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Fish oil substitution by vegetable oils in commercial diets for gilthead sea bream (*Sparus aurata* L.); effects on growth performance, flesh quality and fillet fatty acid profile
Recovery of fatty acid profiles by a fish oil finishing diet under fluctuating water temperatures

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ABSTRACT

The effects of long term feeding (6 months) of commercial diets with low fish meal content and high levels of vegetable oils (69% fish oil substitution level) were determined in gilthead sea bream (110 g). A control diet containing South American fish oil (FO) was evaluated against feeds with either soybean oil (SO), palm oil (PO) or rapeseed oil (RO). Afterwards, all fish were fed a fish oil finishing diet to determine the progressive recovery of the fillet fatty acid profiles.

The results showed that growth and feed utilization in gilthead sea bream are not affected by fish oil substitution with soybean and rapeseed oil, contrary to palm oil inclusion. Flesh and liver docosahexaenoic acid (DHA) and arachidonic acid (ArA) contents were reduced to a lower degree than their reduction in the diet, whereas eicosapentaenoic (EPA) reduction was more pronounced in both tissues. Sensory analysis revealed no difference in the organoleptic characteristics of the dietary groups. However, low acceptance scores were calculated for all treated groups. No histological alterations were seen in gut tissue but liver of the PO group showed intense lipid accumulation. Re-feeding with a fish oil finishing diet for 120 days was not adequate for restoration of DHA, ArA and EPA. Linoleic (LA) and oleic acid (OA) were retained even after 120 days re-feeding with the fish oil diet.

1. Introduction

The presence of $n-3$ highly unsaturated fatty acids (HUFA), especially eicosapentaenoic (EPA) and docosahexaenoic acid (DHA) that provide many health benefits (Sargent et al., 2001) makes seafood a very important component in human nutrition. Fisheries products are the major source of $n-3$ HUFA in the human diet but global food grade fisheries have reached a plateau of about 90 million metric tons/annum. This fact makes clear that this natural source of $n-3$ HUFA is limited and aquaculture production will face the shortfall. Food grade fisheries that provide fish oil and fish meal have reached their limit of sustainability (Pike and Barlow, 2003; Shepherd et al., 2005). The aquaculture industry uses the 40 and 60% of the global production of fish meal and fish oil, respectively, and within the next decade fish oil production may not meet the quantities required for aquaculture (Kaushik, 2004; Tacon, 2005). The same situation is also observed for fish meal production which remained stable from the late 1980s at about 6 million metric tons/annum (FAO, 2004). The consensus is that alternative protein and oil sources are needed to supplement or replace fish meal and fish oil in aquafeeds, thus contributing to long-term sustainability of the aquaculture industry (Hardy, 2008).

Vegetable oils constitute promising candidates for fish oil replacement, having steadily increasing production, with high availability and better economic value. Some vegetable oils such as soybean oil and rapeseed oil are considered possible alternative lipid source for salmonids, freshwater and marine fish since they are rich in polyunsaturated fatty acids (PUFA), especially linoleic ($18{:}2n-6$) and oleic acid ($18{:}1n-9$), but devoid of $n-3$ HUFA, (Caballero et al., 2002; Izquierdo et al., 2005; Montero et al., 2005; Mourente and Bell, 2006). Palm oil is also a potential candidate due to its relatively low level of $18{:}2n-6$ and abundance of 16:0 and $18{:}1n-9$ (Ng et al., 2003a,b). Its production already exceeds the corresponding of soybean oil making it the most abundant vegetable oil globally (USDA, 2008).

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Table 1
Ingredients (g/kg) and chemical composition of the experimental diets containing the different vegetable oils

	FO	SO	PO	RO
Ingredients				
Fish meal[a]	150	150	150	150
Soy bean meal	250	250	250	250
Corn gluten	202	202	202	202
Sun flower	51	51	51	51
Field beans	150	150	150	150
Wheat gluten	50	50	50	50
Soya lecithin	10	10	10	10
Fish oil[b]	160	50	50	50
Soya oil		110		
Rapeseed oil				110
Palm oil			110	
Mineral premix[c]	3	3	3	3
Mono calcium phosphate	17	17	17	17
Water	−4.3	−4.3	−4.3	−4.3
Proximate composition (DM %)				
Dry matter	92.80	92.70	93.18	93.50
Crude protein	46.59	46.63	45.70	46.73
Crude fat	18.53	19.42	19.35	19.89
Ash	6.79	6.89	6.66	6.83
EPA+DHA	4.83	1.69	1.42	1.32
Gross energy kJ/g DM	23.16	23.30	23.37	23.03

[a] Prime South American, 67% crude protein.
[b] South American.
[c] Supplied the following mg/kg feed (α-tocopherol, 175.0; Thiamin, 10.0; Riboflavin, 20.0; Niacin, 40.0; Pyridoxal phosphate, 10.0; Menadione, 10.0; Biotin, 0.3; Ascorbate phosphate, 100.0; Folic acid, 10.0; Zn, 100.0; I, 1.2; Mg, 30.0; Co, 1.0).

Furthermore, the use of palm oil in diets of Atlantic salmon and rainbow trout has given growth and feed utilization efficiency comparable to fish fed equivalent levels of fish oil (Torstensen et al., 2000; Rosenlund et al., 2001; Caballero et al., 2002). However, in marine fish feeds the use of vegetable oils as a sole lipid source is limited since these species have low capacity to convert linoleic and linolenic acids, into arachidonic (ArA), EPA and DHA which are essential for marine fish (Sargent et al., 2002). Partial replacement of fish oil by vegetable oils would be possible only when these fatty acids are present in the diets in sufficient quantities to meet their essential fatty acid requirements. It is worth noting that the replacement of up to 60% of the fish oil by several vegetable oils has not induced compromised growth performance and feed utilization in gilthead sea bream and European sea bass (Izquierdo et al., 2003, 2005; Montero et al., 2005). In rainbow trout, Caballero et al. (2003) observed that replacement of 60% of the fish oil by vegetable oils and particular soybean oil, resulted in increased lipid deposition in the hepatocytes while Montero et al. (2003) observed effects on some immune parameters suggesting undesirable effects on fish health when long feeding periods are tested.

The inclusion of vegetable oils in fish feeds can lead in alterations of the fatty acid profile and in some cases may significantly affect fish fillet quality and sensory characteristics (Guillou et al., 1995; Martínez-Llorens et al., 2007), while some effect on the odour active compounds is also possible (Serot et al., 2001, 2002). Alterations of the fatty acid profiles in fish fillets were mainly the reduction in the *n*−3-HUFA, particularly EPA (Izquierdo et al., 2003, 2005; Montero et al., 2005). Because of the nutritional importance of polyunsaturates for humans, it is recommended to use fish oils which are rich in *n*−3 HUFA and therefore allow a higher replacement with vegetable oils. Since it is desirable to produce fish fillets with a high content of these fatty acids, it is essential to feed the plant oil-fed fish, with a 100% fish oil diet (finishing diet) during the last part of their on-growing period, in order to allow recovery of the *n*−3 HUFA levels in their fillets. In a short time period feeding experiment, Izquierdo et al. (2003) found that fillets from sea bream fed vegetable oils did not differ organoleptically from fish fed on fish oil while, long duration experiments with 60 or 80% fish oil replacement induced slight organoleptic differences (Izquierdo et al., 2005).

Although the replacements of fish oil (Izquierdo et al., 2005; Montero et al., 2005) and fish meal (Gomez-Requeni et al., 2003, 2004; Sitjà-Bobadilla et al., 2005; De Francesco et al., 2007) in gilthead sea bream have been investigated, no data exist for their combined replacement in this species and especially in a long term trial. Thus we attempted, in the present study to replace *n*−3HUFA rich fish oil by vegetable oils in low fish meal commercial diets for gilthead sea bream. The long term feeding effects of diets containing high levels of soybean, palm and rapeseed oil, on growth performance, feed utilization, fillet quality and tissue histology were examined. The progressive evolution of the fillet fatty acid profiles when fish were fed a fish oil finishing diet during the last part of the on-growing period was evaluated under natural fluctuating temperatures.

2. Materials and methods

2.1. Diets

Four diets with relatively low fish meal inclusion (15%) representing 23% of the total crude protein were formulated with plant protein ingredients (Table 1). South American fish oil rich in *n*−3 HUFA was used in the reference diet (diet FO). All other diets contained vegetable oils, substituting for 69% of the fish oil contained in the FO diet, with soybean oil (SO diet), palm oil (PO diet) and rapeseed oil (RO diet). Fish oil was included in all vegetable oil diets at a level high enough to meet the essential fatty acid (EFA) requirements of this species (Ibeas et al., 1994)

Table 2
Fatty acid composition of the experimental diets (% total FAME)

Fatty acid	FO	SO	PO	RO
14:0	6.98	2.09	2.59	1.66
15:0	0.33	0.13		
16:0	18.27	13.90	31.18	10.38
16:1*n*−7	6.78	2.14	2.08	1.91
16:2*n*−4	1.07	0.27	0.24	0.22
17:0	1.44	0.39	0.33	0.28
16:4*n*−3	2.42	0.72	0.58	0.52
18:0	3.27	3.60	3.58	2.17
18:1*n*−9	11.10	16.85	31.33	40.76
18:1*n*−7	2.30	1.62	1.36	2.73
18:2*n*−6	11.14	41.34	16.50	23.38
18:3*n*−6	0.37	0.10		
18:3*n*−3	1.02	5.66	0.80	6.98
18:4*n*−3	1.92	0.59	0.50	0.41
20:0	0.16	0.21	0.23	0.34
20:1*n*−9	0.60	0.28	0.41	0.79
20:1*n*−7	0.19			
20:4*n*−6	0.83	0.24	0.20	0.22
20:4*n*−3	0.50	0.13		
20:5*n*−3	16.74	5.44	4.43	4.09
22:1*n*−11	0.79	0.27	0.43	0.19
22:4*n*−6		0.13		
22:5*n*−6	0.56	0.15		
22:5*n*−3	1.76	0.57	0.50	0.45
24.0	0.12			
22:6*n*−3	9.35	3.25	2.91	2.54
24:1*n*−9	0.25			0.14
Saturates	30.57	20.31	37.90	14.82
Monounsaturates	22.01	21.16	35.61	46.52
n−9	11.94	17.13	31.74	41.55
n−6	12.89	41.95	16.69	23.60
n−3	33.72	16.36	9.72	14.9
n−3 HUFA	28.35	9.39	7.84	7.08
n−3/*n*−6	2.61	0.39	0.58	0.63
DHA/EPA	0.56	0.60	0.66	0.62
ArA/EPA	0.05	0.043	0.044	0.054

HUFA: Highly unsaturated fatty acids, DHA: docosahexaenoic acid.
EPA: Eicosapentaenoic acid, ArA: arachidonic acid.
Values are means of three determinations.