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Krill Meal Boosts Growth and Survival in Atlantic Salmon Smolts After Seawater Transfer

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Abstract

High-quality feeds with sustainable and functional ingredients play a critical role in enhancing the health and robustness of fish. The objective of the present trial was to compare feed intake, growth performance and survival of Atlantic salmon smolts (151±44 g) fed a commercial diet with 15% fishmeal with a diet containing 5% fishmeal + 10% krill meal (KM) after their transfer to seawater. The study was performed at a commercial fish farm for 116 days, and ten sea cages were included in the study. Five cages received the commercial control diet (with average of 198599 fish/cage), while the remaining five cages received a diet with 10% KM (with average of 197101 fish/cage). At the end of the trial, 4.8% enhanced specific growth rate (1.52% with 10% KM and 1.45% in control), and 22% reduced mortality (0.49% in 10% KM and 0.63% in control) were observed with the 10% KM diet, although not statistically significant. Furthermore, no significant differences were observed between the two groups in plasma parameters and fatty acid composition of heart, liver, and fillet. This field trial demonstrated that inclusion of 10% KM could have positive effects on growth and survival of Atlantic salmon smolts.

Introduction

The salmon aquaculture industry has seen a surge in demand for more feed due to increased production (Barberger-Gateau et al., 2007), prompting a shift towards more sustainable and functional ingredients. A change towards using more vegetable sources in salmon feeds can be observed for the past decade, addressing resource sustainability concerns, while presenting challenges related to nutrient deficiency and imbalance due to issues such as reduced palatability and the presence of anti-nutritional factors (Krogdahl et al., 2010; Lall & Anderson, 2005; Sørensen et al., 2011; Aas et al., 2022). For instance, protein and lipid levels in plant feedstuffs are highly variable, depending on processing, and not all carbohydrates (e.g., lignin and cellulose) are of nutritional value to fish (Glencross et al., 2020). Further, only a limited number of crops, such as soybean, rapeseed, corn, wheat, and sunflower, have been explored as aquafeed ingredients. Climate change (Hall, 2015), along with shifts in political, economic, cultural, technological, and demographic factors (Mitra, 2021), can impact the availability of these crops. In addition, the use of plant based proteins and oils in aquafeeds can lead to higher losses of nitrogen and phosphorus in feces (Engin & Koyuncu, 2023). Additionally, plant-based ingredients face direct competition from human consumption and other markets, such as livestock and pet feed, further driving up prices and limiting the availability of raw materials for aquafeeds. In the pursuit of sustainable aquaculture, the quest for innovative raw materials that promote fish health without compromising the environment in terms of its generation, processing or usage in feeds is paramount. New eco-friendly ingredients such as insect-based meals, single cell proteins, and fish trimmings/co-products are being explored as alternatives to traditional ingredients. However, these novel

ingredients face several challenges such as strict and sometimes unclear regulations, scalability, customer acceptance, and the high cost of production (Glencross et al., 2024; Piercy et al., 2023). One promising candidate is Antarctic krill *(Euphausia superba*), which is both sustainable and a functional marine ingredient available at commercial scale (Atkinson et al., 2009; Krafft et al., 2021; Nicol & Foster, 2016; Spiridonov & Casanova, 2010). Krill meal (KM) is derived from a meal of whole Antarctic krill and offers a good combination of high-quality nutrients such as well-balanced amino acids, phospholipids, omega-3 polyunsaturated fatty acids (n-3 PUFAs) including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), valuable micronutrients like astaxanthin, vitamins, minerals, choline, nucleotides, and trimethylamine N-oxide (TMAO) (Kaur et al., 2022) . Numerous studies have highlighted the positive impact of KM on growth, feed intake and feed conversion ratios (FCR) in various development stages of Atlantic salmon (Salmo salar), including the freshwater and seawater phases (Hatlen et al., 2017; Kaur et al., 2022). KM has also been shown to improve organ health such as intestinal, gill and liver health (Kaur et al., 2023; Kvingedal et al., 2023). Furthermore, KM inclusion improves fillet quality by providing better pigmentation, higher firmness and reduced gaping. KM inclusion has also been linked to more robust immune response, muscle properties, improved gut and fatty acid metabolism (Mørkøre et al., 2020). While the benefits of KM are well-documented, studies in challenging environments such as at commercial farms, remain limited. Farmed salmon face a critical phase when they transition from freshwater or brackish water land-based tanks to seawater cages. During this challenging period reduced appetite as well as increased mortality can be observed. In Norway, for instance, the mortality rate for Atlantic salmon ranged from 15 to 16% between 2017 and 2021, with around 35% of total mortality occurring within the first three months in sea cages for the 2010-11 salmon generations (Bleie & Skrudland, 2014; Pincinato et al., 2021) (Grefsrud et al., 2023). This early phase mortality leads to significant financial losses estimated to be several hundred million USD each year. Nutrition plays a significant role in determining fish welfare, contributing to the production of resilient smolt better equipped to handle challenges in seawater, including varying infection pressures, which ultimately leads to improved fish welfare and reduced losses.

The objective of the present field trial was to investigate feed intake, performance, and health parameters of the salmon with KM in their diets in comparison to the control diet, starting from 10-13 days after the seawater transfer and 116 days in the seawater phase. The selected dose was based on findings from previous trials, which recommended that including 8–10% KM is optimal for this developmental stage of salmonids.

Materials and Methods

Site Description and Fish Groups

The trial was conducted at Oterneset, Harstad municipality, by SalMar Farming AS. Average seawater temperature during the trial period was 10.2±2.6°C (min 4.8, max 13.4°C). Approximately 200 000 Atlantic salmon (*Salmo salar*) smolts (counts from hatchery) of the SalmoBreed strain with an average weight of 151±44 g were transferred to each of the ten cages at Oterneset between 13 -16. May. Two groups with five cagesin each group were balanced to have as equal average weights as possible at start of the trial. Average weight did not differ significantly between groups at the start (control: 114, 158, 164, 166 and 252 g and 10% KM: 113, 115, 167, 175 and 238 g, p=0.79). In addition, every other cage received control or test feed to have as equal environmental conditions as possible in the two groups. All fish had been vaccinated with Alpha ERM Salar and Alpha Ject micro 6 (Pharmaq part of Zoetis) in the hatchery, cages were 160 m in diameter and 28 m deep (15 m to bottom ring). Dead fish were manually removed daily from each cage using a circular frame net and counted and registered in Fishtalk (Akvagroup, Klepp, Norway). This trial was performed under the R&D licenses TH0015 and TH0016 issued by the Norwegian Directorate of Fisheries.

Feeding

The two groups were fed the same commercial salmon feed (Spirit Supreme) for the first two weeks after seawater transfer in mid-May 2022, before feeding with experimental diets started. The formulation and estimated composition of experimental feeds is provided in Table 1. Control cages received a commercial feed (Spirit Supreme Plus and Prime, Skretting AS, Stavanger, Norway), whereas test cages received a diet where 10% KM (supplied by Aker Qrill company, Oslo, Norway) was included on the cost of fishmeal. All feeds were produced under commercial conditions at the Skretting Norway Averøy plant on a commercial extruder. The trial lasted for 116 days (from end of May to end of September). Fish were fed using a Huber spreader (Akvapolar, Frei, Norway) until showing signs of satiety based on camera observation. The amount of feed administered through the automated feeding system was registered in Fishtalk on a daily basis. Due to the high incidence of sea lice in all cages, a sea lice-reducing feed (Slice vet- MSD animal health Norway AS) was administered for nine days in mid of July.

Sampling

A total of six fish from each cage were randomly collected by on-site personnel for analysis of blood, heart, liver and fillet. Fish were attracted by hand-

feeding, trapped in an encircling net and then transferred into a water bath with a lethal dose of Finquel (Coyle et al., 2004) by a handheld net. This procedure ensured sampling of fish engaged in feeding. Healthy appearing fish close to cage average weight were included for sampling of biological material.

Fish Growth

Fish weight and weight gain were based on estimates from Fishtalk, the production control system used by SalMar Farming AS. These estimates are a theoretical calculation based on a site-specific FCR (1.2), total biomass and daily feeding amount per cage. End weight = initial weight + (feed amount given pr fish/FCR).

Specific growth rate (SGR) was calculated using the formula:

SGR=[(final weight/initial weight)^(1/number of days)–1]*100

Blood Samples

Pooled blood samples were obtained from six fish per cage. Samples were taken from the Vena caudalis using Vacuette containers with lithium-heparin, following standard procedures (Braceland et al., 2017). After centrifugation on-site (6 min, 6500 rpm, room temperature), the plasma was transferred to Eppendorf tubes, kept cold during transport to Skretting AI (Stavanger, Norway), where it was frozen at -80°C until analysis. The Indiko Plus system (Thermo Fisher Scientific) was used to analyze the following plasma biochemistry parameters: Alanine transaminase (ALAT), Aspartate transaminase (ASAT), Creatine kinase (CK), C-reactive protein (CRP), Ferric reducing ability of plasma (FRAP), Astaxanthin, Cholesterol, HDL-cholesterol, LDL-cholesterol. All analyses were performed according to manufacturer's protocols.

Fatty Acid Analysis in Heart, Liver and Fillet

All tissue samples were kept cold during sampling with the use of ice packs. Fillet samples were frozen at -20°C the day of sampling, whereas pooled samples of heart (without Bulbus arteriosus) and liver tissue were transported overnight to the analyzing laboratory where they were frozen at -80°C until analysis. Pooled samples of tissue from six fish per cage were analyzed for fatty acid (FA) composition (area %). Fillet content of astaxanthin, fat, and fatty acids in the muscle tissue of the NQC (Norwegian Quality Cut) was assessed using Near Infrared Refraction (NIR) (Brown, Kube, Taylor, & Elliott, 2014) with internally developed equations at the Skretting AI Lab. Additionally, the visual color of the NQC was measured using a Minolta CR-410 instrument.

Table 1. Formulation and estimated composition of the experimental feeds. Diet formulation was based on the actual use of raw materials in the feed production. Nutritional values were measured by NIR technology (Skretting AI lab, Stavanger, Norway)

Diet formulation (g/100g)	Control diet	KM diet
Fish meal*	15.7	5.2
Krill meal**	0.0	10.2
Wheat gluten	15.7	16.6
Wheat	6.1	5.9
Soy protein concentrate	22.1	17.1
Horse beans	5.6	6.4
Guar meal	4.1	4.4
Sunflower meal	0.73	5.3
Fish oil high	4.8	3.6
Fish oil low	4.5	4.0
Rapeseed oil	13.8	14.3
Linseed oil	1.1	1.3
Camelina oil	0.09	0.15
Rapeseed lecithin	1.0	1.0
Vitamin mix	0.11	0.11
Mineral mix	1.7	1.7
Pigment	0.05	0.05
Other	2.9	2.8
Nutritional values		
Dry matter (DM) (%)	92	92
Crude protein (% DM)	42.7	42.3
Crude fat (% DM)	28.4	28.4
Ash (% DM)	5.1	4.9
DE (MJ/kg)	20.6	20.6
DP (g/kg)	373	373
EPA+DHA (% of fat)	7.6	7.6
n-6/n-3	0.90	0.92

*Proximate composition of fish meal: ash 16.5%, fat 9.5%, moisture 8.0%, protein 67.8%.

**Proximate composition of krill meal: ash 10.2%, fat 22.5%, moisture 7.8%, protein 55%.

The FA composition from the pooled tissue samples was determined after the separation of the methyl esters in a gas chromatograph (Scion 436 GC with CP-8400 autosampler, Scion Instruments, Livingstone, UK), equipped with PTV split/spitless injector (40°C for 2 min, 20°C/min to 140°C, 2,5°C/min to 220°C, 11 min hold), a CP Wax 52 CB capillary column (L:25m, ID:0.25mm, OD:0.36 mm, DF:0.20µm), a flame ionization detector, and hydrogen as carrier gas. The FA were identified by retention time using standard mixtures of methyl esters (Nu-Chek, Elyian, USA), and the FA composition (area %) was determined. All samples were integrated using the software Chromeleon® software version 7.2 connected to the GC.

Statistical Analyses

All statistics were performed with JMP 17.0.0 (SAS Institute). Student's t-test evaluated differences between groups and $P<0.05$ were denoted as statistical differences.

Results

Feed Intake

A 3% higher feed consumption was observed in the cages that were fed with 10% KM (average 168670 kg per cage for the whole period) in comparison to control group (average 163748 kg per cage for the whole period) as shown in Table 2. Interestingly, this was despite the initial average lower number of fish in each cage in the test group (197101 fish) than in the control group (198599 fish).

Growth and Mortality

Fish that were fed a diet containing 10% KM tended to have enhanced growth over a period of 116 days, as illustrated in Figure 1 and Table 2. Specifically, the 10% KM group exhibited a 449% weight gain, reaching an average of 700 g, while the control group experienced a 413% weight gain, reaching an average of 676 g. Additionally, the SGR for the 10% KM group was 4.8% higher at 1.52, compared to the control group where the SGR was 1.45. However, the difference was statistically non-significant ($P>0.05$).

The average mortality in the control cages was 0.63% of the initial number of fish transferred to seawater, whereas in the 10% KM group the corresponding percentage was 0.49 (Table 2, Figure 2). This represents a 22% lower mortality in 10% KM group, compared to the control group, even though it was not statistically significant.

Plasma Parameters and Fatty Acid Profile of Heart, Liver and Fillet

No statistically significant differences in plasma parameters between the two groups were found at any of the samplings (Table 3). Plasma parameters indicated a decent health status of the fish. No significant differences in EPA and DHA content in heart and liver tissue were observed between groups (Table S1 and S2). However, the test group showed significantly higher 16:0, 18:0, 18:1n-7 and sum of saturated FA in heart tissue (Table S1). In the liver small differences between groups were found, mainly higher 18:1n-7 in the test group compared to the control group (Table S2). Fillet quality parameters were similar between both groups at final sampling (Table S3). Fillet quality parameters and detailed fatty acid profiles in heart, liver and fillet is given in Supplementary materials (Table S1-S3).

Discussion

This article reports a field trial using a diet with 10% KM for Atlantic salmon smolts, highlighting a potential trend towards improved growth and survival after their transfer to the seawater phase over a 116-day testing period. While in controlled experiments variations in start weight is very limited, variation in commercial scaled trials, as in case of the current study, could be higher. To account for this, cages were divided into two groups to have as similar starting weight distribution and average weight as much as possible. A 4.8% higher SGR and 22% lower mortality rate was observed in fish fed with 10% KM compared to the control group, but without statical significance.

Table 2. Growth performance and mortality data in the control and 10% KM diet groups over a period of 116 days feeding field trial. All values represent means±SD, N=5

	Control	10% krill meal	p value
Average weight at SW transfer (g)	150±46	142±47	0.81
Avg nr of fish at SW transfer/cage	198599±1672	197101±4091	0.47
Average feed given/cage (kg)	163748±20660	168670±30854	0.77
Average feed given pr fish (kg)*	0.82±0.10	0.85±0.15	0.71
Average start weight (g)	171±50	162±52	0.79
Weight gain per group (g)	676±82	700±122	0.72
Weight gain per group (%)	413±78	449±68	0.45
Average SGR (%)	1.45±0.13	1.52±0.11	0.42
Average mortality (number of fish)	1250±478	969±214	0.26
Average Mortality (% of number at SW transfer)	0.63±0.23	0.49±0.1	0.27

*Estimate is based on the initial number of fish in the pen and does not take into account mortality during the period.

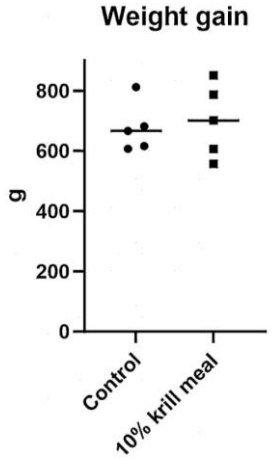

Figure 1: Weight gain (g) of control and 10% krill meal group during the 116 days of feeding trial. Each dot represents one of the five cages in each group. The lines represent the respective means.

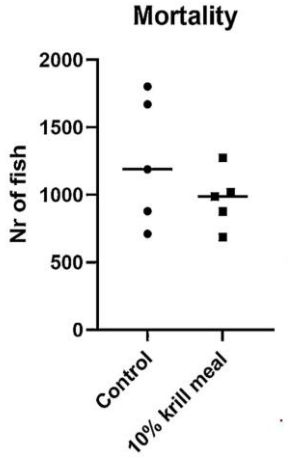

Figure 2: Mortality (%) of control and 10% krill meal group during the 116 days of feeding trial. Each dot represents one of the five cages in each group. The lines represent the respective means.

The transition to the seawater phase poses challenges for Atlantic salmon smolts. This phase is linked to appetite suppression, potentially reducing the intake of essential compounds necessary for optimal growth, immune system development, and adaptation to physiological changes. These factors collectively impact fish health, welfare, and contribute to increased economic losses in the aquaculture industry (Bleie & Skrudland, 2014; Pincinato et al., 2021). KM, owing to its nutritional profile and palatability, has the potential to enhance feed intake and robustness during challenging periods for Atlantic salmon smolts (Hatlen et al., 2017; Kaur et al., 2022).

The 3% higher feed consumption and better growth (4.8% higher SGR) with 10% KM in the current trial was in line with the results from a study by Hatlen et al. in 2017, where significantly improved growth was observed in Atlantic salmon smolts with 7.5% and 15% KM inclusion during a 13-week period in seawater (Hatlen et al., 2017). The higher palatability resulting in enhanced growth may be attributed to the presence of nutrients such as short peptides, free amino acids, nucleotides, and TMAO in KM.

A 22% reduction in mortality was observed with 10% KM. This is especially noteworthy considering the concerning mortality rates at Atlantic salmon farms, with a remarkable 56.7 million Atlantic salmon reported to have died during the seawater phase in 2022 (Grefsrud et al., 2023), marking a record high in salmon losses. These alarming figures demonstrate an urgent need to reduce these mortalities at salmon farms both for better fish welfare and for economic reasons. High quality nutrients from sustainable sources such as KM to enhance Atlantic salmon's growth and robustness and reducing mortality could be a part of the attempts needed to achieve a more thriving salmon industry.

The differences in growth parameters and mortality observed in the present study were not statistically significant. This may be attributed to confounding factors, such as fluctuating environmental conditions in the cages, which likely introduced high variability, making it more difficult to detect significant differences compared to the controlled conditions typically seen in laboratory trials. Nevertheless, it is important to emphasize that while the differences were not statistically significant, the observed trends with

Table 3. Plasma parameters at initial sampling in May and final sampling in September. ALAT: alanine aminotransferase, ASAT: aspartate aminotransferase, CK: creatine kinase, CRP: C-reactive protein, LDH: lactate dehydrogenase, FRAP: Ferric-reducing ability of plasma, HDL: High density lipoprotein, LDL: Low density lipoprotein, KM: krill meal. N=5

	Initial sampling		Final sampling	
	Control	10% KM	Control	10% KM
Albumin (g/L)	12.1	11.1	16.4	16.3
ALAT (U/L)	13.5	9.36	7.78	8.1
ASAT (U/L)	452	336	458	426
CK (U/L)	3716	1190	14803	12458
Creatinine (µmol/L)	6.66	8.66	24.0	17.2
CRP (mg/L)	2.5	2.5	3.6	5
LDH (U/L)	1133	1245	461	289
FRAP (µmol e/L)	918	913	1081	1040
pH	7.47	7.50	7.15	7.10
Calcium (mmol/L)	2.88	2.75	3.35	3.32
Chloride (mmol/L)	139	137	146	145
Magnesium (mmol/L)	0.81	0.93	1.34	1.47
Phosphorous (mmol/L)	3.66	3.65	6.47	6.72
Potassium (mmol/L)	3.74	4.16	5.72	5.64
Sodium (mmol/L)	168	165	182	182
Total protein (g/L)	27	24.6	38.6	38.6
Urea (mmol/L)	1.78	1.78	1.08	1.24
Cholesterol (mmol/L)	6.54	5.98	8.86	8.63
HDL-cholesterol (mmol/L)	2.13	2.06	2.81	2.89
LDL-cholesterol (mmol/L)	0.63	0.55	0.53	0.48

10% KM inclusion—4.8% improved growth and 22% reduced mortality—could significantly impact salmon farmers and the aquaculture industry. These improvements not only promote better fish welfare but also offer economic advantages to farmers. Reduced fish losses lead to higher yields, enhancing overall efficiency as more fish reach market size, ultimately boosting potential revenue. Thus, even marginal improvements in growth and survival can translate into substantial economic benefits for farmers.

Finally, the author acknowledges that the higher cost of krill meal may limit its adoption, despite its potential for better growth and reduced mortality. To address this, future studies should focus on evaluating its cost-efficiency through comprehensive economic analyses, detailed cost-benefit assessments, and comparisons of the cost-effectiveness of krill meal in conventional feeds.

Conclusions

The findings of this study suggest that feeds with 10% KM inclusion showed trends toward better growth and lower mortality in Atlantic salmon smolts during the initial period after seawater transfer. These improvements could enhance fish welfare and provide economic benefits to farmers.

Ethical Statement

All handling of fish complied with the Guidelines of the EU legislation (2010/63/EU), as well as the Norwegian legislation. The study was considered a non-regulated procedure according to the National Legislation on Animal Research since the fish had not been exposed to any pain or stress.

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Author Contribution

Conceptualization- KK, LB and KB; methodology- KB and DK; formal analysis- FG and LL.; investigation- KB, DK and LL; data curation- LL, DK and KB.; writing—KK, LL.; writing—KK, FG, KB; project administration- KB, LL and DK.

Conflict of Interest

Lb and KK are employees of AkerBioMarine Antarctic AS that has provided the krill meal. KB, LL, DK and FG work at Skretting As responsible for conducting the study. The authors declare that they have no other competing interests.

References

Aas, T. S., Åsgård, T., & Ytrestøyl, T. (2022). Utilization of feed resources in the production of Atlantic salmon (*Salmo salar*) in Norway: An update for 2020. *Aquaculture Reports, 26*, 101316. https://doi.org/10.1016/j.aqrep.2022.101316

Atkinson, A., Siegel, V., Pakhomov, E., Jessopp, M., & Loeb, V. (2009). A re-appraisal of the total biomass and annual production of Antarctic krill. *Deep Sea Research Part I: Oceanographic Research Papers, 56*(5), 727-740.

Barberger-Gateau, P., Raffaitin, C., Letenneur, L., Berr, C., Tzourio, C., Dartigues, J.-F., & Alpérovitch, A. (2007).

Dietary patterns and risk of dementia: the Three-City cohort study. *Neurology, 69*(20), 1921-1930.

Bleie, H., & Skrudland, A. (2014). Tap av laksefisk i sjø. *Rapport fra Mattilsynet*.

Braceland, M., Houston, K., Ashby, A., Matthews, C., Haining, H., Rodger, H., & Eckersall, P. D. (2017). Technical pre-analytical effects on the clinical biochemistry of Atlantic salmon (*Salmo salar L.*). *J Fish Dis, 40*(1), 29-40. https://doi.org/10.1111/jfd.12476

Brown, M. R., Kube, P. D., Taylor, R. S., & Elliott, N. G. (2014). Rapid compositional analysis of Atlantic salmon (S*almo salar*) using visible-near infrared reflectance spectroscopy. *Aquaculture Research, 45*(5), 798-811. https://doi.org/10.1111/are.12021

Coyle, S. D., Durborow, R. M., & Tidwell, J. H. (2004). *Anesthetics in aquaculture* (Vol. 3900): Southern Regional Aquaculture Center Texas.

Engin, K., & Koyuncu, C. (2023). The Recent Advances to Increase Nutrient Utilization of Dietary Plant Proteins by Enzyme Supplementation and Fermentation in Rainbow Trout (*Oncorhynchus mykiss*): A Review. *Journal of Agricultural Sciences, 29*(4), 960-972.

Garseth, Å. H., Olsen, A. B., Gjerset, B., & Sindre, H. (2023). Risk based health monitoring of wild finfish in Norway 2022. Surveillance program report. Norwegian Veterinary Institute report 10_2023.

Glencross, B. D., Huyben, D., & Schrama, J. W. (2020). The application of single-cell ingredients in aquaculture feeds—a review. *Fishes, 5*(3), 22.

Glencross, B., Ling, X., Gatlin, D., Kaushik, S., Øverland, M., Newton, R., & Valente, L. M. (2024). A SWOT analysis of the use of marine, grain, terrestrial-animal and novel protein ingredients in aquaculture feeds. *Reviews in Fisheries Science & Aquaculture*, 32(3), 396-434.

Grefsrud, E. S., Andersen, L. B., Grøsvik, B. E., Karlsen, Ø., Kvamme, B. O., Hansen, P. K., ... & Solberg, M. F. (2023). Risk report on Norwegian fish farming 2023-production mortality in farmed fish and environmental effects of Norwegian fish farming. Hall, G. M. (2015). Impact of climate change on aquaculture: the need for alternative feed components. *Turkish Journal of Fisheries and Aquatic Sciences, 15*(3), 569-574.

Hall, G. M. (2015). Impact of climate change on aquaculture: the need for alternative feed components. Turkish Journal of Fisheries and Aquatic Sciences, 15(3), 569-574.

Hatlen, B., Berge, K., Nordrum, S., Johnsen, K., Kolstad, K., & Mørkøre, T. (2017). The effect of low inclusion levels of A ntarctic krill (*Euphausia superba*) meal on growth performance, apparent digestibility and slaughter quality of A tlantic salmon (*Salmo salar*). *Aquaculture Nutrition, 23*(4), 721-729.

Kaur, K., Kortner, T. M., Benitez-Santana, T., & Burri, L. (2022). Effects of Antarctic krill products on feed intake, growth performance, fillet quality, and health in salmonids. *Aquaculture Nutrition, 2022*(1), 3170854.

Kaur, K., Krogdahl, Å., & Kortner, T. M. (2023). Phosphatidylcholine in Krill Meal and Krill Oil as a Source of Choline for Prevention of Intestinal Steatosis in Atlantic Salmon. *Aquaculture research, 2023*(1), 4001633.

Krafft, B. A., Macaulay, G. J., Skaret, G., Knutsen, T., Bergstad, O. A., Lowther, A., Murphy, E. (2021). Standing stock of Antarctic krill (*Euphausia superba* Dana, 1850) (Euphausiacea) in the Southwest Atlantic sector of the Southern Ocean, 2018–19. *Journal of Crustacean Biology, 41*(3), ruab046.

Krogdahl, Å., Penn, M., Thorsen, J., Refstie, S., & Bakke, A. M. (2010). Important antinutrients in plant feedstuffs for aquaculture: an update on recent findings regarding responses in salmonids. *Aquaculture Research, 41*(3), 333-344. https://doi.org/10.1111/j.1365-2109.2009.02426.x

Kvingedal, R., Vigen, J., Nanton, D., Ruohonen, K., & Kaur, K. (2023). Effects of Different Phospholipid Sources on Growth and Gill Health in Atlantic Salmon in Freshwater Pre-Transfer Phase. *Animals, 13*(5), 835.

Lall, S., & Anderson, S. (2005). Amino acid nutrition of salmonids: Dietary requirements and bioavailability. *Cahiers options mediterraneennes, 63*(63), 73-90.

Mitra, A. (2021). *Thought of alternate aquafeed: conundrum in aquaculture sustainability?* Paper presented at the Proceedings of the Zoological Society.

Mørkøre, T., Moreno, H. M., Borderías, J., Larsson, T., Hellberg, H., Hatlen, B., Jiménez-Guerrero, R. (2020). Dietary inclusion of Antarctic krill meal during the finishing feed period improves health and fillet quality of Atlantic salmon (*Salmo salar* L.). *British Journal of Nutrition, 124*(4), 418-431.

Nicol, S., & Foster, J. (2016). The fishery for Antarctic krill: Its current status and management regime. *Biology and ecology of Antarctic krill*, 387-421.

Pincinato, R. B., Asche, F., Bleie, H., Skrudland, A., & Stormoen, M. (2021). Factors influencing production loss in salmonid farming. *Aquaculture, 532*, 736034.

Piercy, E., Verstraete, W., Ellis, P. R., Banks, M., Rockström, J., Smith, P., & Guo, M. (2023). A sustainable waste-to-protein system to maximise waste resource utilisation for developing food-and feed-grade protein solutions. Green Chemistry, 25(3), 808-832.Spiridonov, V., & Casanova, B. (2010). Order euphausiacea dana, 1852. In *Treatise on Zoology-Anatomy, Taxonomy, Biology. The Crustacea, Volume 9 Part A* (pp. 5-82): Brill.

Sørensen, M., Berge, G. M., Thomassen, M. S., Ruyter, B., Hatlen, B., Ytrestøyl, T., Åsgård, T. E. (2011). Today's and tomorrow's feed ingredients in Norwegian aquaculture. *Nofima rapportserie*.

Supplementary Tables

Table S1. Fatty acid composition (area %) of heart tissue at initial sampling in May and final sampling in September. Different lower-case letters indicate statistically significant difference between groups. KM: krill meal. N=5

Fatty acids	Initial sampling		Final sampling	
	Control	10% KM	Control	10% KM
12:0	0.06	0.05	0.06	0.07
14:0	1.52	1.58	1.54	1.56
15:0	0.18	0.18	0.14	0.14
16:0	16.07	15.76	14.32[b]	14.78[a]
16:1n-7	1.57	1.63	1.61	1.53
16:2n-4	0.06	0.07	0.10	0.09
18:0	4.62	4.50	4.35[b]	4.53[a]
18:1n-5	0.13	0.13	0.08	0.07
18:1n-7	2.58	2.55	2.29[b]	2.45[a]
18:1n-9	20.62	20.91	20.97	21.40
18:2n-6	6.44	6.49	8.27	8.36
18:3n-3	2.18	2.24	3.98	4.03
18:4n-3	0.46	0.47	0.35[a]	0.30[b]
20:0	0.21	0.21	0.23	0.25
20:1n-11	0.22	0.25	0.14[a]	0.10[b]
20:1n-7	0.10	0.10	0.10	0.10
20:1n-9	2.72	2.82	2.37[a]	2.16[b]
20:2n-6	0.54	0.55	0.73[b]	0.81[a]
20:3n-3	0.15	0.16	0.31[b]	0.35[a]
20:3n-6	0.41	0.40	0.43	0.44
20:4n-3	0.57	0.56	0.75	0.72
20:4n-6	1.17	1.15	1.11	1.03
20:5n-3 (EPA)	4.03	3.94	7.01	7.30
22:0	0.08	0.09	0.13	0.13
22:1n-11	2.33	2.39	1.74[a]	1.41[b]
22:1n-9	0.41	0.41	0.36	0.36
22:5n-3	1.00	0.97	1.76	1.79
22:5n-6	0.30	0.31	0.28[a]	0.23[b]
22:6n-3 (DHA)	23.87	23.47	18.84	18.05
24:1n-9	1.10	1.09	0.96	0.91
Sum n-3	32.35	31.89	33.12	32.63
Sum n-6	8.92	8.98	10.85	10.91
n-6/n-3	0.28	0.28	0.33	0.33
Sum saturated	22.74	22.37	20.86[b]	21.52[a]
Sum monounsaturated	31.78	32.27	30.61	30.49
Sum polyunsaturated	41.40	41.00	44.31	43.81
Sum unsaturated	73.18	73.28	74.93	74.30
Unsaturated/saturated	3.22	3.28	3.59[a]	3.45[b]

Table S2. Fatty acid composition of liver tissue at initial sampling in May and final sampling in September. Different lower-case letters indicate statistically significant differences between groups. KM: krill meal. N=5

Fatty acids	Initial sampling		Final sampling	
	Control	10% KM	Control	10% KM
C12:0	0.004	0.004	0.002	0.00
C14:0	2.02	1.92	1.07	1.03
C15:0	0.21	0.20	0.10	0.08
C16:0	11.15	11.41	9.82[b]	9.56[a]
C16:1n-7	2.56	2.51	1.58	1.61
C16:2n-4	0.07	0.06	0.06	0.05
C18:0	4.09	4.17	5.55	5.69
C18:1n-5	0.27	0.14	0.06	0.07
C18:1n-7	2.67	2.7	2.14[b]	2.41[a]
C18:1n-9	28.85	28.68	26.98	28.78
C18:2n-6	7.78	7.58	7.85	8.02
C18:3n-3	2.54	2.43	3.07	3.06
C18:4n-3	0.61	0.54	0.15[b]	0.11[a]
C20:0	0.14	0.15	0.19	0.20
C20:1n-11	0.28	0.27	0.28	0.20
C20:1n-7	0.12	0.12	0.11	0.12
C20:1n-9	3.09	3.05	4.05	4.06
C20:2n-6	1.01	1.01	1.84	2.00
C20:3n-3	0.30	0.30	0.74	0.82
C20:3n-6	0.73	0.75	0.49	0.47
C20:4n-3	1.19	1.12	0.80[a]	0.70[b]
C20:4n-6	1.1	1.15	1.18	1.02
C20:5n-3 (EPA)	4.38	4.34	7.41	7.05
C22:0	0.03	0.03	0.04[b]	0.05[a]
C22:1n-11	1.32	1.32	1.05[a]	0.79[b]
C22:1n-9	0.29	0.28	0.28	0.28
C22:5n-3	0.83	0.78	1.65	1.65
C22:5n-6	0.12	0.13	0.21	0.18
C22:6n-3 (DHA)	15.10	15.52	14.59	13.21
C24:1n-9	1.00	1.04	1.37	1.30
Sum n-3 FA	25.10	25.18	28.52	26.71
Sum n-6 FA	10.93	10.79	11.59	11.70
n-6/n-3	0.44	0.43	0.41	0.44
Sum saturated FA	17.64	17.89	16.84	16.66
Sum monounsaturated	40.45	40.10	37.91	39.62
Sum polyunsaturated	36.31	36.22	40.39	38.69
Sum unsaturated FA	76.76	76.33	78.30	78.31
Unsat/saturated	4.36	4.29	4.65	4.70

Table S3. Color, pigment, and fatty acid composition (% of fillet) in fillet at final sampling in September. KM: krill meal. N=5

	Control	10% KM
Moisture (g/100g)	68.4	67.9
Fat (g/100g)	10.9	11.3
22:5n-3	0.1	0.1
20:4n-3	0.1	0.1
20:4n-6	0.7	0.7
18:2n-6	1.4	1.4
22:6n-3	0.5	0.5
20:5n-3	0.3	0.3
Sum n-3	1.7	1.7
Sum n-6	1.6	1.6
Sum saturated	1.5	1.6
Astaxanthin (mg/kg)	3.3	3.3
Totalt pigment (mg/kg)	3.7	3.8
SalmoFan Color	23.2	23.2