18th International Symposium on Fish Nutrition and Feeding
40 Years of Research in Fish Nutrition
Las Palmas de Gran Canaria, Spain
June 3rd - 7th, 2018

# Recent developments in aquaculture feeds - an industry perspective

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Fish meal and fish oil have traditionally been the main ingredients in aquaculture feeds. These are excellent raw materials; however, they are finite. The Food and Agriculture Organisation (FAO) published an update on the state of the World Fisheries and Aquaculture last year. According to the FAO, aquaculture is expected to grow by almost 40% in the next 10 years. This means another 30 million tonnes of seafood to be produced in 2025. Today more than 70% of the world production of fish meal and fish oil goes into aquafeeds. In order for aquaculture to grow we need to eliminate our dependence on marine ingredients and to find alternative sources that could provide all the benefits, without the limitations.

Fish meal and fish oil replacement have been one of the main focus in fish nutrition research for the last two decades, and several EU-funded projects involving major research institutions and other industry stakeholders have addressed the issue. Due to this extensive research, since 2016, diets without fish meal have become commercially available for Atlantic salmon.

The next challenge has been to reduce our dependence on fish oil. A significant proportion of the fish oil in aquafeeds had already been replaced by alternative fat sources, both of vegetable and animal origin. However, complete substitution of fish oil has been difficult due to the lack of alternative sources providing the long-chain n-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Today new ingredients with EPA and/or DHA are available, such as algae meals and oils or genetically modified plant oils, although in relatively small volumes and at a higher cost.

Growing salmon with diets without fish meal and fish oil is today possible and opens an ocean of opportunities to develop new raw materials that can contribute to make our industry even more sustainable.

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# Shooting ourselves in the "food": the unintended consequences of demonising fishmeal and fish oil

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Since the early '90s, the fish nutrition scientific community has engaged in research activities aimed at reducing the aquafeed sector's reliance on fishmeal and fish oil (FM/FO). Later, some scientists raised a series of environmental concerns associated with the practice of using FM/FO in aquafeed, initiating an ongoing and globally heated debate based on the assumption that the growing aquaculture industry would place an increased demand on FM/FO, to be realised by increased fisheries landings, and in turn, triggering an unsustainable pressure on finite oceanic stocks. Whilst we as a scientific community know that this has not eventuated given the existence of strict quota systems, we as a sector have unintentionally accepted the concept that using FM/FO is environmentally unsustainable. Whilst economic and logistical constraints justify the continued prioritisation for reducing the reliance placed on FM/FO, we should avoid the "intellectual injustice" of demonising the use of these resources, as it has a series of detrimental unintended consequences.

In a vicious circle, unjustly condemning FM/FO is triggering misinformed public perception, driven in particular by multiple forms of unsubstantiated scientific reporting and lay communication, and ultimately resulting in a direct damage to the aquaculture sector.

In this conceptual paper, we will present the case for a more moderate and substantiated use of words when addressing the issue of FM/FO utilisation in aquafeed in relation to scientific rationale and marketing activities. We will demonstrate how this point was reached and discuss actions to overcome this apparent impasse.

Aquaculture is a unique sector for many reasons, with the most salient being that it is one of the few that has a direct competitor: the wild-caught fisheries sector. Though in most cases aquaculture products are more environmentally sustainable, more socially equitable, more nutritious, safer and tastier than wild counterparts, most markets worldwide are penalising cultured products in favour of wild-caught seafood. Unintentionally, this outcome is partially stimulated by the demonization of FM/FO, rendering the aquaculture sector increasingly marginal, resulting in a reduced ability to support R&D and innovation, and thus negatively impacting the fish nutrition scientific community.

# Omega-3 Canola Oil effectively replaces fish oil as a dietary source of docosahexaenoic acid (DHA) in feed for Atlantic salmon in freshwater and seawater

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The limited availability of traditional fish oils rich in long-chain omega-3 fatty acids is one of the major constraints for further growth in the aquaculture industry. Long-chain omega-3 rich oils from crops genetically modified with algal genes are promising new sources for the industry. This project studied the use of Omega-3 Canola Oil from Nuseed Pty Ltd (Australia) in diets of Atlantic salmon both in the pre-smolt and post-smolt life stages. The Omega-3 Canola Oil studied has a favorable fatty acid profile compared to conventional plant oils, with high proportions of the omega-3 fatty acids 18:3n-3 and DHA. Levels of phytosterols, vitamin E and minerals was within the natural variation of commercial canola oils. Pesticides, mycotoxins and PAHs were not found above recommended values. There was no plant DNA detected in either of the oils.

The feeding trial in freshwater was conducted to evaluate effects of Omega-3 Canola Oil diets compared to conventional fish oil diets on salmon performance, composition and health. The experiment showed high survival across all dietary groups and equal growth in salmon fed the fish oil diets compared to Omega-3 Canola Oil diets. Salmon fed Omega-3 Canola Oil diets had the same EPA + DHA level in muscle as salmon fed fish oil diets. Analyses of gene expression showed only an effect of dietary oil level, and not of the source of the oil. The experiment showed no differences in expression of selected health markers between the diet groups.

A feeding trial with salmon in seawater from 500 g to 1.2 kg was also carried out, aiming at studying how Omega-3 Canola Oil in the feed affected growth, tissue fatty acid composition and muscle quality. Salmon fed increasing dietary levels of Omega-3 Canola Oil had similar growth rates and feed intake. Increasing the inclusion of Omega-3 Canola Oil in the diet led to increased fillet levels of 18:3n-3, EPA, DHA, increased n3/n6 fatty acid ratio and improved skin and fillet color. These studies show that Omega-3 Canola Oil is a sustainable alternative to fish oil in diets for Atlantic salmon.

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# Heterologous synthesis of omega-3 long chain polyunsaturated fatty acids in transgenic plants: a terrestrial source of fish oils

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We have been evaluating the feasibility of producing omega-3 LC-PUFAs in different transgenic hosts, to provide a sustainable source of these important nutrients, with a specific interest in meeting the needs of the aquaculture sector. Our attempts to metabolically engineer plants with the primary algal biosynthetic pathway for LC-PUFAs has been successfully carried out in Camelina sativa, a member of the Brassicaceae family and established crop in N. America. By adopting an iterative approach, we have developed plants which contain different levels of EPA and/or DHA, up to 30% of the total seed oil. Such plants have now been tested in the field in the UK, US and Canada, and represent part of the coming wave of new GM-plant-derived sources of EPA and DHA. We have carried out a number of aquafeed trials using these novel oils, and will report on the results from our most recent studies on salmon, focused on diets which closely mimic commercial formulations. In addition, we will compare the different GM plant oils in terms of their composition and potential utility for the aquafeed industry.

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# An alternative source of long chain Omega-3 fatty acids from Novel Canola oil for salmonid farming. Feeding trial report.

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Demand from rapidly growing salmon farming industry and market expansion projections revealed sustainability concern and need for an alternative ocean-independent source for long chain Omega-3 (LC Omega-3) fatty acids. In response to the industry trends Cargill and BASF jointly developed novel plant based source of LC Omega-3 fatty acids. Novel seeds were grown in North America and oil was produced via typical canola crushing protocol.

Atlantic salmon, Salmo salar feeding trials were conducted with commercial feed made with fish oil (FO, diet 0), or with novel canola oil as LC Omega-3 oil (O3, diet-1 and diet-2). Diets made with O3 oil contained the equal sum of docosahexaenoic (DHA) and eicosapentenoic (EPA), in diet-1 or equal amount of LC Omega-3 fatty acids: DHA, EPA and docosapentenoic (DPA), in diet-2 as in diet-0 made with FO. After 72 days of feeding there was no significant difference in weight development, mortality, feed consumption or feed conversion ratio (FCR) between FO diet and O3 diets. Liver and intestine histology results clearly indicated no adverse effect of plant O3 diet on fish health. There was no significant difference in hepatosomatic index (liver weight% of whole fish weight) between diets. Fish fed with O3 oil had similar amount of EPA and DHA as fish fed with FO diet.

Feeding study revealed that healthy Atlantic salmon can grow and accumulate LC Omega 3 fatty acids on a typical commercial formulation where fish oil is replaced with O3 oil. Agricultural production of EPA, DHA and DPA omega-3 oils is a sustainable alternative to growing salmon farming industry and could prevent wild small fish depletion.

# Novel feed resources from blue and green renewable biomass

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Developing novel feed resources from blue-green biomass can contribute to a sustainable growth in the aquaculture industry. While the ocean offers large opportunities for cultivation of seaweed as sustainable feed resources, using green biomass such as spruce trees to produce feed can also help secure further growth in the blue sector. We are currently developing high-quality protein sources from spruce trees, brown seaweed, and fish and chicken co-products in an integrated biorefinery process. The process involves advanced processing technology, including mechanical, chemical, thermal and enzymatic pre-treatment to convert trees fibers into fermentable sugars. Likewise, new enzyme technology contributes to more efficient hydrolysis of seaweed into sugars, nitrogen-rich compounds and other nutrients. To ensure a high growth rate of the yeast, a rich fermentation media with optimal combination of sugars, nitrogen and other nutrients is essential. Thus, in this process we use hydrolysates from fish and animal co-products from the slaughter industry as additional sources of nitrogen and nutrients. Thus, sugars from spruce trees, sugars and nutrients from seaweed, combined with nutrient-rich hydrolysates from fish and animal co-products are used in an integrated biorefinery process for the production of yeast as a protein source. The yeast is harvested, centrifuged and dried, and the final product have a crude protein content of approximately 50-55%, and favorable amino acid composition. Yeast also contains a number of bioactive components such as β-glucans, mannoproteins, and nucleic acids that can have positive health effects. Nutritional value of yeast may vary depending on the species, fermentation process and downstream processing conditions. Optimum drying and downstream processing of yeast provide opportunities for increased nutritional value. Several experiments with yeast as a protein source for salmon have been performed in freshwater and seawater. In general, the results show that fish perform well when fed yeast-based diets compared to a high-quality fish meal control or plant-based diets. Feeding yeast also has positive health effects, including improved gut barrier function and stimulation of the innate immunity. Further research and development within yeast production can be important to secure the future sustainability and economic viability of intensive aquaculture.

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# Are Terrestrial Plants the Solution to Sustainable Aquafeeds?

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The transition of aquafeeds from fishmeal and fish oil to alternatives has been in progress since the early 2000s. A wide variety of products are being investigated including microbial proteins, fish and animal processing waste, insect meal, algae and terrestrial plants. Terrestrial plant products appear to be the most promising alternatives due primarily to the quantity of protein and oil required. Concurrent with the shift toward alternative feedstuffs, there has been a growing awareness of the potential environmental effects of both aquaculture and agriculture, and a desire to make aquaculture "sustainable." In 1990 the U.S. government passed a law (U.S. Code, title 7, Section 3103) that defined sustainable agriculture and aquaculture. Sustainability is site-specific and over the long-term is required to:

(1) Satisfy human food and fiber needs.

(2) Enhance environmental quality and the natural resource base upon which the agriculture economy depends.

(3) Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.

(4) Sustain the economic viability of farm operations.

(5) Enhance the quality of life for farmers and society as a whole.

An excellent paper (Aquaculture Research 2007 38, 551-579) contains a review of some "sustainable" plant products that may provide potential feedstuffs and improve aquaculture sustainability. This paper did not contain a definition of sustainability, as there were no conventionally produced crops that were certified as sustainable in 2007. Constance (2010 Sustainability 2 (1) 48-72) wrote "because the concept of sustainability is deeply contested, agribusiness is able to exploit the ambiguity surrounding the definition of sustainable and exercise power in attempts to frame sustainable agriculture in their favor." It will be difficult to claim that intensive aquaculture is sustainable without sustainable feeds. Although numerous feedstuffs are being examined, soy appears to be the leading candidate to provide a majority of the protein in aquafeeds. In 2013 soybeans, grown in the USA, were certified as being sustainably produced. My presentation will examine the current U.S. stainability law, an ecological definition of sustainability, and the certification process in general.