# AN OVERVIEW OF LIPID NUTRITION WITH EMPHASIS ON ALTERNATIVE LIPID SOURCES IN TILAPIA FEEDS

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## Abstract

This paper presents an overview of our current knowledge on the lipid and fatty acid requirements of cultured tilapia. The importance of lipids is discussed with reference to the relatively low levels of lipids currently used in commercial tilapia feeds. The contradictory research results as to the requirement of tilapia for omega-3 and omega-6 polyunsaturated fatty acids (PUFA) are presented and recommendations as to their inclusion levels in feeds given. In this overview, we describe how tilapia respond in terms of growth performance, feed utilization and fillet quality to various dietary vegetable oils when used to replace fish oils in feeds. Research has shown that vegetable oils can replace a significant part of fish oil in tilapia feeds without affecting growth and feed utilization efficiency. The effects of vegetable oils on fish health requires further studies but the use of more saturated vegetable oils (such as palm oils) may reduce oxidative stress in tilapia thereby reducing pathological conditions associated with this condition. The supply of beneficial omega-3 PUFA in tilapia fillets to the human consumer can be maintained by using a "wash-out" feeding strategy just prior to harvesting. The use of vegetable oils such as palm oil can also add additional benefits to fillet quality and health benefits to the consumer due to the bioaccumulation of tocopherols and tocotrienols in tilapia flesh. Strategies to market nutritionally enhanced tilapia fillets are suggested.

## Overview

The intensive farming of tilapia is rapidly expanding at an annual rate of about 12% and there is currently a great demand for formulated feeds. Global tilapia aquaculture production has surpassed one million metric tons with more than 80% of the production coming from Asian countries (FAO, 1999). Feed ingredients used in commercial tilapia diets in many developing countries in Asia are mostly imported. In the production of tilapia feeds, feed manufactures are constantly faced with the need to reduce feed costs to match fluctuating and at times low ex-farm prices of tilapia. Whenever there is an increase in the cost of imported feed ingredients, this greatly cuts into the profit margin of local tilapia growers. Since fish feeds can account from 45 to 85% of the farm prices of tilapia, there is currently great interest to reduce feed costs by using locally available or alternative feed ingredients.

Fish oil is a major dietary lipid source used in tilapia feeds. Other than providing a source of energy and essential fatty acids, it is commonly used to coat the extruded pellets to improve the palatability and appearance of the feed. Other important functions of lipids include aiding in absorption of fat-soluble vitamins, precursors of hormones and prostaglandins and as building blocks of cellular and membrane structures. The stagnation in global fish oil production coupled with increased demand for its use in aquaculture feeds, especially salmonid feeds, has greatly inflated fish oil prices (Barlow, 2000). Therefore, in order to sustain the rapid growth of the tilapia industry, many developing countries where tilapia is farmed will have to partially or totally replace fish oil with cheaper and sustainable sources of dietary lipid.

An understanding of the lipid and fatty acid requirements of tilapia is needed before we can embark on a successful program to replace fish oil with vegetable oils in commercial tilapia feeds. Tilapia, like other warmwater fish, are more inclined to require greater amounts of n-6 fatty acids compared to n-3 fatty acids for maximal growth (NRC, 1993). High levels of n-3 PUFA have been reported to depress the growth of tilapia (Kanazawa *et al*., 1980; Huang *et al*., 1998) and other researchers have showed that no enhancement in growth was obtained when 18:3n-3 or n-3 HUFA (highly unsaturated fatty acids) was supplemented in tilapia diets (Takeuchi *et al*., 1983). In an earlier study, we have shown that hybrid tilapia fed a cod liver oil (CLO) diet showed a slight depression in growth and feed efficiency ratio that might be associated with the higher n-3 PUFA concentrations found in CLO (Ng et al. 2001). Growth of *O. aureus* has been reported to be depressed when fed more than 1% dietary linolenic acid (Stickney and McGeachin, 1983a). The fatty acid requirement for Nile tilapia is reported to be 0.5% for 18:2n6 (Takeuchi *et al*., 1983) and that for *Tilapia zillii* to be about 1% for 18:2n6 or 20:4n6 (Kanazawa *et al*., 1980).

However, other researchers have reported that both n-3 and n-6 fatty acids are essential for maximal growth of hybrid tilapia (Chou and Shiau, 1999). Chou *et al*. (2001) reported no growth depression in hybrid tilapia fed semipurified diets with graded levels of CLO up to 5% and suggested that hybrid tilapia may also require n-3 fatty acids for maximum growth. Santiago and Reyes (1993) observed that Nile tilapia broodfish fed 5% CLO supplemented diets had the highest weight gain but showed significantly lower reproductive performance compared to broodfish fed soybean, coconut or corn oil.

To date, research on the fatty acid requirements of tilapia has produced contradictory results. This could be due to various factors such as length of experiment, nutritional history of the experimental fish, size of fish, source of dietary lipids, water temperatures, etc. Considering the fact that fish are not able to synthesize both the omega-3 and omega-6 series of fatty acids and require them in their diets, and based on fatty acid requirements determined for other fish species, it is recommended that until further research data is forthcoming, a provision of about 0.5 to 1.0% of both omega-3 and omega-6 PUFA should be included in the aquafeeds of tilapia. The ability of Nile tilapia to synthesize the physiologically more important C20 and C22 HUFA from C18 n-6 and n-3 PUFA has been confirmed by Olsen *et al.* (1990) using radiolabelled $^{14}$C-18:2n-6 and 18:3n-3. However, the elongation and desaturation of these essential C18 fatty acids to their HUFA end products is probably insufficient to supply the needed amounts and dietary supplementation with preformed

HUFA may still be necessary. More research is still needed to understand the activities of the various desaturation/elongation pathways in tilapia.

Chou and Shiau (1996) reported that a minimum of 5% dietary lipid should be provided in feeds for hybrid tilapia. Fitzsimmons *et al*. (1997) did not find any significant differences in growth, feed utilization efficiency and fillet fat levels in Mozambique tilapia fed diets containing 3,6 or 8% dietary lipid and suggested that lower levels of dietary lipid could be used in tilapia feeds for intensive recirculation production systems provided the energy value of the diet is provided by suitable carbohydrate sources. Commercial tilapia feeds currently contain about 5% dietary oils, mostly fish oils, which meet the minimum requirement of dietary lipids in most culture systems. However, optimum dietary lipid level for various tilapia species has been reported to be between 10% and 15% depending on dietary ingredients used (El-Sayed and Garling, 1988; Chou and Shiau, 1996). Studies on *T. zilli* (El-Sayed and Garling, 1988) indicated that graded levels of dietary oil up to 15% improved protein utilization efficiency. Recent technological advances in aquafeed manufacturing has permitted the inclusion of high levels of dietary oils to produce energy-dense diets, especially in salmon diets which usually contains 20 to 40% added oils. With the availability of such technology and the increasing environmental challenges facing intensive aquaculture today, more research is needed to evaluate whether higher dietary lipids in commercial tilapia feeds might give added benefits to both the fish farmer and the environment.

Using semipurified casein-based diets, Huang *et al*. (1998) reported that hybrid tilapia (*Oreochromis niloticus* x *O. aureus*) fingerlings fed 8% soybean oil or fish oil showed no difference in growth and feed utilization efficiency after 10 weeks on the diets. Oxidative stress (as measured by TBARS test) in fish fed soybean oil or fish oil was similar but significantly higher than fish fed diets containing lard. No significant differences were detected in growth of *O. aureus* fed diets supplemented with 10% menhaden oil, catfish oil or soybean oil but growth was depressed in fish fed diets supplemented with beef tallow (Stickney and McGeachin, 1983b). Gaber (1996) reported good growth of Nile tilapia fed soybean oil-based diets. Hybrid tilapia fed diets supplemented with vegetable oils such as sunflower oil, crude palm oil (CPO), crude palm kernel oil or palm fatty acid distillates (PFAD) showed comparable or slightly higher growth compared to fish fed a fish oil-based diet (Ng *et al*., 2001). Other studies currently conducted in our lab (Fish Nutrition Laboratory, University Sains Malaysia, Penang, Malaysia) similarly showed that the use of vegetable oils such as linseed, soybean and various palm oil products do not significantly affect growth performance and feed utilization of tilapia (unpublished data). This is consistent with fish oil replacement studies conducted on other fish species (Kaushik, 2004; Ng, 2004; Ng *et al*., 2004).

Despite the lack of growth effects when using vegetable oils to replace fish oils in fish diets, fillet fatty acid profile is known to be markedly influenced by dietary fatty acid compositions. The use of vegetable oils (lacking in EPA and DHA) in tilapia feeds will decrease the concentrations of beneficial omega-3 HUFA in fish fillets destined for the human consumer. EPA and DHA are known to provide positive health benefits such as decreasing the risks of degenerative diseases such as cardiovascular diseases, cancer and many others. A recent study in our lab showed that the fatty acid composition of fillets of hybrid tilapia raised to marketable size (after 5 months) reflected that of dietary oils used (Figures 1 and 2) with a marked decrease in omega-3 HUFAs in fish fed 100% added soybean oil (SBO) or crude palm oil (CPO). Reduction in omega-3 HUFA in the fillets of tilapia fed diets with CPO blended with fish oil (FO) or linseed oil (LSO) were not as drastic.

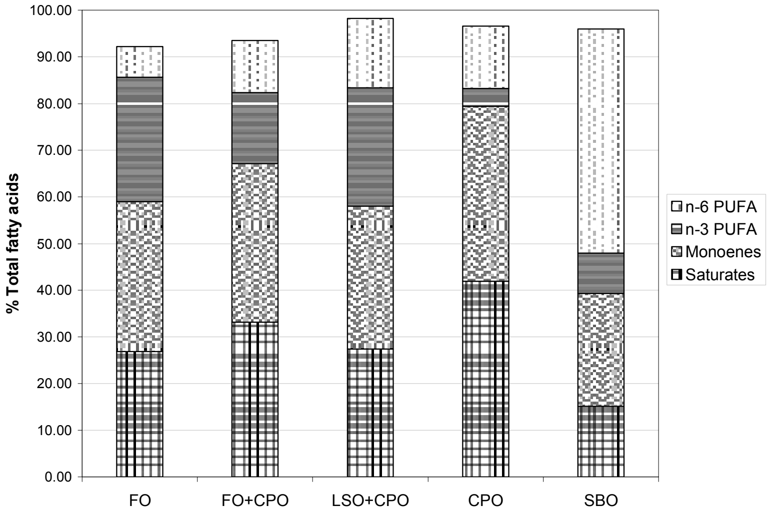


Figure 1. Experimental diet fatty acid composition.

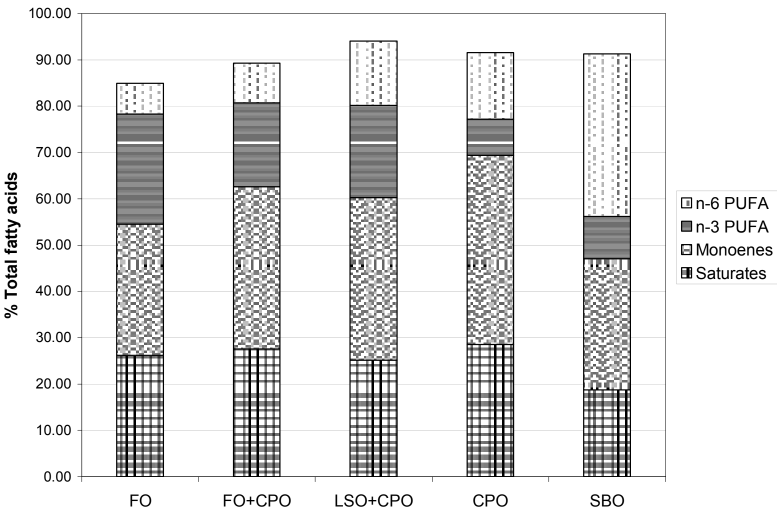


Figure 2. Tilapia fatty acid composition after feeding diets with various added oils for 5 months.

Other than finding an appropriate blend of fish oil, vegetable oil in tilapia diets, another innovative strategy that can be used to normalize the flesh levels of beneficial omega-3 HUFA is to revert back to a fish oil-based diet at an appropriate time before harvest. This feeding strategy will allow the use of higher levels of vegetable oils in tilapia diets for the major part of the grow-out phase thus providing cost savings without significantly altering the health benefits of the resultant fish fillet for the human consumer. Nevertheless, even after 3 months of "wash-out" using a fish oil finishing diet, fillets of tilapia fed 100% added CPO or SBO were still significantly lower compared to fillets of fish fed a fish oil diet throughout even though significant deposition of omega-3 HUFAs were observed (Figure 3). The total omega-3 content of tilapia fillets in fish fed blended oils (fish oil or linseed oil with CPO; 1:1) were restored to values comparable to that found in fish fed the 100% fish oil diet. After 1 month of FO feeding, n-3 PUFA in fillets from fish fed LSO+CPO was increased and did not significantly differed from fish fed FO. After 2 months of the washout phase, n-3 PUFA in fish fed the FO+CPO diet was not different significantly compared to those fed FO and LSO+CPO diet.

The use of vegetable oils such as soybean oil that contains very high levels of linoleic acid will cause high levels of this fatty acid to be deposited in the tilapia fillets (Figures 2 and 4). Despite a significant drop in linoleic levels in tilapia fillets after the "wash-out" period (Figure 4), levels were still significantly higher compared to fish fed the other diets.

A major dietary concern to human nutritionists in recent years is the increase in the intake of omega-6 fatty acids relative to omega-3 fatty acids. Omega-3 to omega-6 ratio varies from 1:2.5 for Inuit Eskimos on a fish-based diet to 1:20 for many urban dwellers on modern diets rich in vegetable oils. Eskimos who rely on their traditional diets are relatively free of degenerative diseases common to urban dwellers. Since modern human diets already contain too much omega-6 PUFA, a good fish oil substitute should limit the deposition of these fatty acids in fish fillets. In this respect, vegetable oils such as linseed oil (rich in 18:3n-3) and palm oil (rich in monoenes) are superior alternatives compared to other vegetable oils for use in replacing fish oils in aquafeeds.

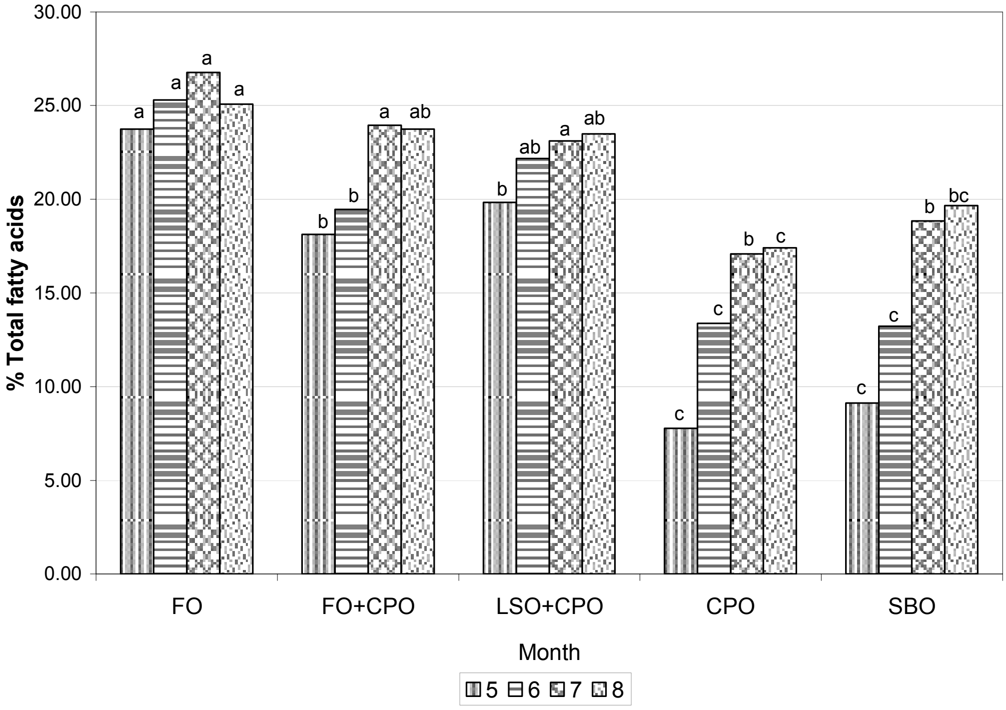


Figure 3. Total n-3 fatty acids in tilapia fillet after reverting back to a fish oil-based diet for 3 months. Bars assigned with different letters, within each month, are significantly different ($P < 0.05$).

The relative ease whereby the fatty acid composition of tilapia fillets can be manipulated and tailored by altering the fatty acid composition of their diets is a positive aspect of farmed tilapia which can be exploited by feed manufacturers to cater for the discerning consumer. Recent studies in our lab (Ng *et al*., 2004; Wang *et al*., 2004) has also shown that when tilapia are fed palm oil-based diets, potent natural antioxidants such as tocopherols and tocotrienols are deposited in their fillets. Other than imparting antioxidant properties to the tilapia fillets thereby prolonging self-life and seafood freshness,

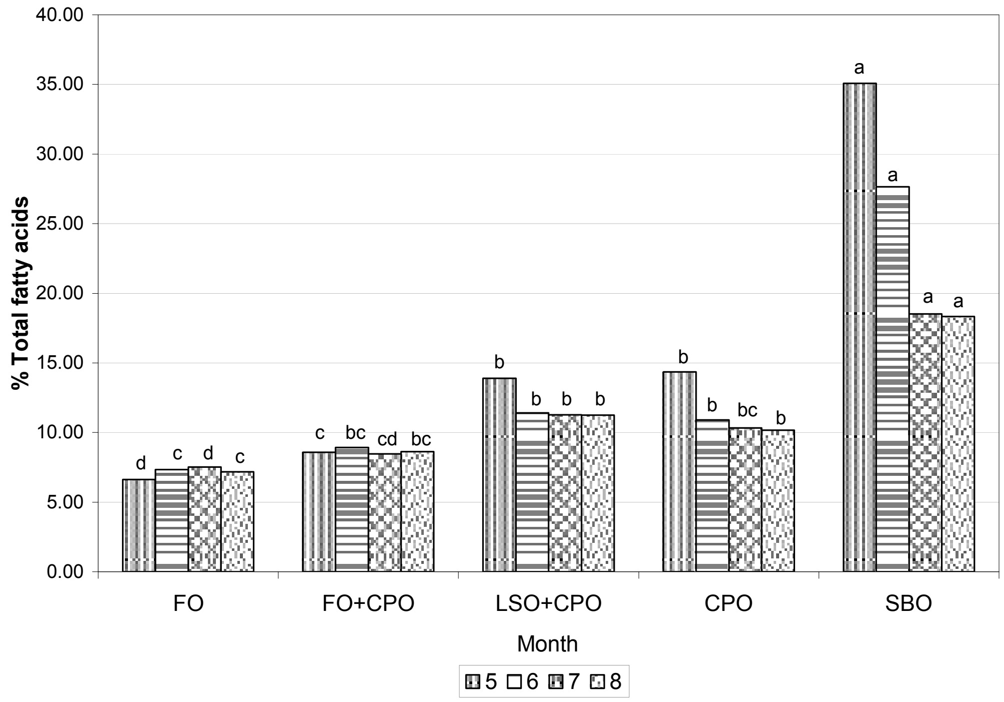


Figure 4. Total n-6 fatty acids in tilapia fillet after reverting back to a fish oil-based diet for 3 months. Bars assigned with different letters, within each month, are significantly different (P < 0.05).

the deposition of tocotrienols also adds value to the product, especially if eaten raw as sushi or sashimi. The potential health benefits of tocotrienols in humans may include beneficial effects on the prevention of cardiovascular diseases and cancer. Niche markets may therefore be developed for these nutritionally enhanced tilapia fillets.

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