Palm Oil as a Novel Dietary Lipid Source in Aquaculture Feeds

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INTRODUCTION

One key ingredient used in the formulation of aquaculture feeds is fish oil, which is produced from small marine pelagic fish and represents finite fishery resources. Other than providing a source of energy and essential fatty acids, it is commonly used to coat extruded feed pellets to improve the palatability and appearance of the feed. Aquafeeds currently use about 70% of the global supply of fish oil and by 2010, fish oil use in aquaculture is estimated to reach about 97% of the world supply. At present, global fish oil production has reached a plateau and is not expected to increase beyond current levels. Recent estimates suggest that fish oils may be unable to meet demands from the rapidly growing aquaculture industry as early as 2005. The stagnation in global fish oil production, coupled with increased demand for its use in aquaculture feeds, has greatly inflated fish oil prices (Barlow, 2000). Fish oil production is also heavily localized in specific regions of the temperate world resulting in it becoming increasingly expensive and difficult to obtain in many tropical countries practicing aquaculture. Therefore, there is currently great urgency within the aquafeed industry in evaluating alternatives to fish oil.

One potential replacement for fish oil in aquafeeds is palm oil. Global production of crude palm oil (CPO) exceeds 28 million tonnes and is the most traded and abundantly available vegetable oil in the world. The aim of this paper is to review the major studies conducted to date on the use of palm oil products in the diets of various fish species.

PALM OIL PRODUCTS FOR FISH FEED FORMULATION

Palm oil is extracted from the mesocarp of the fruit of the oil palm, *Elaeis guineensis*. CPO has a deep orange-red colour due to the high content of carotenoids and is a rich source of vitamin E consisting of tocopherols and tocotrienols (Nesaretnam and Muhammad, 1993). Both beta-carotenes and vitamin E are well known nutritional antioxidants. During refining of CPO, the carotenoids present are thermally destroyed and the oil bleached to produce the desired colour for a refined, bleached, deodorized (RBD) palm oil. Two by-products produced in the refining of CPO are spent bleaching clay (SBC) and palm fatty acid distillates (PFAD). Both SBC and PFAD still contain significant amounts of valuable nutrients such as lipids and vitamin E. To widen the range of its use, RBD palm oil is fractionated by thermomechanical processes to produce RBD palm olein and RBD palm stearin. Crude palm kernel oil (CPKO) is extracted from palm kernels with palm kernel cake as a by-product. The physical and chemical properties of the various palm oil products have been reviewed by Chong (1993).

The ever expanding oil palm cultivation in Malaysia and other tropical countries offers the possibilities of an increased and constant availability of palm oil-based feedstuffs for aquaculture feed formulations. Novel locally available sources of energy, lipids and vitamins from palm oil products and by-products will contribute to the development of cost-effective pelleted feeds for the aquaculture industry.

POSITIVE EFFECTS OF PALM OIL IN FISH DIETS

Comparable Growth Performance

Research into the use of palm oil in fish diets only started around mid 1990s. Viegas and Contreras (1994) reported that tambaqui (*Colossoma macropomum*) fingerlings fed diets with higher percentages of CPO as a dietary lipid showed better performance (compared to fish fed a deodorized distillate of soyabean oil) in terms

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of length gain and protein efficiency ratio but no significant differences were observed in fish weight gain and feed conversion ratios. Fish fry of an African catfish, *Heterobranchus longifilis*, showed the highest growth when fed experimental diets containing palm oil compared to fish fed diets with copra, peanut, cottonseed or cod liver oil as the lipid source (Legendre *et al*., 1995). Al-Owafeir and Belal (1996) reported that palm oil could replace soyabean oil in feeds for Nile tilapia, *Oreochromis niloticus*, without any negative effects on fish growth or body composition. Climbing perch, *Anabas testudineus*, fed 20% dietary palm oil grew just as well as fish fed a similar level of coconut oil or cod liver oil (Varghese and Oommen, 2000). Growth of adult Atlantic salmon fed 29.5% dietary palm oil was not significantly different compared to fish fed diets with a similar level of capelin oil, oleic-enriched sunflower oil or a mixture (1:1 w/w) of capelin oil and oleic-enriched sunflower oil (Tortensen *et al*., 2000). Other research into the use of CPO in the diets of Atlantic salmon (Rosenlund *et al.*, 2001; Bell *et al*., 2002) had similarly reported growth and feed utilization efficiency comparable to fish fed equivalent levels of dietary marine fish oils.

Studies conducted in the Fish Nutrition Laboratory at Universiti Sains Malaysia with a tropical bagrid catfish, *Mystus nemurus*, showed that 90% of fish oil in their diets could be replaced by RBDPO or CPO without affecting growth, feed utilization efficiency or body composition (Ng *et al.*, 2000). In another study (Ng *et al.*, 2003), African catfish, *Clarias gariepinus*, was observed to show better growth when fed semi-purified diets containing 10% palm oil as the sole dietary lipid compared to fish fed cod liver oil-based diets. It would seem that certain species of catfish have very low requirements of n-3 fatty acids (from fish oil) and the use of palm oil in the diets of these fish have great potential. Hybrid tilapia (*Figure 1*) fed diets supplemented with vegetable oils such as sunflower oil, CPO, CPKO or PFAD showed comparable or slightly higher growth compared to fish fed a fish oil-based diet (Ng *et al.*, 2001). Research carried out in collaboration with the Institute of Aquaculture, University of Stirling (Scotland), BioMar AS (Norway) and BioMar Ltd. (U.K.) on Atlantic salmon had shown similar encouraging results (Ng *et al.*, 2004).

In this respect, palm oil is similar to other vegetable oils that had been reported in numerous scientific papers to be able to replace a significant part of fish oil in fish diets without negatively affecting growth, feed utilization and survival. Nevertheless, in addition to its low cost and high availability, palm oil also has many additional advantages over other vegetable oils when used in aquafeed formulations.

Reduces Feed Rancidity and Oil Leakage

Conventional vegetable oils are highly susceptible to attack by atmospheric oxygen resulting in rancidity. The low concentrations of polyunsaturated fatty acids (PUFA) in palm oil give it exceptional resistance to oxidation. Together with the protective effects of potent natural antioxidants (carotenoids and vitamin E) in palm oil, the incidence of feed rancidity is substantially reduced when palm oil is used in aquafeed formulations. Aquafeeds can therefore be stored longer while maintaining freshness and palatability. The inclusion of palm oil in salmonid feeds will also reduce the incidence of oil leakage common in such high lipid diets. This is because palm oil is semi-solid with a higher melting point compared to other vegetable oils and fish oils. The use of palm oil can reduce the migration of lipids to the pellet surface that causes loss of valuable nutrients, staining of packaging materials and feed equipment.

Palm Oil is a Superior Energy Source

Palm oil is a superior source of dietary energy. *In vitro* studies done on mitochondrial β-oxidation in fish suggest that there exists a substrate preference for saturated and monounsaturated fatty acids

Figure 1. Red hybrid tilapia fed palm oil-based diets up to marketable size.

over PUFA (Henderson and Sargent, 1985). Palm oil contains abundant saturates (48%) and monoenes (42%). Studies done in our laboratory have shown the protein sparing effect of palm oil in catfish diets (Lim *et al*., 2001). We found that growth and feed efficiency of *C. gariepinus* responded significantly in a positive manner to palm oil additions of up to 8% (in isoenergetic diets) with no further improvement beyond this dietary level. Protein sparing effects resulting in higher protein retention in fish fed RBDPO-supplemented diets were also observed.

Improved Fillet Quality

While most vegetable oils contain almost exclusively tocopherols, palm oil is unique because tocotrienols represent about 70%-80% of the vitamin E content. We have recently shown that the deposition of palm vitamin E in the fillets of tilapia fed a tocotrienol-rich fraction extracted from palm oil imparts higher oxidative stability compared to the fillets of fish fed diets supplemented with equivalent levels of dietary synthetic α-tocopherol acetate (Wang *et al*., 2004). Fillets of catfish fed increasing levels of dietary PFAD also showed increasing deposition of vitamin E with subsequent reduction in lipid peroxidation products (*Figure 2*; Ng *et al.*, 2004). This would translate to longer shelf life for seafood products. Alpha-tocopherol concentrations in muscle and liver tissues increased linearly in response to increasing dietary α-tocopherol originating from RBDPO and CPO (Lim *et al*., 2001). The level of vitamin E in fish muscle is known to influence the freshness and long-term storage properties of fish fillets. The use of palm oil, and especially CPO and PFAD, in fish diets has great potential as a practical and cost-effective means of adding value to the flesh quality of aquaculture products. Further research into the biopotency and bioavailability of palm tocopherols and tocotrienols and their roles in flesh quality improvement is currently being conducted.

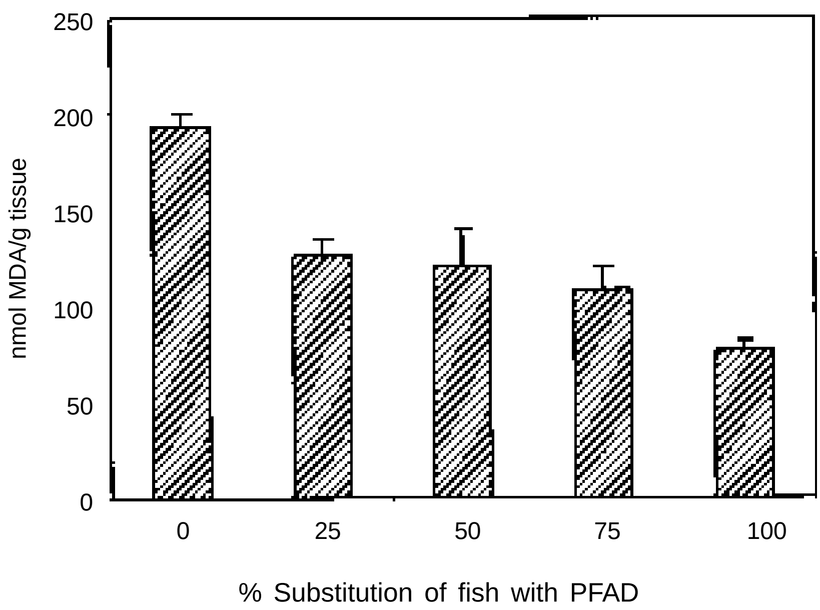

Figure 2. *Thiobarbituric acid-reactive substances in catfish fillets from fish fed diets with increasing levels of palm fatty acid distillate (PFAD) expressed as nmole malonaldehyde (MDA) per gramme tissue. Values are means ± SE, n = 3.*

The deposition of tocotrienols in fish fillets (Ng *et al*., 2004) also adds value to the product, especially if eaten raw as sashimi, since the potential health benefits of tocotrienols in the human diet may include the prevention of cardiovascular diseases and cancer. It may also increase the market value and consumer acceptance of salmon steaks in which pigmentation is a quality parameter. The potential accumulation of palm vitamin E in salmon flesh would slow down the oxidation of these pigments thereby maintaining colouration for longer periods. Further research is being planned along these lines.

Beneficial to Fish and Consumers' Health

Feeding high levels of fish oil and vegetable oils that contain a high proportion of PUFA that are highly susceptible to oxidation can also lead to increased oxidative stress for the fish that may result in pathological conditions. One practical and cost-effective way to produce high-energy diets without the damaging side effects of increased lipid radicals is to use a more saturated lipid source that contains high levels of natural antioxidants such as vitamin E. These are found in palm oil.

Contemporary human diets have caused our intake of omega-6 fatty acids to increase, drastically altering dietary omega-3 to omega-6 ratios. These ratios vary from 1:2.5 for Eskimos on a fish-based diet to 1:20 for modern diets rich in vegetable oils. Eskimos who rely on their traditional diets are relatively free of degenerative diseases common to urban dwellers. It is generally known that the fatty acid composition of fish fillets reflects the fatty acid composition of the dietary oil used. Since our diets already have too much omega-6 PUFA, a good fish oil substitute should limit the deposition of these undesirable fatty acids in fish fillets. This makes palm oil superior to most conventional vegetable oils that contain high proportions of omega-6 PUFA that would be deposited in fillets when used in fish feed formulations.

Further Research Needs

Palm oil does not contain omega-3 highly unsaturated fatty acids (HUFA), which are required by some fish, especially marine species. Consequently, palm oil in the diets of these fish should be formulated with HUFA sources such as fish oil and fishmeal to assure that the minimal HUFA requirements are met.

Apart from not prejudicing the health and welfare of fish, the use of palm oil products in aquafeeds should also not affect the taste and health promoting benefits to the consumer (especially in terms of its n-3 PUFA content). In all the studies conducted using palm oil where the fatty acid composition of the fish fillet was determined, it was observed that fish fed palm oil diets generally show a fatty acid profile similar to that present in their diet. The use of high levels of palm oil in fish diets will decrease the concentrations of beneficial omega-3 HUFA in fish fillets destined for the human consumer (Bell *et al*., 2002; Ng *et al*., 2003; 2004). One strategy that can be used to normalize the flesh levels of beneficial omega-3 HUFA is to revert to a fish oil-based diet at an appropriate time before harvest. This feeding strategy will allow the use of higher levels of palm oil in fish diets for the major part of the grow-out phase thus providing feed cost savings without significantly altering the health benefits of the resultant fish fillet in the human diet. These, and other aspects of fish oil substitution, will need to be thoroughly investigated.

The high melting point of palm oil may also pose a problem when used in the diets of coldwater fish. The water temperature is low during winter season and we found that this reduces lipid and fatty acid digestibility in rainbow trout and Atlantic salmon fed high levels of dietary palm oil (Ng *et al*., 2003; 2004). Nevertheless, growth performance was not compromised even at 100% replacement of added fish oil. The reduced lipid digestibility was due in part to the increasing resistance of dietary triglycerides to digestion. Future research plans include using emulsifiers and palm free fatty acids to facilitate absorption of this lipid source at lower water temperatures.

CONCLUSION

In summary, information on the use of palm oil products in fish diets is currently limited to a few species. Some fish species seems to be able to effectively utilize high levels of palm oil in their diets both as dietary energy and fatty acid sources without adverse effects on growth and feed utilization efficiency. Since different fish have different abilities to utilize various dietary lipids, more research work is necessary to fully investigate the use of palm oil in fish diets. The price of palm oil is much lower than other vegetable oils such as soyabean and rapeseed oils, which are imported by tropical countries like Malaysia. Considering the lower price and high availability of palm oil in the tropics, its potential as an alternative dietary lipid source for fish warrants further investigation. Enhancing the use of palm oil in aquafeeds will decrease feed costs, decrease demand for fish oil and reduce environmental pollution (in the case of SBC). Each of these will have a positive impact on the aquaculture industry and also on the palm oil industry.

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