costs. It would, however, allow the promotion of a more environmentally friendly production system. Such alternative oils sources are likely to be economical in the near future as prices for fish oil continue to rise. Such modifications to the feed can only be done if the replacement strategy takes into account nutrient requirements of the species in terms of essential amino acids, fatty acids and minerals, as well as potential palatability shifts in the diets.

INTRODUCTION

Properly managed capture fisheries are a renewable resource, but harvests cannot be expanded beyond current levels and may actually need to be reduced. Presently, the majority of wild seafood harvests goes toward human consumption, as this is the most valuable market for these products and a critical source of essential nutrients to our diet. Of the world total, around 20-30 million tons are not acceptable for human consumption and have traditionally been used for industrial products, primarily fish meal and oil for the animal feed industry. The production of industrial products has been fairly stable; over the last 20 years, 6-7 million tons of fish meal, and close to 1 million tons of fish oil per year have been produced. This value is not expected to dramatically increase, although there will be increases as waste products from the processing of seafood products are increasingly converted towards products for the animal feed industry. Due to the exceptionally good nutritional quality and limited supply, marine ingredients are valuable commodities for which demand far exceeds supply, and prices are likely to continue to be high.

Aquaculture is currently the primary user of fish meal and fish oil, accounting for 60% and 80% of the use, respectively. Reduction of fish meal and oil use in feeds is a lesson learned by other animal industries a long time ago and one that the aquaculture industry has talked about for a long time. Despite warnings, it took a 40% increase in fish meal prices in less than a year to finally wake the industry to the fact that our excessive and casual use of fish meal and oil must stop. In addition to economic concerns caused by limited supplies and increasing demand, the use of marine ingredients has received considerable attention by the public in terms of perceived sustainability issues. Hence, the overall reduction in the use of fish meal and other marine ingredients is of considerable concern to the industry and should be viewed as a high priority.

Based on reports by Tacon and Metian (2008), manufacturing of marine shrimp feed uses 24-27% of the world's fish meal. When looking at fish meal use, one has to

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remember shrimp farming developed in a market environment in which shrimp were a luxury item demanding a high price, and often produced high profit margins for producers. This has resulted in a number of inefficient practices, which include the use of very expensive feeds which are often over formulated and contain high levels of marine ingredients. As shrimp prices have fallen, the profit margins have also decreased making it more difficult to run a profitable commercial shrimp farm. Considering that feed represents one of the largest variable costs associated with fed culture systems, reducing feed costs can produce considerable savings.

The use of feeds with reduced levels of fish meal is one potential method to reduce feed costs if production efficiencies can be maintained. Commercial shrimp formulations historically contain from 25% to 50% fish meal, representing the primary and most expensive protein ingredient (Tacon and Barg 1998, Dersjant-Li 2002). Clearly, the high inclusion levels of fish meal make it the preferred protein source. After all, it is an excellent source of essential nutrients such as protein and indispensable amino acids, energy, essential fatty acids, cholesterol, vitamins, minerals, attractants and unidentified growth factors (Swick et al. 1995, Samocha et al. 2004). Because of fish meal's nutritional value, it has a high demand resulting in a corresponding high market value. Due to limited supply and increasing prices, we must shift our emphasis and use this ingredient only when nutrient requirements of the animal demand its use. In cases where we can substitute fish meal with a combination of other ingredients, we must embrace these technologies. We have not identified how to remove fish meal from diets for a number of species and life stages, but for the vast majority of species we can either remove fish meal or reduce it to reasonable levels.

ALTERNATIVES TO FISH MEAL

Given the nutritional requirements of shrimp, the obvious question is why is fish meal used extensively in shrimp feeds? The nutrient requirements of larval and early post-larval stages demand a highly nutritious diet that warrants the use of fish meal and other high quality marine ingredients that are cost effective. However, production diets must be economically viable and use the most economical ingredients that can be used to produce a nutritionally complete diet. To use a protein source that costs almost twice as much as that of other ingredients is not acceptable. For example, if fish meal FOB Peru is selling at $800/ton, the cost for a 65% protein meal is $12.30 per unit of protein; however, if the FOB price for an alternative protein source such as soybean meal is $300/ton, the cost for a 48% protein meal is only $6.25 per unit of protein. Hence, there is a considerable cost saving in shifting protein sources when it is economical and nutritionally viable. Based on numerous research studies with *L. vannamei* reared under a variety of culture conditions and densities, there is clearly no requirement for fish meal in properly balanced production diets (Samocha et al. 2004, Browdy et al. 2006, Patnaik et al. 2006, Amaya et al. 2007a,b).

The use of alternative protein sources in both fish and shrimp feeds has been summarized in a recently published book edited by Lim et al. (2008). Animal and plant based alternatives are reviewed in this book, so this discussion will only focus on a few examples. There are numerous alternatives and combinations if one desires to maintain a reasonable level of animal protein in the diet. These include meat and bone meal, blood meal, poultry by-product meal, feather meal (e.g. hydrolyzed or enzyme treated), and specialized protein blends (Tacon and Forster 2000). These feedstuffs are characterized by higher production and lower cost than fish meals, but they are of variable composition and quality. In addition, their nutritional quality (as a single ingredient) is lower than that of fish meals (e.g. imbalances in essential amino acids). They may also have palatability problems as well as possible microbial contamination (Tacon 1994, Tacon and Forster 2000). Hence, each ingredient must be judged based on the available product, the inclusion level, as well as how well it compliments other ingredients.

One way in which fish meal inclusion level can be reduced in shrimp feeds is by replacing it with poultry-meal (PM). Albeit a relatively expensive ingredient, we have found this to be an excellent protein source that appears to have good palatability characteristics for a number of species. Several studies have demonstrated the viability of replacing fish meal with PM in shrimp diets (Davis and Arnold 2000, Amaya et al. 2007a, Cruz-Suarez et al. 2007). Unfortunately, the use of some animal protein sources are restricted by legislative actions that must also be considered when utilizing them in feed formulations. Researchers have also focused on the development of alternatives that effectively replace or minimize the inclusion of animal protein sources in commercial shrimp formulations using plant proteins (Colvin and Brand 1977, Lim and Dominy 1990, Piedad-Pascual et al. 1990, Hardy 1999, Divakaran et al. 2000, Davis and Arnold 2000, Conklin 2003, Cheng and Hardy 2004, Samocha et al. 2004, Amaya et al. 2007a,b).

There are numerous examples were fish meal and other marine meals have been replaced in aquatic feed formulations, in part or totally, using a combination of plant protein sources (e.g. Viola et al. 1982, Viola et al. 1988, Webster et al. 1992c, Tidwell et al. 1993a,b, Kaushik et al. 1995, Sudaryono et al. 1995, Wu et al. 1995, Lim 1997, McGoogan and Gatlin 1997, Olvera-Novoa et al. 1997, Mambrini et al. 1999, Davis and Arnold 2000, Paripatananont et al. 2001, Davis et al. 2004, Samocha et al. 2004,., Olsen et al. 2007, Stickney et al. 2007).

Plant based proteins sources have a number of advantages in that: they are produced in larger quantities than fish meals, their production is more stable, they are often less expensive, and their expanded use does not threaten over-exploitation of a limited resource as can occur with fisheries products. Among different sources of vegetable proteins, soybean meal (SBM) is the most abundant and is commonly used as a partial or complete replacement for marine proteins (Hertrampf and Piedad-Pascual 2000, Olvera-Novoa and Olivera-Castillo 2000, Amaya et al. 2007a,b). Levels of SBM as high as 58% of the diets have been used in grow out feeds for *L. vannamei* without any adverse effects on production (Markey 2007). Other sources of plant proteins - such as cottonseed meal, peanut meal, canola meal, distiller's grain with solubles, and some legume meals - have also been utilized (Li et al. 2000). Usually the use of plant proteins shows some limitation due to a variety of factors, including a deficiency or imbalance of essential amino acids (EAAs), presence of anti-nutritional factors or toxins, and decreased palatability. Many of these limitations can be overcome through the use of proper combinations of different types of plant proteins to balance essential nutrient profiles (e.g. amino acids and fatty acids); by developing specific processing procedures to inactivate, reduce, or eliminate anti-nutritional factors (e.g. heat treatment to inactivate heat labile components); and/or by limiting their inclusion in the diet to a level that does not influence animal performance (Li et al. 2000).

The use of plant based ingredients is an interesting alternative as the world supply is more elastic, albeit there are also limitations in supply often attributed to import restrictions. In addition to or as a compliment to soybean meal, pea meal is a promising alternative for shrimp feeds (Cruz-Suarez et al. 2001, Davis et al. 2002, Bautista-Teruel et al. 2003). Pea meal has a moderate level of protein but it has an amino acid profile that compliments soybean meal, resulting in a better balanced amino acid profile. Yet another alternative protein source that can be used in association with soybean meal is distiller's dried grain with solubles (DDGS). This is a co-product of the ethanol distillery industry and has been suggested as a less expensive alternative to soybean meal on a per unit protein basis. Several studies have indicated that DDGS is a promising feed ingredient in several fish species, including rainbow trout, channel catfish and tilapia (Tidwell et al. 1990, Webster et al. 1991, Webster et al. 1992a,b, Webster et al. 1993, Cheng and Hardy 2004). At moderate levels of inclusion (16% diet), DDGS have been found to be a suitable component of the diet (Molina-Poveda and Morales 2002).

It is clear that from a purely protein delivery standpoint, there are a variety of options for replacing the protein originating from fish meal. However, at the commercial level there are other considerations that often come into play. These include farmers demand, price, ingredient availability as well as the content of other nutrients such as lipids, essential fatty acids, cholesterol, vitamins and minerals. Quite often we forget that marine protein sources are a rich source of other nutrients, which must be considered in the overall replacement strategy.

ALTERNATIVES TO FISH OIL

Our use of fish oil follows a similar trend to fish meal. In the past, fish oil was a very inexpensive oil source used in a variety of "industrial" applications. Hence, this has been one of the best ways to provide energy to the diet and meet the essential fatty acid requirements of a variety of species. As fish oil prices have risen, it is now more cost effective to mix various oil sources to provide the required energy. However, as feed formulations evolve away from marine based ingredients, the feed formulator must also take into account essential nutrients that originated from those ingredients. In the case of marine oils, this includes essential fatty acids and other oil soluble nutrients. Due to the economic importance of oil as a nutrient source, a considerable amount of research has been carried out on fish oil replacement strategies in aquaculture diets.

While marine species tend to have limited abilities, freshwater species are often capable of chain elongation of polyunsaturated fatty acids PUFAs (linoleic acid, 18:2n6 and linolenic acid, 18:3n3) to highly unsaturated fatty acids HUFAs (e.g. arachidonic acid, 20:4n6 (ARA); eicosapentaenoic acid, 20:5n3 (EPA); and docosahexaenoic acid, 22:6n3 (DHA). As freshwater species can chain elongate, using alternative lipids as an energy source while meeting the essential fatty acid requirements is relatively easy. For marine species this is more complicated, as shrimp have limited abilities to chain elongate, and consequently one has to ensure that the essential fatty acids requirements are met.

The use of vegetable oil in feeds without marine oil sources is often limited by the potential problems associated with insufficient levels of essential amino and fatty acids (Francis et al. 2001, Gonzalez-Felix et al. 2002). Although we can use a number of alternative oil sources as a partial replacement for fish oil, the implications for human health must also be considered because of the known health benefits of seafood.

By adjusting the inclusion level and source of non marine oils, the level of dietary lipids as well as the n3 to n6 ratio can be adjusted. However, current alternative oil sources are lacking in highly unsaturated fatty acids. This is one of the primary limitations to continued expansion of marine aquaculture, as marine oil production is limited. Future expansion will require additional sources of essential fatty acids that could originate from genetic modification of oil seed or extraction from cultured organisms. Heterotrophically grown algae and products obtained by fermentation processes have been reported to be a good source of nutrients and essential fatty acids for live food enrichment for larvae and for formulated broodstock diets of marine teleosts (Harel et al. 2002). In a recent study, Patnaik et al. (2006) showed that fish meal and fish oil can be successfully replaced in diets for *L. vannamei* using co-extruded soybean and poultry by-product meal (Profound™, American Dehydrated Foods Inc., Verona, MO, USA) and spray dried cells of *Schizochytrium* and *Mortierella* sp. obtained by a proprietary commercial fermentation process. Irrespective of the source of HUFAs, they will play a critical role in the continued expansion of aquaculture.

PERSPECTIVES

Using proper replacement strategies, a number of studies have demonstrated that fish meal and marine oil levels can be reduced or eliminated from growout diets. A mixture of lower cost, high quality plant proteins (e.g. solvent extracted soybean meal, corn gluten meal, distillers grain solubles, pea meal, canola meal) or terrestrial animal protein sources (e.g. poultry by-product meal, meat and bone meal) can be used to successfully replace fish meal in shrimp feeds without compromising shrimp growth. However, this can only be done if shifts in nutrient requirements - such as essential amino acids (in particular Methionine), energy content of the diet, essential fatty acids s as well as minerals such as phosphorus - are accounted for. Based on a number of trials under research and commercial conditions, the reduction or replacement of fish meal levels in production diets has resulted in reductions in feed costs and improved economic returns on the investment in feeds. Marine fish oils can also be reduced simply by blending oil sources to meet a minimal essential fatty acid requirement. There are also examples of the complete removal of marine oils from the feed by using a suitable combination of plant oils and alternative sources of highly unsaturated fatty acids (e.g. fermented products). Such a technique has been demonstrated, but may not reduce overall costs due to current prices of the alternative sources of essential fatty acids. Such a technique would allow the promotion of more environmentally friendly production systems, which could support increased sales prices to the consumer. Such alternative oil sources are likely to be economical in the near future as prices for fish oil continue to rise.

In summary, marine shrimp have no dietary requirements for fish meal or fish oil. However, both are excellent sources of a number of nutrients that are difficult to obtain using other ingredients. As marine ingredients are of limited supply, they should only be used in diets for which price and nutrient profiles demand their use. Most production diets do not require the use of marine ingredients in feed formulations. In fact, the use of alternative protein sources such as solvent extracted, de-hulled soybean meal, in combination with corn gluten meal, reduces product variability and is often cost effective and a nutritionally balanced source of protein for many of our cultured species. Such modifications to the feed can only be done if the replacement strategy takes into account nutrient requirements of the species for essential amino acids, fatty acids and minerals, as well as potential palatability shifts in the diets. Approaches to reduce or eliminate marine ingredients from production diets have been successful, but there is still a need to identify limiting nutrients and further develop cost effective solutions that will ensure the long term success of the shrimp industry.

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