Review Article

Potential of palm oil utilisation in aquaculture feeds

Wing-Keong Ng PhD

Fish Nutrition Laboratory, School of Biological Sciences, Universiti Sains Malaysia, Penang, Malaysia

One key ingredient used in the formulation of aquafeed is fish oil, which is produced from small marine pelagic fish and represents a finite fishery resource. At the present time, 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 by as early as 2005. Therefore, there is currently great interest within the aquafeed industry in evaluating alternatives to fish oils. The ever-expanding oil palm cultivation in Malaysia and other tropical countries offers the possibility of an increased and constant availability of palm oil products for aquafeed formulation. Research into the use of palm oil in aquafeed begun around the mid-1990s and this review examines some of the findings from these studies. The use of palm oil in fish diets has generally shown encouraging results. Improved growth, feed efficiency, protein utilisation, reproductive performance and higher concentrations of α-tocopherol in fish fillets have been reported. Recent evidence for the ability of palm oil to substitute for fish oil in catfish diets is reviewed. The potential of palm oil use in aquafeed and future experimental directions are suggested. The aquaculture feed industry offers a great avenue to increase and diversify the use of palm oil-based products.

Key words: aquaculture, α-tocopherol, aquafeed, fish oil, fish, palm oil.

Introduction

Aquaculture is currently the fastest growing animal production sector in the world, expanding at an average annual rate of about 11% since 1984.[1] Aquaculture production is expected to continue to increase at a rapid pace to meet the seafood demand of a growing human population and to compensate for the shortfall in wild-caught fish due to the overexploitation of many capture fisheries.[2] This predicted increase in aquaculture production must be supported by a corresponding increase in the production of formulated diets for the cultured aquatic animals.

Artificially formulated diets (aquafeed) play a crucial role in sustaining the continued expansion of aquaculture production, mainly because feed can make up 50% or more of the production cost of most aquaculture systems. One key ingredient used in the formulation of aquafeed is fish oil, which is used to supply dietary energy and essential fatty acids. Fish oil is produced from small marine pelagic fish and represents a finite fishery resource. At the present time, global fish oil production has reached a plateau and is not expected to increase beyond current levels. The rapidly growing aquaculture industry cannot continue to rely on finite stocks of marine pelagic fish for fish oil supply. Fish oil production is also heavily localised 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 interest within the aquafeed industry in evaluating alternatives to fish oil.

One potential substitute for fish oil in aquafeed is palm oil, which is the second largest volume of vegetable oil produced in the world today. 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 and by-products

Crude palm oil is extracted from the mesocarp of the fruit of the oil palm tree, *Elaeis guineensis*. Palm oil and its refinery products are now consumed worldwide as cooking oil, margarine and shortening, and is also incorporated into fat blends and a wide variety of food products.[3] The beneficial nutritional properties of palm oil for human consumption have been well researched and documented.[4,5]

Crude palm oil (CPO) has a deep orange-red colour due to the high content of carotenoids. It is also a rich source of vitamin E, namely tocopherols and tocotrienols.[5] Both β-carotene and vitamin E are well-known nutritional antioxidants. During the refining of CPO, apart from removing impurities in the oil, the carotenoids present are thermally destroyed to produce the desired colour for a refined, bleached, deodorised (RBD) palm oil.[6] To widen the range of its use, RBD palm oil can be fractionated by thermomechanical processes to produce RBD palm olein (used mainly as cooking oil) and RBD palm stearin (used mainly in margarines and shortenings). Differences in the physical

Correspondence address: Dr Wing-Keong Ng, Fish Nutrition Laboratory, School of Biological Sciences, Universiti Sains Malaysia, Penang 11800, Malaysia.
Tel: +60 4 6577888, ext. 4005; Fax: +60 4 6565125
Email: wkng@usm.my

and chemical properties of CPO, RBD palm oil, RBD palm olein and RBD palm stearin have been reviewed by Chong.[7]

Two by-products produced during the refining of CPO are spent bleaching clay (SBC) and palm fatty acid distillates (PFAD). In the case of SBC, about 20 000 tons is generated for every million ton of palm oil processed,[8] and is currently discarded in landfills. Both SBC and PFAD still contain significant amounts of valuable nutrients such as lipids, vitamin E and carotenoids. Crude palm kernel oil (CPKO) is extracted from palm kernels with palm kernel cake as a by-product.

The ever-expanding palm oil cultivation in Malaysia and other tropical countries offers the possibility of an increased and constant availability of palm oil-based feedstuff for aquaculture feed formulations. Non-conventional locally available sources of energy, lipid and vitamin from palm oil products and by-products will contribute to the development of low-cost pelleted feeds for the aquaculture industry. The potential utilisation of waste products from palm oil refineries will also contribute to alleviating environmental pollution.

Palm oil in fish diets

Research into the use of palm oil in fish diets only started around the mid-1990s, and limited information is available (Table 1). Viegas and Contreras 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 deodorised distillate of soybean oil) in terms of length gain and protein efficiency ratio, but no significant differences were observed in fish weight gain and feed conversion ratios.[9] They later reported that tambaqui fed up to 6% palm oil did not show any negative effect in terms of flesh quality parameters such as flavour and colour.[10]

Al-Owafeir and Belal reported that palm oil could replace soybean oil in feeds for Nile tilapia (*Oreochromis niloticus*) without any negative effects on fish growth or body composition.[11] Shiranee and Natarajan reported that practical diets with added CPO had a positive influence on ovarian development and maturation of the pearlspot (*Etroplus suratensis*) when fed together with 1% fish oil.[12] Fish fed this diet showed a higher gonadosomatic index, higher percentage of ripe fish and larger eggs. They speculated that this positive effect of CPO on the reproduction of pearlspot might be due to its high carotenoid and tocopherol content.[12] Carotenoids and vitamin E have been reported to play an important role in the reproductive performance of fish[13] and the role of dietary CPO warrants further investigation. Shiranee and Natarajan also reported that pearlspot fed 4% CPO in their diets did not affect the organoleptic characteristics of fish fillet.[14]

Climbing perch (*Anabas testudineus*) fed 20% dietary palm oil grew just as well as fish fed a similar level of coconut or cod liver oils.[15] However, Varghese and Oommen reported increased hepatic 3-hydroxy-3-methyl-glutaryl conenzyme A (HMG-CoA) reductase activity in fish fed the palm oil diet, which might have accounted for the higher cholesterol content found in the liver of these fish.[15] Fish fed palm oil or coconut oil showed significantly lower levels of lipid peroxidation products such as thiobarbituric acid reactive substances (TBARS) and conjugated dienes in the liver compared to fish fed cod liver oil diets.

The growth of adult Atlantic salmon fed 29.5% dietary palm oil was not significantly different 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.[16] In contrast to Varghese and Oommen, Torstensen *et al.* did not find any increase in plasma or lipoprotein cholesterol levels in Atlantic salmon fed high dietary levels of palm oil.[16] They speculated that this might have been due to the low digestibility of the saturated fatty acids of palm oil to Atlantic salmon.

Beneficial effects of palm oil in catfish diets

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 oils as the lipid source.[17] The lowest growth was observed in fish fed the cod liver oil diet. In a recent study in our laboratory (Ng *et al.* unpubl. obs., 2001), another African catfish, *Clarias gariepinus*, was observed to show the lowest growth when fed semipurified diets containing 10% cod liver oil as the sole dietary lipid compared to fish fed palm oil-based diets (Table 1). 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 has great potential. Studies with a tropical bagrid catfish (*Mystus nemurus*) showed that 90% of fish oil in their diets could be replaced by RBD palm oil (RBD-PO) or CPO without affecting growth, feed utilisation efficiency or body composition.[18]

In another study, we found that growth and feed efficiency of *C. gariepinus* responded significantly in a positive manner to palm oil additions of up to 8%, with no further improvement beyond this dietary level.[19] Protein sparing effects resulting in higher protein retention in fish fed RBD-PO-supplemented diets were observed. α-Tocopherol concentrations in muscle and liver tissues increased linearly in response to increasing dietary α-tocopherol originating from RBD-PO and CPO. The level of vitamin E in fish muscle has been reported to influence the freshness and long-term storage properties of catfish fillets.[20,21] The use of palm oil, and especially CPO, in fish diets has great potential as a practical and cost effective means of adding value to the flesh quality of aquaculture products. Now that we know vitamin E from palm oil can be concentrated in fish flesh, further research into the biopotency and bioavailability of palm tocopherols and tocotrienols and its role in flesh quality improvement is needed.

Concluding remarks

In summary, information on the use of palm oil products in fish diets is limited to a few species. Tropical catfish seem to be able to effectively utilise high levels of palm oil in their diets, both as dietary energy and fatty acid sources, without adverse effects on growth and feed utilisation efficiency.

Table 1. Summary of positive effects of palm oil utilisation in aquafeed

Common name	Species name	Palm oil product	Dietary level (%)	Positive effects
Pearlspot	*Etroplus suratensis*[14]	CPO	4	Did not negatively affect organoleptic characteristics of fillet.
	E. suratensis[12]	CPO	4	Positive influence on ovarian development and maturation when fed together with 1% fish oil.
Tambaqui	*Colossoma macropomum*[9]	CPO	Up to 6	Diets containing a higher percentage of palm oil showed better overall growth.
	C. macropomum[10]	PO	Up to 6	Did not negatively affect flesh quality such as flavour and colour.
Nile tilapia	*Oreochromis niloticus*[11]	PO	1–3	Can replace soybean oil without negatively affecting growth or body composition.
Climbing perch	*Anabas testudineus*[15]	PO	20	Similar growth compared to fish fed coconut oil or cod liver oil.
				Reduction in lipid peroxidation products.
Atlantic salmon	*Salmo salar*[18]	PO	29.6	Similar growth, feed efficiency and protein utilisation to fish fed capelin oil, oleic-enriched sunflower oil or 1:1 (w/w) mixture of capelin oil and oleic-enriched sunflower oil.
				Did not increase plasma or lipoprotein cholesterol levels.
Bagrid catfish	*Mystus nemurus*[19]	CPO	5 and 9	Fish fed 9% RBD-PO showed enhanced growth.
		RBD-PO		CPO-fed fish showed similar growth compared to fish fed cod liver, corn or soybean oils.
African catfish	*Heterobranchus longifilis*[17]	PO	7.5	Survival of fish larvae fed palm oil diets was similar to fish fed diets with cod liver, copra, peanut or cottonseed oils, or with *Artemia* nauplii.
	Clarias gariepinus[19]	CPO	8, 12 and 16	Improved growth and feed utilisation efficiency.
		RBD-PO	4, 8, 12 and 16	Protein sparing effects.
				Fish fed RBD-PO-based diets showed increased protein retention.
				Increased α-tocopherol concentration in muscle and liver tissues of CPO-fed fish.
	C. gariepinus	CPO	10	Fish fed palm-based oils performed better than fish fed cod liver oil diets and
		RBD-PO	10	showed similar growth to fish fed sunflower oil diets.
		CPKO	10	α-Tocopherol present in various palm oils was concentrated in muscle tissues.
		PFAD	5	
		SBC (residual oil)	5	

CPKO, crude palm kernel oil; CPO, crude palm oil; PFAD, palm fatty acid distillates; PO, palm oil; RBD, refined, bleached, deodorised; SBC, spent bleaching clay.

Because different fish have different abilities to utilise 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 soybean and corn oil, which are imported into 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 aquafeed 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 the palm oil industry.

Apart from not prejudicing the health and welfare of fish, the use of palm oil products in aquafeed should also not affect the taste and health-promoting benefits to the consumer, especially in terms of its n-3 polyunsaturated fatty acid (PUFA) content. In all the studies listed in Table 1 where the fatty acid compositions of the fish were determined, it was observed that fish fed palm oil diets generally show a fatty acid profile similar to that present in their diet. Therefore, in certain cases, it might be necessary to manipulate the nutritional quality of a fish in terms of its n-3 PUFA content by feeding it a fish oil-based diet to restore its eicosapentaenic acid and docosahexahoic acid concentrations before reaching marketable size. If such a strategy is successful, fish diets containing high levels of palm oil could be used for the majority of the culture period, with only a short reversion to a fish oil-based diet to manipulate the end-product quality of the fish. These and other aspects of fish oil substitution will need to be thoroughly investigated.

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