COMPLETED PROJECT CASE STUDY

ENHANCING LIPID METABOLISM AND HEALTH IN FARMED ATLANTIC SALMON

PARTNERS

The Roslin Institute | University of Stirling's Institute of Aquaculture | Mowi Scotland | Glasgow Polyomics at the University of Glasgow

BACKGROUND

Given recent shifts in the raw material inclusion in aquaculture feeds, consideration must be given to potential impacts on the health of farmed Atlantic salmon. While these dietary changes support sustainability, they may also introduce challenges related to salmon health and nutritional quality. Vegetable oils, which are high in short-chain omega-6 polyunsaturated fatty acids (PUFAs), have increasingly replaced fish oils that are rich in omega-3 long-chain PUFAs. This shift alters the omega-3 to omega-6 ratio, leading to imbalances that can affect salmon health and reduce its nutritional value for humans.

Excessive omega-6 fatty acids lead to lipid accumulation in the liver, visceral adipocytes and muscle tissue. Over time, these effects contribute to lipotoxicity and inflammation, compromising metabolic health and immune function in salmon.

This project explored the role of autophagy – a cellular recycling mechanism that breaks down lipids – in salmon health, and whether supplementing diets with spermidine will improve the health and nutritional value of Atlantic salmon. The Roslin Institute, based at the University of Edinburgh, led this project. The Institute of Aquaculture at the University of Stirling hosted the feed trial and provided valuable expertise on feed formulation and assay development. Mowi Scotland provided salmon for analysis, while lipidome analysis was carried out by Glasgow Polyomics at the University of Glasgow.

AIMS

This project aimed to:

1. Determine the role of autophagy on free fatty acids (FFAs) for mitochondrial β-oxidation, inflammation and arterial plaque in late-stage Atlantic salmon raised in marine pens;
2. Evaluate the effects of spermidine-supplemented feed on lipid metabolism, mitochondrial function, and inflammatory and plaque markers in salmon;
3. Investigate whether enhancing autophagy improves the nutritional value of salmon fillets;
4. Share results and insights with stakeholders in the aquaculture industry and academia.

LIPIDOME ANALYSIS AND SPERMIDINE FEED TRIALS IN SALMON

The research was conducted in multiple phases, each addressing different aspects of lipid metabolism in Atlantic salmon.

The first phase examined the lipidome and fatty acid composition across three key life stages: parr, smolt, and harvest-size salmon, which allowed for the identification of significant variations linked to growth stages.

The second phase focused on evaluating the effects of spermidine, an anti-ageing and autophagy-inducing polyamine, as a dietary supplement for Atlantic salmon. The study assessed its impact on lipid metabolism and overall health under aquaculture conditions. Post-smolt salmon were fed either a diet enriched with soy oil (70% soy oil: 30% fish oil) supplemented with spermidine at 5 mg/kg or a control diet without the supplement for five weeks.

The study's final phase involved disseminating research findings to a broader audience. Additionally, new assays were introduced, expanding the project's scope. These milestones included:

- Analysing the metaproteome to understand broader protein expression changes related to spermidine's impact;
- Developing a proteomics atlas across different life stages of salmon, serving as a reference database for protein-level changes from parr to harvest size.

RESULTS

By developing lipidomic profiles and measuring total and free fatty acids (TFA and FFA respectively), the research identified significant variations linked to growth stages.

Lipidome analysis revealed distinct profiles at each life stage, highlighting stage-specific lipid accumulation patterns. Notably, triglycerides were more abundant in the muscle of harvest-stage salmon compared to parr. A progressive increase in total lipid content was observed from parr to harvest size, along with a consistent decline in the omega-3 to omega-6 ratio, influenced by diet and metabolism. Furthermore, docosahexaenoic acid (%DHA), a vital omega-3 fatty acid for human health known to reduce inflammation and support cardiac function, showed a notable decrease in muscle at the harvest stage. This decline in DHA, along with a reduction in the omega-3 to omega-6 ratio, may have implications for both salmon health and its nutritional value for human consumers.

A significant increase in palmitic acid was observed in the muscle of harvest-size salmon compared to parr, alongside a decline in its free fatty acid form. While palmitic acid is a common saturated fatty acid found in animal and vegetable fat, excessive levels contribute to lipotoxicity, despite being an important energy source.

A five-week trial was performed at MERL, Machrihanish, where spermidine was supplemented in salmon feed in experimental tanks. Spermidine supplementation proved palatable to Atlantic salmon, with no decline in feed acceptance or consumption rates. It also enhanced the recycling of lipids into free fatty acids (free fatty acids are fuel for mitochondria to generate ATP) in salmon muscle, the key metabolic tissue with huge ATP demand, supporting its proposed mechanism of action.

Lipid metabolism improved, with reductions in total palmitic acid and increases in its free fatty acid form. Additionally, triglyceride levels decreased in muscle suggesting a healthier lipid profile. Overall, spermidine supplementation led to a shift toward a healthier lipid profile and reduced lipotoxicity in key metabolic tissues of Atlantic salmon.

IMPACT

This project provides the first evidence that spermidine supplementation may help counteract negative effects of plant-based diets on salmon metabolism. Findings suggest that spermidine supplementation could be most impactful during the final grow-out stage, by shifting the lipid profile of salmon toward a healthier composition, with metabolic improvements observed across muscle, adipose, and liver tissues. The use of spermidine could enhance the health, robustness, and overall performance of farmed salmon in food production systems.

The results were presented at three national and international meetings (AQUA 2024, Scottish Metabolomics Network Meeting, and the 5th European Association of Fish Pathologists UK-Ireland Branch Conference) and published in several industry magazines, reaching key stakeholders in aquaculture. It won the best talk award at the Scottish Metabolomics Network Meeting 2024.

This research paves the way for a spermidine-based product aimed at improving salmon health, optimising lipid metabolism, and enhancing disease resistance (which will require further testing). By bridging research with market-driven solutions, these findings contribute to sustainable aquaculture practices and innovation in salmon health. The potential industry-wide impact of this work underscores its significance in advancing aquaculture standards and human nutrition.