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Fish-Oil Finishing Diets: A strategy to recover long-chain polyunsaturated fatty acids in Fish previously fed alternative dietary lipids

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ABSTRACT

The global aquaculture industry is one of the fastest growing food production sectors, playing an important role in fulfilling the seafood demand of a growing human population. Marine fish oils have been widely used as the main lipid source in feeds for farmed fish being a good and only reliable source of n-3 highly unsaturated fatty acids (n-3 HUFAs). Although the fish oil production has remained static, the demand for fish oil is increasing over recent years. Thus the current trend is finding the suitable alternatives to fish oils in aquafeeds, without compromising overall growth performance and final nutritional quality of farmed fish. The terrestrial alternative lipids (vegetable oils and animal fats) are the poor sources of n-3 HUFAs. The flesh of farmed fish raised on feeds containing alternative lipids may contain limited amount of n-3 HUFAs. One way to reduce to the use of declining fish oil resources in aquafeeds and to improve the nutritional quality (in terms of n-3 HUFAs)of farmed fish fed on alternative lipids, may be to use finishing feeds containing fish oil before harvesting. This review attempts to compile all principal information available regarding the efficacy of finishing feeding strategy in aquaculture.

Keywords: Fish oil, Alternative lipids, Finishing feeds, n-3 HUFAs

INTRODUCTION

Since the late 1980s, with capture fishery production relatively static, aquaculture has been responsible for the impressive growth in the supply of fish for human consumption (SOFIA, 2016). During the last 25 years, aquaculture production grew by up to 8.5% annually (FAO, 2012) and currently covers roughly half the global demand for fish and fish products for human consumption. The rapidly increasing aquaculture industry has been fuelled by the subsequent use of manufactured aqua feeds. Conventionally, fish oil (FO) is one of the key biological sources of feeding components for aquaculture.

FO-enriched feeds used in aquaculture currently accounts for up to 87% of the global supply of FO as a lipid source (Tacon et. al., 2006). Thus, the challenge for fish nutritionists is to reduce the utilization of fish oil in aqua feed formulations with readily available and more economical terrestrial alternatives (Turchini et. al., 2009). In comparison with terrestrial alternatives (vegetable oils and animal fats), fish oils used in aquaculture feeds are highly enriched in beneficial omega-3 polyunsaturated fatty acids (n-3 PUFA). In particular, dietary long-chain (C20–22) LC-PUFA such as eicosapentaenoic (EPA; 20:5n-3), docosahexaenoic (DHA; 22:6n-3) and arachidonic (ARA; 20:4n-6) acids are required by fish to support somatic growth and survival (Harel et. al., 2001; Copeman et. al., 2002; Trenzado et. al., 2008), stress resistance (Bell et. al., 1998) and successful ontogeny (Mourente et. al., 1991; Villalta et. al., 2005; Benitez-Santana et. al., 2007). However, the terrestrial alternatives to fish oil are characterized by a wide range of fatty acid compositions and are notably lacking in meaningful concentration of LC-PUFA (Turchini et. al., 2010). Thus, the substitution of fish oil with any alternative source results in a reflection of the dietary fatty acid composition in fish flesh, a potentially undesirable trait from n-3 LC-PUFA consumption viewpoint (Rosenlund et. al., 2010).

As a consequence of this, there is an interest to combat fatty acid modification of farmed fish. The most common approach has been the potential implementation of a finishing period on a FO-based diet (wash-out or finishing diet) to modify the final fatty acid make-up of fish previously reared on diets containing alternative dietary lipids (Jobling, 2004; Turchini et. al., 2006). However, the initial concentration of fat in the tissue in question directly affects the time required for the fatty acid composition of a tissue to be influenced by a dietary change. The main results of this research are reported and discussed in the present review.

Alternative dietary lipid sources

Marine fish oils have been widely used as the main lipid source in feeds for farmed fish because they have been a good source of the n-3 HUFAs. The demand for fish oils has increased over recent years although production has remained static, and the current trend is towards the complete or partial replacement of fish oils by alternative lipid sources such as vegetable oils and animal fats in feeds for farmed fish which are characterized by the wide fatty acid compositions (Table1). The common vegetable oils used as alternative lipids in the feeds of farmed fish species include palm oil, soybean oil, canola oil, sunflower oil, cottonseed oil, groundnut oil, coconut oil, olive oil, corn oil, sesame oil, linseed oil etc, has been studied in many fish species such as rainbow trout (Trushenski et. al., 2011a; Masiha et. al., 2013, Twibell et. al., 2011; Guler and Yildiz, 2011; Brown et. al., 2010; Yildiz et. al., 2013), brown trout (Arslan et. al., 2012), cobia (Trushenski et. al., 2011b), pike perch (Kowalska et. al., 2010), Huso huso (Hosseini et. al., 2010), Litopenaeus vannamei (Gonzalez-Felix et. al., 2010), Caspian great sturgeon (Hassankiadeh et. al., 2013), African catfish (Bababola et. al., 2011), Japnese seabass (Xue et. al., 2006), etc. Most vegetable oils are rich in unsaturated18C fatty acids viz. oleic acid (18:1n-9), linoleic acid (18:2 n-6), alpha-linolenic acid (18:3 n-3) but are poor sources of n-3 HUFAs, so the flesh of farmed fish given feeds containing high concentrations of vegetable oils may contain a limited amount of n-3 HUFAs. The terrestrial animal lipid sources used in the feeds of farmed fish are processing by-products, such as lard (rendered fat from pigs), poultry fat, goat fat, tallow (TAL from cattle and sheep), which has been studied in many fish species such as Brown trout (Turchini et. al., 2003), Japanese sea bass (Xue et. al., 2006), Grass carp (Zhen-Yu et. al., 2006), catfish (Bababola et. al., 2011), Rainbow trout (Liu et. al., 2004; Bayraktar and Bayir, 2012), common carp (Baweja and Babbar, 2015) etc. In general, animal fats contain high levels of SFA, ranging from 28.5% in poultry fat to 47.5% in beef TAL. Together with the high levels of MUFA, animal fats are good sources of dietary energy for fish. Although VO are completely lacking in n-3 HUFA, animal fats are reported to contain these fatty acids (Moretti & Corino, 2008). In particular, there are several studies in which the presence of eicosapentaenoic acid, 20:5 n-3 (EPA) and docosahexaenoic acid, 22:6 n-3 (DHA) in the lipid fraction of swine, bovine and poultry derived products have been reported. However, the n-3 HUFA content of animal fat is extremely limited, commonly reported only at trace level, and hence these lipid sources can be considered lacking in n-3 HUFA. In general, research reports that animal fats when incorporated at no more than 50% of the dietary lipid level have no negative effects on fish growth performance as long as the EFA requirements are met (Turchini et. al., 2003; Bureau & Gibson, 2004).

However, PUFA conversions are known to occur in a variety of freshwater fish species. In general, both desaturases and elongases are activated in fish fed a diet (vegetable oils or animal fats) containing 18-carbon

Table 1: Fatty acid composition (% total fatty acids) of fish oils, vegetable oils and animal fats used in aqua feed formulations

Oils/fats	SFA	MUFA	LA	ALA	EPA	DHA	n-6 PUFA	n-3 PUFA	n-3/n-6 ratio
Fish oils									
Anchovy oil	28.8	24.9	1.2	0.8	17.0	8.8	1.3	31.2	24.0
Capelin oil	20.0	61.7	1.7	0.4	4.6	3.0	1.8	12.2	6.8
Menhaden oil	30.5	24.8	1.3	0.3	11.0	9.1	1.5	25.1	16.7
Herring oil	20.0	56.4	1.1	0.6	8.4	4.9	1.4	17.8	12.7
Cod liver oil	19.4	46.0	1.4	0.6	11.2	12.6	3.0	27.0	9.0
Vegetable oils									
Crude palm oil	48.8	37.0	9.1	0.2	-	-	9.1	0.2	0.0
Soybean oil	14.2	23.2	51.0	6.8	-	-	51.0	6.8	0.1
Canola oil	4.6	62.3	20.2	12.0	-	-	20.2	12.0	0.6
Sunflower oil	10.4	19.5	65.7	-	-	-	65.7	0.0	0.0
Cottonseed oil	45.3	17.8	51.5	0.2	-	-	51.5	0.2	0.0
Groundnut oil	11.8	46.2	32.0	-	-	-	32.0	0.0	0.0
Corn oil	12.7	24.2	58.0	0.7	-	-	58.0	0.7	0.0
Linseed oil	9.4	20.2	12.7	53.3	-	-	12.7	53.3	4.2
Animal fats									
Pork lard	38.6	44.0	10.2	1.0	-	-	10.2	1.0	0.1
Poultry fat	28.5	43.1	19.5	1.0	-	-	19.5	1.0	0.0
Beef tallow	47.5	40.5	3.1	0.6	-	-	3.1	0.6	0.2

Data compiled from National Research Council, 1993; Gunstone et. al., 1994; Hertrampf and Piedad-Pascual, 2000
ALA, a-linolenic acid, 18:3 n-3; DHA, docosahexaenoic acid, 22:6 n-3; EPA, eicosapentaenoic acid, 20:5 n-3; LA, linoleic acid, 18:2 n-6; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

fatty acids (18:3n-3, 18:2n-6) in comparison with fish fed a diet (fish oil) containing HUFA (Tocher et. al., 2001; Leaver et. al., 2008).

The first step in the fatty acid elongation and desaturation pathway is the production of stearidonic acid (18:4 n-3) from alpha-linolenic acid (18:3 n-3) catalyzed by the D6 desaturase enzyme. The product can then be successively elongated by fatty acid elongase and further desaturated by the D5 desaturase enzyme to EPA (20:5 n-3) (Sargent et. al., 2002; Nakamura & Nara, 2004). The eventual production of DHA (22:6 n-3) requires the combination of two further elongations, a D6 desaturation and, finally, a chain-shortening reaction (Sprecher et. al., 1995). The fatty acid desaturation and elongation pathway has been extensively studied in fish at both the molecular and enzymatic levels (Tocher et. al., 2003, 2006; Bell et. al., 2001; Hastings et. al., 2004; Agaba et. al., 2004; Zheng et. al., 2004, 2005; Oxley et. al., 2005). However, for many freshwater fish species, the conversion of C18 PUFA to long-chain PUFA seems to occur at a very slow rate (Tocher et. al., 2006) because of limiting delta-6 and delta-5 desaturation steps (Buzzi et. al., 1997; Tocher et. al., 2006; Vagner and Santigosa, 2011).

Finishing Feeding Strategy

The principal drawback of fish oil replacement is the resultant influence on fillet fatty acid composition (Sargent et. al., 2002; Turchini et. al., 2003; Seierstad et. al., 2005). One way to boost the n-3 HUFA concentration of farmed fish could be to use 'finishing' feeds (wash-out diets) containing fish oil to modify the final fatty acid composition of fish previously reared on diets containing alternative lipid sources so that fatty acid composition of the fish flesh could thus be altered to meet the consumer expectation of a product that is rich in n-3 HUFAs (e.g. Jobling et. al., 2002; Bell et. al., 2003; Glencross et. al., 2003; Robin et. al., 2003). Although switching back to a FO-based finishing feed will restore tissue LC-PUFA levels (Lane et. al., 2006; Turchini et. al., 2006; Jobling et. al., 2008; Benedito-Palos et. al., 2009; Fountoulaki et. al., 2009), the restoration rate and magnitude of fillet fatty acid profile vary with the composition of the grow-out feed used. Such a finishing diet strategy has been suggested and developed for various fish species, including medium fatty fish species such as turbot (Psetta maxima) (Robin et. al., 2003), fatty fish such as Atlantic salmon (Salmo salar) (Jobling, 2003; 2004) and lean fish species such as Atlantic cod (Gadus morhua) (Jobling et. al., 2008) and Murray cod (Maccullochella peelii peelii) (Turchini et. al., 2006).

Bell et. al., 2003 suggested that Atlantic salmon can be raised on diets in which FO is replaced with different blends of vegetable oils and fish oil for the entire seawater culture phase, without apparent detriment to fish growth and health. However, for fish in which vegetable oil replaced >66% of the added dietary oil, considerable reductions of flesh concentrations of both 20:5(n-3) and 22:6(n-3) occurred. Returning fish previously fed 100% vegetable oils to a marine fish oil diet for a period before harvest allowed flesh (n-3) HUFA concentrations to be restored to 80% of values in fish fed FO throughout the seawater phase although 18:2(n-6) remained significantly higher. Restoration of the fatty acid composition of red seabream (Pagrus auratus) using a fish oil finishing diet after grow-out on plant oil based diets was reported by Glencross et. al., 2003. The results of this study, particularly the increases in LC-PUFA, supported the usefulness of a fish oil based finisher diet for fish raised predominantly on plant oil based diets. Izquierdo et. al., 2005 also suggested that it is possible to substitute up to 60% fish oil by vegetable oils in diets for gilthead seabream without affecting growth and feed utilization even for a long feeding period. Muscle DHA and ARA contents are reduced but recovered after 60 days of feeding a fish oil diet, whereas EPA muscle contents are not only reduced in a higher extent but are not recovered after 90 days of feeding fish oil. Whereas, Fountoulaki et. al., 2009, concluded that re-feeding gilthead sea bream previously fed vegetable oil based diets with a fish oil finishing diet for 120 days was not adequate for restoration of DHA, ARA and EPA. Baweja and Babbar, 2016 suggested that inducing a dietary shift from terrestrial oil (vegetable oil or animal fat) based feeds to fish oil based feeds supplied as finishing diet before harvesting strongly increases long chain PUFA concentration in common carp as compared to those fed only terrestrial oil based feeds throughout the rearing period. Similarly, Maraz et. al., 2012 and Schultz et. al., 2014 also suggested finishing feeding strategy for production of common carp with a required flesh FA composition for purposes of special nutritional needs. Yildiz et. al., 2017 documented recovery of fatty acid (n-3 HUFA) in rainbow trout initially fed vegetable oils was slow and requires more than 12 weeks of re-feeding with FO diet for complete restoration. Suomela et. al., 2017 examined that after receiving a vegetable oil-rich diet, restorative fish oil-rich feeding in the last stages of growth in European whitefish is nutritionally justified in order to balance nutritional gain for consumers with sustainable use of finite marine oils. Various studies have suggested that fish are unable to accumulate excessive amounts of SFA or MUFA. However, they seem to be able to accumulate significantly higher amounts of C18 PUFA which considerably affects the overall fatty acid composition (Torstensen et. al., 2004; Turchini et. al., 2003, 2006; Mourente et. al., 2005; Francis et. al., 2006). On the other hand, the general C18 PUFA elongase and desaturase capability in fish, even if stimulated by the use of vegetable oils, seems ineffective in compensating the exhausted HUFA intake in fish fed alternative lipid sources (Tocher et. al., 2003; Zheng et. al., 2004; Stubhaug et. al., 2005; Turchini et. al., 2006). Thus the use of alternative vegetable lipid sources characterized by a high content of SFA, i.e. palm oil, or MUFA, i.e. olive oil, or a blend of these oils is preferential in comparison with vegetable oils rich in C18 PUFA such as sunflower and linseed oils. The efficacy of a finishing period with a FO-based diet after a grow-out period during which fish have been fed with diets containing alternative lipid sources has been largely tested in Atlantic salmon (Bell et. al., 2003, 2004; Torstensen et. al., 2004), in temperate marine fish species (i.e. gilthead seabream, European sea bass and red seabream) (Glencross et. al., 2003; Izquierdo et. al., 2005; Montero et. al., 2005) and in warm water, fresh water species such as Murray cod and sunshine bass (Lane et. al., 2006; Turchini et. al., 2006, 2007). In all instances, the fatty acid make-up of fish can return to within the normal variability of fish continuously fed a FO-based diet after a period of several weeks. Consequently, fish fed diets with lower concentrations of dietary C18 PUFA will be able to restore the original fatty acid composition of the fish fillets more effectively (Turchini et. al., 2007). Thus, the results so far have been promising and adoption of finishing feed strategy for commercial applications has been proposed.

CONCLUSION

The review studied so far suggest that by using a mixed feeding strategy, the farmed fish can be started on feeds containing high concentrations of alternative lipids low in n-3 HUFAs and then given 'finishing feeds' containing high concentrations of marine fish oils high in n-3 HUFAs, improve the final fatty acid make-up of fish previously fed with alternative lipid sources. Thus, restoration of an optimal fatty acid profile with a finishing diet following an alternative lipid grow-out diet, expected to result in a more rational utilization of aquaculture's still highly dependent limited resource of fish oils.

Conflicts of interest: The authors stated that no conflicts of interest.

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