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Lipid and fatty acid dynamics in Atlantic cod, *Gadus morhua*, tissues: Influence of dietary lipid concentrations and feed oil sources

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ABSTRACT

The influence of dietary fish and plant oils on fatty acid compositions of Atlantic cod tissues was examined to test whether modulation of fatty acid profile following a dietary change differs between lipid-poor (fillet) and lipid-rich (liver) tissues. A dilution model [Robin, J.H., Regost, C., Arzel, J., Kaushik, S.J., 2003. Fatty acid profile of fish following a change in dietary fatty acid source: model of fatty acid composition with a dilution hypothesis. Aquaculture 225, 283–293.] was used for the test. The experiment was divided into a build-up and a restoration phase. Fish weight increased from an initial 30 g to 100 g at the end of build-up and to 300 g at termination. During build-up, triplicate tanks of fish were fed one of four feeds; LF (fish oil, 13% lipid), HF (fish oil, 18% lipid), PO (40 palm oil:20 linseed oil:40 fish oil, 13% lipid) or RO (40 rapeseed oil:20 linseed oil:40 fish oil, 13% lipid). During restoration the cod were fed either LF or HF; four groups experienced a feed change (ROLF, ROHF, POLF, and POHF), and two groups were fed either LF or HF during both build-up and restoration. There were triplicate tanks of fish for each restoration phase treatment. Samples were taken at the start, at the end of build-up, mid-way through restoration and at termination, with four fish being taken from each tank each time; tissue indices were calculated, and analyses of lipid and fatty acids were undertaken, with a focus on 18C fatty acids (18:1 isomers, 18:2n-6 and 18:3n-3) and two n-3 HUFAs 20:5n-3 and 22:6n-3.

During build-up, the cod fed HF and LF accumulated relatively more liver lipid than those fed PO and RO, implying that there were differences in the ways in which the lipids in the fish oil and plant oils were digested, absorbed and metabolised. At the end of build-up the cod fed PO and RO had tissues with higher 18C fatty acid, and lower n-3 HUFA, concentrations than the cod fed LF and HF; tissue fatty acid compositions reflected those of the feed oils.

The fatty acid profiles of ROLF, ROHF, POLF, and POHF cod were modified during restoration. The changes in concentrations of 18C fatty acids were more rapid than predicted by the dilution model, implying preferential metabolism of 18:1 isomers, 18:2n-6 and 18:3n-3. Concomitant with the decrease in 18C fatty acid percentages there were increases in both 20:5n-3 and 22:6n-3. At termination, fillet percentages of n-3 HUFAs were statistically indistinguishable across treatments, but feed effects on liver lipids 20:5n-3 and 22:6n-3 were still discernible; cod fed PO and RO during build-up had liver lipids with lower percentages of n-3 HUFAs than those of cod fed LF and HF throughout the experiment. The fatty acid compositions of cod tissues are modified following a change in feed oils, but there are some tissue-specific differences in the responses shown. The results indicate that it should be possible to manipulate the fatty acid compositions of cod tissues in desired directions by introducing mixtures of different feed oils at various points in the production cycle.

1. Introduction

Interest in farming Atlantic cod, *Gadus morhua*, was rekindled around the turn of the century and research and development is currently being conducted in several northern hemisphere countries that border the Atlantic basin. Some of this activity involves studies of cod feeding and nutrition with a focus on novel feed ingredients; this research is deemed important because of the predicted shortfall of fish meals and oils that have traditionally been major components of aqua-feeds (Jobling, 2004c; Deutsch et al., 2007; Karalazos et al., 2007; Pickova and Mørkøre, 2007). Plant meals and oils have a long history of use in human nutrition and in agri-feeds, are being increasingly

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used as ingredients in aqua-feeds (Hertrampf and Piedad-Pascual, 2000; Dubois et al., 2007; Gatlin et al., 2007; Ng et al., 2007), and in recent years there have been numerous studies carried out to examine the influences of plant oils on lipid metabolism and fatty acid compositions of fish tissues (Sargent et al., 1989, 2002; Bell, 1998; Higgs and Dong, 2000; Jobling, 2001, 2004c; Tocher, 2003; Bell et al., 2006). The main consensus is that the types of oils used can have profound influences upon the fatty acid compositions of fish tissues, and that it is possible to manipulate fish tissue fatty acid compositions by changing feed oils at various points in the production cycle (Bell et al., 2001, 2003a,b, 2006; Jobling, 2003, 2004a,b; Robin et al., 2003; Mørkøre et al., 2007). Robin et al. (2003) presented a mathematical 'dilution' model that gave good predictions of the time-course of changes in fatty acid compositions of neutral lipids (NLs), and sometimes also of total fatty acids (Jobling, 2003, 2004a,b), in fish tissues following a change in the type of feed oil used. On the other hand, the changes in the fatty acid profiles of polar lipids (PL) did not comply with the 'dilution' model (Robin et al., 2003).

Thus, when undertaking modelling of temporal changes in the total fatty acids in fish tissues the relationship between the NL and PL present in the tissues being examined needs to be considered. The NLs have a storage function whereas the PLs are central components of cell membranes; differences in fatty acid composition between the PLs and NLs arise because of selective incorporation of certain fatty acids into the PLs, so a limited number of fatty acids (16:0, 18:1n-9, 20:5n-3 and 22:6n-3) tend to dominate (Henderson and Tocher, 1987; Sargent et al., 1989, 2002; Bell, 1998; Higgs and Dong, 2000; Tocher, 2003). This means that the change in the fatty acid profile of the total lipids may not comply with the 'dilution' model when the tissue in question contains a relatively high proportion of PLs. One such tissue is cod fillet in which the percentage of total lipids is generally below 1%, and the lipids are dominated by PLs (dos Santos et al., 1993; Jobling, 2001, 2004c; Karalazos et al., 2007; Mørkøre et al., 2007). On the other hand, the cod liver tends to be lipid-rich, with the liver lipids being dominated by NLs (dos Santos et al., 1993; Jobling, 2001, 2004c; Karalazos et al., 2007; Standal et al., 2008). As such, it might be predicted that the cod fillet and liver would differ in their responses to changes in the nature of the feed oils, and that the model developed by Robin et al. (2003) might be more suited to describing the temporal changes in the fatty acid profile of the liver than that of the fillet.

The aims of the present study were to examine the influence of dietary fish and plant oils on lipid dynamics and fatty acid compositions of Atlantic cod tissues, and to test the hypotheses that modulation of tissue fatty acid profiles following a dietary change differs between lipid-poor (fillet, with PLs dominating) and lipid-rich (liver, with NLs dominating) tissues, and that the changes observed in the lipid-rich tissues are primarily the result of dilution. The model proposed by Robin et al. (2003) was used as the basis for these tests. The tests were carried out using data relating to the influences of various feed oils (North Atlantic marine fish, palm, rapeseed and linseed oils) and dietary lipid concentrations on body composition and tissue (fillet, liver and the rest of the carcass) fatty acid profiles of juvenile Atlantic cod that exhibited an approximately ten-fold increase in body weight during the course of the experiment.

2. Materials and methods

The experiment was carried out at Tromsø Aquaculture Research Station, Kårvika, northern Norway using hatchery-produced juvenile cod, *G. morhua*, that were transported from the production unit (Troms Marin Yngel AS, Norway) to the research station in mid-August. The fish were tagged with uniquely numbered Floy FTF-69 tags (Floy Tag, Seattle, USA) and randomly distributed among 12 tanks (106 fish per tank) that received seawater at ambient temperature. Throughout the study, 300 l tanks were used, and water flow was set to ensure an oxygen concentration above 70% saturation and a current speed equivalent to about one fish body length s^{-1}. The fish were exposed to continuous light (24 L:0D) and feed was provided in excess once per day from 0400 to 0800 h using automatic disc feeders fitted with a timer.

The fish were held for four weeks prior to the start of the experiment. The average fish weight at the start of the experiment was 30 g. An initial sample of fish was taken for the analysis of the relative sizes of body parts and their lipid content. The experiment was divided into two phases, designated the build-up and restoration phases, respectively (Fig. 1). In an attempt to ensure that the feed treatments would have measurable effects on tissue lipid content and fatty acid compositions, it was decided that the fish should exhibit an approximately three-fold increase in weight during each phase of the experiment, i.e. initial 30 g → 100 g at the end of build-up → 300 g at the end of the experiment.

During the early part of the experiment the seawater supply to the tanks was at ambient temperature, and when water temperature fell to 8 °C (in mid-November) this temperature was maintained for the remainder of the experiment. During the build-up phase, which lasted for 19 weeks, four feeds were used with three tanks of fish being

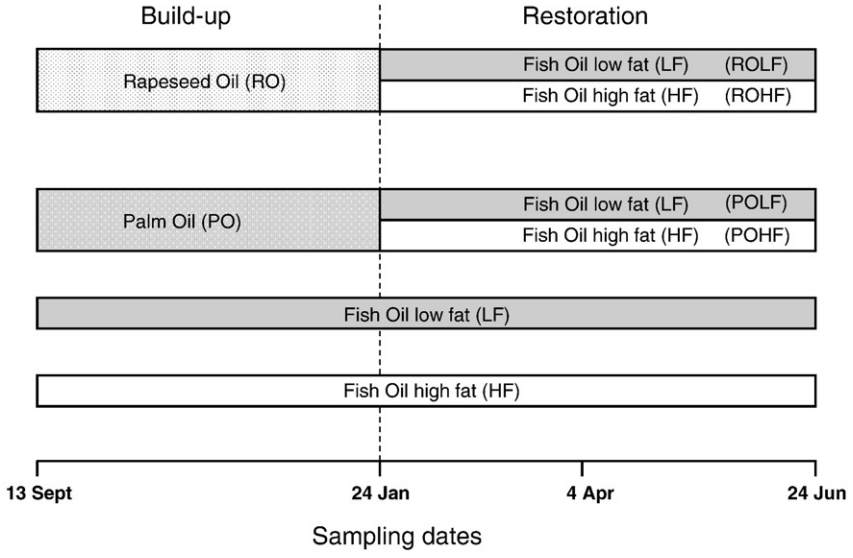

Fig. 1. Schematic presentation of the experimental design, showing the durations of the two phases of the experiment (Build-up and Restoration), the designations of the dietary treatments and the timing of sampling.