Alternative Lipid Sources in Aquafeeds

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Aquafeeds and Fish Oils

The global aquaculture industry is one of the fastest growing food production sectors with farmed seafood currently accounting for about 50% of all fish consumed in the world. It is estimated that aquaculture produces about 65 million tonnes of seafood valued at more than US$78 billion annually. Aquaculture is anticipated to play an increasingly important role in meeting the seafood demand of a growing human population. The rapid increase in aquaculture production worldwide has been fueled by the use of industrially manufactured aquafeeds. Conventionally, marine fish meal and fish oil are used as the major feed ingredients in the formulation of commercial aquafeeds to supply dietary protein and lipid, respectively. It is estimated that aquafeeds currently consume about 90% of the global supply of fish oil and many have predicted that the demand for fish oil from the aquaculture industry will imminently out strip supply. Marine fish oil production has not increased beyond 1.5 million tonnes for the past quarter of a century and in order to further expand, the global aquaculture industry cannot continue to rely solely on this source of lipid. The high demand, impending short supply and often times high prices makes dietary fish oil a bottle-neck in the farming of aquatic animals, and there is currently great urgency within the global aquafeed industry in finding suitable alternatives to replace marine fish oils. This article will give an overview of the various alternative lipid sources, grouped according to their main chemical characteristics. Their unique potential advantages and challenges for use in aquafeeds will be highlighted. The physiological effects of various lipid sources and their components on growth, lipid metabolism, health and post-harvest qualities of the farmed fish are briefly discussed.

Figure 1. *Stacks of imported fish oil in drums are a common sight at aquafeed mills in Asia.*

Figure 2. *The annual world production (1995-2008) of the three major vegetables oils as compared to fish oil.*

Alternative Lipid Sources

Oils and fats are characterized by their unique fatty acid composition. The major vegetable oils have one common characteristic; none contain n-3 long chain-polyunsaturated fatty acids (LC-PUFA). In contrast, marine fish oils have a high content of n-3 LC-PUFA. In consideration of the fact that the dietary fatty acid composition is mirrored in farmed fish fillet, the inclusion of alternative lipid sources in aquafeed can have significant impacts on the nutritional qualities of farmed seafood products. The n-3 LC-PUFA are known to impart health-promoting benefits to human consumers.

Saturated fatty acid (SFA)-rich plant oils include palm oil, palm kernel oil and coconut oil. Global production of crude palm oil (CPO) exceeded 43 million tonnes and together with about 9 million tonnes of coconut and palm kernel oils, constitutes a highly available and sustainable source of lipids for the aquafeed industry. When freshly extracted, CPO is the richest known natural source of β-carotene and is also a rich source of vitamin E, consisting of tocopherols and tocotrienols. Several studies have shown that various palm oil fractions can be successfully used either singly or in combination with other plant oils in the aquafeeds of commercially farmed species. The limited PUFA content, combined with the presence of natural antioxidants (in the case of CPO), has been reported to impart enhanced pellet and fillet oxidative stability. Furthermore, the overall fatty acid modification of the fish fillet is less detrimentally affected by SFA-rich oils, when compared to other alternative lipid sources. Nevertheless, concerns have been expressed on its potential negative effect on nutrient digestibility, particularly when fed to cold water fish species during the winter season.

Figure 3. *Palm oil is the most produced and fractionated oil in the world and many fractions have been successfully evaluated in aquafeeds.*

Soybean, corn, safflower, cottonseed and sunflower oils are the main n-6 PUFA-rich (namely linoleic acid, 18:2n-6) oils produced. When incorporated into aquafeeds, these n-6 PUFA-rich plant oils have been reported to be high quality sources of dietary energy and fatty acids during the grow-out cycle in most fish tested to date. However, a major concern of using these oils is that linoleic acid is abundantly and preferentially deposited in the fish fillet. Since our human diets already contain too much n-6 PUFA, some scientists believe that a good fish oil substitute should limit the deposition of these less desirable fatty acids in fish fillets. Once deposited, linoleic acid is also known to be selectively retained in fish fillets and resistant to “dilution” even after switching to a fish oil finishing diet. This may be problematic in the context of using fish oil finishing diet strategies to restore beneficial n-3 to n-6 PUFA ratios in farmed fish fillets. Several selected cultivars of these oilseeds have been recently developed to contain significantly lower concentrations of linoleic acid.

The major monounsaturated fatty acid (MUFA)-rich oil produced is rapeseed (canola) oil with olive, peanut and rice bran oils making up the rest of this class of lipids. Oleic acid (18:1n-9) and other MUFA are readily digested and β-oxidized by fish to produce energy and have been reported to have no known adverse effect on fish growth performance. Depending on market prices, rapeseed oil is currently one of the commonly utilized lipid alternatives in commercial aquafeeds, especially those formulated for cold water and temperate species.

Plant oils rich in n-3 PUFA [namely α-linolenic acid, ALA (18:3n-3), and stearidonic acid, SDA (18:4n-3)] has generated much research interest due to the ability of these fatty acids to be bio-converted into the longer chain, more unsaturated, physiologically important n-3 LC-PUFA by many farmed species, albeit mostly at limited capabilities. Despite encouraging evidence of potential bio-conversion of ALA and SDA into n-3 LC-PUFA, the inclusion of these oils (i.e. linseed/flaxseed, camelina, perilla and echium) in aquafeeds is limited, as they are currently relatively expensive and limited in supply. However, they can be useful in oil blend formulations to adjust dietary n-3 PUFA levels.

Terrestrial animal fats include tallow, poultry by-product fat and lard. About 12 million tonnes of rendered animal fats are manufactured every year around the world and are generally more economical than fish and plant oils. Animal fats represent a very diverse group of products but are generally rich in SFA although some can be rich in MUFA and contain PUFA. Their fatty acid composition is largely influenced by the diet of the livestock. For example, poultry by-product fat in Australia is enriched with MUFA as chickens are commonly fed a rapeseed-based diet, while in the USA, it has relatively higher n-6 PUFA as birds are commonly fed a soybean-based diet. Recent studies have reported that these lipid sources are well digested and utilized by most fish species. Growth performance of aquaculture species are generally not negatively impacted by dietary animal fats as long as the diets are formulated to contain sufficient amount of MUFA and PUFA to facilitate the digestion of SFA and meet the essential fatty acid requirements of the aquatic animal. Terrestrial animal fats are increasingly recognized as safe and cost-effective lipid sources when properly used in aquafeeds.

In recent years, new lipid sources containing n-3 LC-PUFA are the subject of intense research interest. These include oils derived from marine invertebrates such as copepods, krill and amphipods. Given the significantly large biomass of marine invertebrates and projecting a "safe" level of harvest, it has been estimated that these new sources have the potential to produce more marine oils than current global fish oil production. However, there are some technical concerns on the use of such oils, such as harvesting technologies and the large content of waxes and phospholipids together with great variability in fatty acid composition. One good n-3 LC-PUFA-rich source are oils derived from by-catch and fishery or aquaculture by-products. With better management and utilization, it is estimated that the total quantities of fish meal and fish oil coming from aquaculture and fishery derived waste and by-products are most likely in the range of several million tonnes. Single cell oils (from microalgae) and genetically modified oilseeds represent novel n-3 LC-PUFA-rich oils. Nutritionally, single cell oils are likely to be the best alternative to fish oil as they contain even higher amounts of beneficial n-3 LC-PUFA, but their very high production costs and limited availability make their use almost prohibitive. Oils from genetically modified oilseeds are not yet a commercial commodity and legislative issues may need to be addressed before such oils can be used in aquafeeds.

Impact of Lipid Sources on Farmed Fish

As mentioned above, dietary fatty acid composition directly influences flesh fatty acid composition, the extent of which depends on the level of substitution of fish oil, the duration of feeding and the precise fatty acid composition of the substituting oils. In general, substitution with vegetable oils results in increased proportions of C18 fatty acids (18:1n-9, 18:2n-6 and 18:3n-3), and decreased proportions of n-3 LC-PUFA (EPA, 20:5n-3 and DHA, 22:6n-3). In choosing substituting oils, we should aim to minimize these effects and so, ideally, the replacing oil should satisfy some general criteria. The oil should have a high MUFA content, not only to provide a good energy source, but also to reduce the level of C18 PUFA, which should be relatively low. For this reason, oils with high C18 PUFA, particularly 18:2n-6, should be used sparingly. The replacement oil should contain 18:3n-3, not simply for potential conversion to EPA and DHA, but also because its inclusion will help to balance the n-3/n-6 ratio and limit 18:2n-6 inclusion. Some researchers suggest that oil blends consisting of several plant oils are better in terms of health and welfare of the fish when used in aquafeeds.

Dietary fatty acid composition also influences various aspects of lipid and fatty acid metabolism. These include digestibility, lipogenesis, lipid transport and uptake, fatty acid catabolism, and fatty acid desaturation and elongation that can all influence tissue fatty acid composition. For example, the amount of dietary SFA influences the digestibility of lipids especially at low water temperatures. LC-PUFA synthesis from 18:3n-3 has been shown to be increased in fish fed diets with fish oil substituted by vegetable oils through up-regulation of desaturase and elongase gene expression and consequently increased activity of the desaturation/elongation pathway. Unfortunately this is restricted to certain species and does not occur in marine fish and crustaceans. Irrespective of species, increased synthesis of LC-PUFA is not able to compensate for the lack of dietary n-3 LC-PUFA.

Lipids and fatty acids are now known to be highly metabolically active, involved in controlling and regulating cell metabolism and animal physiology through mechanisms involving gene expression and several lipid signalling pathways. Therefore, modification of tissue fatty acid compositions can have wide ranging effects. Among the most studied are the eicosanoids (e.g. prostaglandins, leukotrienes and resolvins) that are metabolically active derivatives of LC-PUFA with important roles in mediating inflammatory and immune responses to a variety of stresses. The n-6-derived eicosanoids are pro-inflammatory whereas n-3-derived eicosanoids are either less potent or anti-inflammatory. Thus, substitution of n-3-rich fish oil by n-6-rich vegetable oils will alter the eicosanoids produced resulting in effects on inflammatory and immune responses, which can be potentially detrimental or beneficial depending upon the particular stress.

The above illustrates one mechanism whereby altered dietary fatty acids, especially n-3/n-6 balance, can affect the health and welfare of fish. However, substitution of fish oil with vegetable oils affects the immune system in several ways, including both cellular and humoral immunity, although these effects do not always alter resistance to disease. Other aspects of health status of fish that may be affected by dietary fatty acids include welfare, through altering the cortisol response to stress, tissue morphology (e.g liver and intestine) that may or may not affect organ functionality, skeletal development, cataracts, and development of atherosclerosis and cardiac lesions. However, many factors can affect stress, immunity and pathogen resistance in fish, including the type, level and duration of vegetable oil feeding, other dietary nutrients, fish species and environmental conditions.

Product quality encompasses physical aspects such as freshness and appearance, and organoleptic properties, as well as nutritional quality, which is largely defined by the n-3 LC-PUFA content. Seafood from farmed animals fed diets with high fish oil replacements remains a good source of n-3 LC-PUFA that, although reduced, are still higher than in any alternative meat or food item and so contribute positive health benefits. Impacts of dietary lipid source on physical quality aspects are few, but lower oxidation values in flesh during shelf life in fish fed vegetable oils compared to fish oil is the most consistent. Other influences include some limited effects on flesh colour, texture and gaping, and liquid holding, but not freshness, during shelf life. In most farmed species studied, taste panelists tend not to show any specific preference between fish fed different lipid sources suggesting that effects on organoleptic properties, if any, may have minimal impact on the final marketability of the product. The product quality factors can, to a large extent, be restored through the use of finishing diets rich in fish oil.

Figure 4. *Farmed seafood fed alternative lipid sources remains a good dietary source of health-promoting omega-3 fatty acids for the human consumer.*

In conclusion, in the current era of increased consumer demands for food safety, traceability and quality, the challenge for the aquaculture industry is to maintain the recognized benefits of seafood consumption for human health, especially when alternative lipids are used in aquafeed formulations, while maintaining sustainability and profitability of the industry.

Editor's note:

The subject matter of this article will be the topic of an upcoming book entitled "Fish Oil Replacement and Alternative Lipid Sources in Aquaculture Feeds" edited by the authors and published by CRC Press (Taylor and Francis Group; http://www.crcpress.com/).