Norwegian Centre for Research-based Innovation

FINAL REPORT

FOODS OF NORWAY

Norwegian University of Life Sciences

FOODS OF NORWAY AIMS TO FEED FISH AND FARM ANIMALS USING SUSTAINABLE NEW INGREDIENTS.

Foods of Norway was funded by the Research Council of Norway (grant no. 237841/O30), our partners and our host institution - the Norwegian University of Life Sciences (NMBU) from 2015-2024.

Centre director: Margareth Øverland (NMBU)

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FOREWORD

The SFI Foods of Norway is a Centre for Research-Based Innovation established in 2015 with a nine-year Centre period. The Centre's primary goal has been to develop novel, sustainable, and locally sourced protein ingredients for aquaculture and livestock feeds. Our research has focused on harnessing Norway's abundant natural resources, such as woody biomass, seaweed and grass to create innovative feed solutions that support sustainable food production, enhance animal performance and health, reduce dependence on imported feed raw materials, and lower the environmental footprint of aquaculture and livestock production.

This final report presents the key highlights and outcomes achieved during the Centre's operation. It includes essential information about the Centre's organization, financing, and collaborative structure throughout its nine-year journey. The report aims to provide a comprehensive overview of our accomplishments: research findings that have led to innovation and delivered significant value to our partners, as well as to the broader community. For a more detailed account of specific activities, we refer to the Centre's Annual Reports for 2015-2023 and the scientific publications produced during this period.

Through groundbreaking research, documented in numerous peer-reviewed publications, Foods of Norway has played a pivotal role in elevating local feed production to a central position on the political and industrial agenda. Our efforts have contributed strongly to the foundation for a national mission on sustainable feed. The innovations developed at Foods of Norway address critical challenges, reducing reliance on imported feed ingredients, alleviating pressure on global natural resources, lowering greenhouse gas emissions associated with transport and enhancing feed and food safety. Ultimately, these innovations contribute to more resilient and sustainable food production systems.

The success of Foods of Norway has been made possible through the invaluable support of the Norwegian Research Council, the active engagement of our industry partners, and the dedication of a talented team of researchers, technicians and students. To all who have contributed to this journey, we extend our heartfelt gratitude. Your efforts have enabled us to advance the development of sustainable feed resources for fish and livestock and to set new benchmarks for the future of food production.

Centre Director,
Professor Margareth Øverland

Margareth Øverland

Foods of Norway has contributed to lifting and positioning NMBU within our core areas, and it has been achieved in line with NMBU's long tradition of close collaboration with industry.

Foods of Norway marks a significant milestone in the development of Norwegian-based feed ingredients. This important center for research-based innovation (SFI) has played a key role in mowing toward securing Norwegian food production by increasing the proportion of locally produced feed in a sustainable way.

Throughout the center period, Foods of Norway has focused on developing sustainable feed ingredients from renewable bioresources that are not suitable for consumption by humans. These ingredients have the potential to be produced in large quantities at a competitive price. The emphasis on developing innovative processing techniques by utilizing state-of-the-art biorefining technologies has been crucial, enabling the conversion of natural bioresources into high-quality feed ingredients for fish and livestock.

The Foods of Norway team has successfully executed and completed a large, demanding center involving many partners, with 20 industry and innovation partners. High-profile academic institutions have worked closely with essential industry partners along the value chain in this SFI, driving new knowledge, technology, and solutions. Foods of Norway is a success in fostering meaningful research collaboration for the development of new knowledge for both industry and society, as well as for NMBU.

Foods of Norway has published the work in a variety of scientific journals, including high-impact ones, and shared key results with stakeholders, and the public. As a result, Foods of Norway has significantly contributed to placing local feed on the political agenda, reach helped lead to the Norwegian mission on sustainable feeds.

Kari Kolstad
Director
Research, innovation & external relations

SUMMARY

Norway's aquaculture and livestock industries face major sustainability challenges, especially in securing sustainable feed. As the world's largest salmon producer, Norway plans to grow production from 2 to 5 million tons by 2050. Currently, 92% of aquaculture feed is imported, and livestock also relies heavily on imported protein. This raises concerns about feed security, sustainability, and emissions, as feed production accounts for 75–83% of sector greenhouse gas emissions. Sustainable, locally sourced feed solutions are crucial for future growth.

The vision of Foods of Norway has been to increase value creation in the Norwegian aquaculture, meat and dairy industries by developing novel feed ingredients from natural bioresources and by improving feed utilization.

To achieve this vision, Foods of Norway' s main objective has been to develop novel feed ingredients from locally sources blue and green biomass and by improving feed efficiency of fish and farm animals through cutting-edge research on bioprocessing, nutrition, health, genetics and product quality.

The Foods of Norway consortium has consisted of three faculties at NMBU and 20 industry and innovation partners. Professor Margareth Øverland from the Faculty of Biosciences, NMBU has been the centre director. This expertise is further strengthened through a close collaboration with several international partners and collaborators.

Through innovative research, Foods of Norway has pioneered advances in sustainable feed production using local bioresources. Ingredients such as yeast and fungi derived from spruce-sugars and seaweed have demonstrated their ability to improve health and productivity of livestock and fish, while providing a more sustainable alternative to conventional feed ingredients. These advancements play a key role in promoting sustainable food production, benefitting both farmers, the society at large and the environment.

The centre has produced a large number of scientific publications. The original target of peer reviewed articles of 75 has been exceeded, and currently the centre has published 87 articles and is expected to reach about 100 publications. Foods of Norway scientists have actively participated in scientific meetings and conferences, often as keynote speakers or panelists. They have also engaged with stakeholders from the aquaculture, forestry and agricultural industries, as well as with politicians and regulatory authorities. Two PhD candidates from the centre have received international awards for their scientific work.

Foods of Norway has made substantial efforts in creating sustainable and resource-efficient feed and feed ingredients from Norwegian bioresources. In partnership with industry, the centre has successfully fostered collaboration, innovation, and the development of new knowledge for both industry and society.

The centre has pioneered the production of high-quality microbial proteins derived from local forestry side streams as sustainable alternatives to imported conventional protein sources Foods

of Norway has also successfully integrated seaweed, a macroalgae abundant along the Norwegian coast, into feed rations for salmon, broiler chickens and ruminants. Seaweed is rich in health-promoting substances and offers a sustainable feed option. The centre has developed methods to enhance the nutritional value of grass silage for ruminants. By adding organic acids and enzymes to degrade the fibers in grass, the nutritional value of late-harvested grass is improved. Finally, researchers have developed a method to track individual feed utilization in large groups of farmed animals, such as salmon. By using stable isotopes as markers, the amount of feed consumed relative to growth rate is determined for each animal.

The centre has played a significant role in training the next generation of scientist. PhD students actively participated in the centre's research activities alongside senior researchers, bioengineers and industry partners. The centre has provided 12 Ph.D. candidates and 33 master's degrees, effectively matching the industry recruitment needs. This approach is one of the most effective ways to build expertise.

Foods of Norway has established a robust framework for global collaboration through personnel exchanges, creation of new networks, and participation in conferences and research projects. There have been two international industry partners: the Canadian company, Lallemand and the Finnish partner, Enifer. Foods of Norway have facilitated the Enifer's involvement in upscaling innovative feed solutions for the aquaculture industry.

The long lifespan of an SFI, allows for more in-depth research, competence building, and interdisciplinarity compared to short term projects. The industry's employees expand their professional expertise and network through the program and thereby strengthening the industry's competitive position. The centre generates new project ideas that form the basis for spin-off projects both internally and externally. The centre has become an important meeting point for knowledge exchange and network building – activities that will continue also after the SFI period has ended.

The Foods of Norway Centre is committed to continue to advance sustainable feed research and industry collaboration after its operational period ends. We plan to secure new funding from various sources, including the Research Council of Norway, EU Horizon projects, and Nordic funds, to continue the work on sustainable feed solutions. Mowing forward, we aim to transition research into industrial applications by collaborating with key industry partners and expanding into new fields like biotechnology and AI for feed traceability. The data and infrastructure developed during the Centre's operation, will be maintained and used for future research, ensuring Norway remains a leader in sustainable feed development.

SAMMENDRAG

Norges oppdretts- og husdyrnæring står overfor store bærekraftsutfordringer, særlig når det gjelder å sikre bærekraftig fôr. Norge er verdens største lakseprodusent, og har planer om å øke produksjonen fra 2 til 5 millioner tonn innen 2050. I dag importeres 92 % av fôret til oppdrettsnæringen, og også husdyrholdet er i stor grad avhengig av importert protein. Dette gir grunn til bekymring for fôrsikkerhet, bærekraft og utslipp, ettersom fôrproduksjonen står for 75-83 % av klimagassutslippene i sektoren. Bærekraftige løsninger for lokal produksjon av fôr er avgjørende for fremtidig vekst.

Foods of Norway har som visjon å øke verdiskapingen i norsk oppdretts-, kjøtt- og meieriindustri ved å utvikle nye fôringredienser fra naturlige bioressurser og ved å forbedre utnyttelsen av fôret.

For å nå denne visjonen har Foods of Norway hatt som hovedmål å utvikle nye fôringredienser fra lokal blå og grønn biomasse og ved å forbedre fôrutnyttelsen hos fisk og husdyr gjennom banebrytende forskning på bioprosessering, ernæring, helse, genetikk og produktkvalitet.

Foods of Norway-konsortiet har bestått av tre fakulteter ved NMBU og 20 industri- og innovasjonspartnere. Professor Margareth Øverland fra Fakultet for biovitenskap, NMBU har vært senterleder. Denne ekspertisen er ytterligere styrket gjennom et tett samarbeid med flere internasjonale partnere og samarbeidspartnere.

Gjennom innovativ forskning har Foods of Norway vært en pioner innen bærekraftig fôrproduksjon ved hjelp av lokale bioressurser. Ingredienser som gjær og sopp fra gransukker og tare har vist seg å kunne forbedre helsen og produktiviteten til husdyr og fisk, samtidig som de utgjør et mer bærekraftig alternativ til konvensjonelle fôringredienser. Disse fremskrittene spiller en nøkkelrolle i arbeidet med å fremme bærekraftig matproduksjon, noe som kommer både bønder, samfunnet og miljøet til gode.

Senteret har produsert et stort antall vitenskapelige publikasjoner. Det opprinnelige målet om 75 fagfellevurderte artikler er overoppfylt, og senteret har per nå publisert 87 artikler og forventes å nå rundt 100 publikasjoner. Forskerne ved Foods of Norway har deltatt aktivt på vitenskapelige møter og konferanser, ofte som hovedforedragsholdere eller paneldeltakere. De har også hatt kontakt med interessenter fra oppdretts-, skogbruks- og landbruksnæringen, samt med politikere og regulerende myndigheter. To doktorgradskandidater fra senteret har mottatt internasjonale priser for sitt vitenskapelige arbeid.

Foods of Norway har gjort en betydelig innsats for å skape bærekraftig og ressurseffektivt fôr og fôringredienser fra norske bioressurser. I samarbeid med industrien har senteret lykkes med å fremme samarbeid, innovasjon og utvikling av ny kunnskap for både industri og samfunn.

Senteret har vært en pioner innen produksjon av mikrobielle proteiner av høy kvalitet fra lokale sidestrømmer fra skogbruket, som et bærekraftig alternativ til importerte konvensjonelle proteinkilder. Foods of Norway har også lykkes med å integrere tare, en makroalge som det finnes mye av langs norskekysten, i fôrrasjoner til laks, slaktekyllinger og drøvtyggere. Tare er rik på

helsefremmende stoffer og er et bærekraftig fôralternativ. Senteret har utviklet metoder for å øke næringsverdien i surfôr til drøvtyggere. Ved å tilsette organiske syrer og enzymer for å bryte ned fiber i gresset, kan næringsverdien i sent høstet gress forbedres. Forskere har også utviklet en metode for å spore individuell fôrutnyttelse i store dyregrupper, som for eksempel laks. Ved å bruke stabile isotoper som markører kan man finne ut hvor mye fôr hvert enkelt dyr har spist i forhold til tilvekst.

Senteret har spilt en viktig rolle i utdanningen av neste generasjons forskere. Doktorgradsstudenter har deltatt aktivt i senterets forskningsaktiviteter sammen med seniorforskere, bioingeniører og industripartnere. Senteret har utdannet 12 doktorgradskandidater og 33 mastergradskandidater, noe som effektivt matcher industriens rekrutteringsbehov. Denne tilnærmingen er en av de mest effektive måtene å bygge kompetanse på.

Foods of Norway har etablert et robust rammeverk for globalt samarbeid gjennom utveksling av personell, etablering av nye nettverk og deltakelse i konferanser og forskningsprosjekter. Det har vært to internasjonale industripartnere: det kanadiske selskapet Lallemand og den finske partneren Enifer. Foods of Norway har lagt til rette for Enifers engasjement i oppskalering av innovative fôrløsninger for havbruksnæringen.

Den lange levetiden til en SFI gir mulighet for mer dyptgående forskning, kompetansebygging og tverrfaglighet sammenlignet med kortsiktige prosjekter. De ansatte i næringen utvider sin faglige kompetanse og sitt nettverk gjennom senteret og styrker dermed sin konkurranseposisjon. Senteret genererer nye prosjektideer som danner grunnlag for spin-off-prosjekter både internt og eksternt. Senteret har blitt en viktig møteplass for kunnskapsutveksling og nettverksbygging - aktiviteter som vil fortsette også etter at SFI-perioden er over.

Foods of Norway-senteret har forpliktet seg til å fortsette å fremme forskning på bærekraftig fôr og industrisamarbeid etter at senterperioden er over. Vi planlegger å sikre ny finansiering fra ulike kilder, inkludert Norges forskningsråd, EUs Horizon-prosjekter og nordiske fond, for å fortsette arbeidet med bærekraftig fôr. Vi tar sikte på å overføre forskning til industrielle anvendelser ved å samarbeide med viktige industripartnere og utvide til nye felt som bioteknologi og kunstig intelligens for sporbarhet av fôr. Dataene og infrastrukturen som er utviklet i løpet av senterets drift, vil bli vedlikeholdt og brukt til fremtidig forskning, slik at Norge forblir ledende innen utvikling av bærekraftig fôr.

VISION AND OBJECTIVES

The Foods of Norway vision is to increase value creation in the Norwegian aquaculture, meat and dairy industries by developing novel feed ingredients from natural bioresources and by improving feed utilization.

The main objective of Foods of Norway is to make Norwegian fish and animal farming industries more competitive and innovative by developing novel feed ingredients from bioresources and ensuring efficient feed resource utilization.

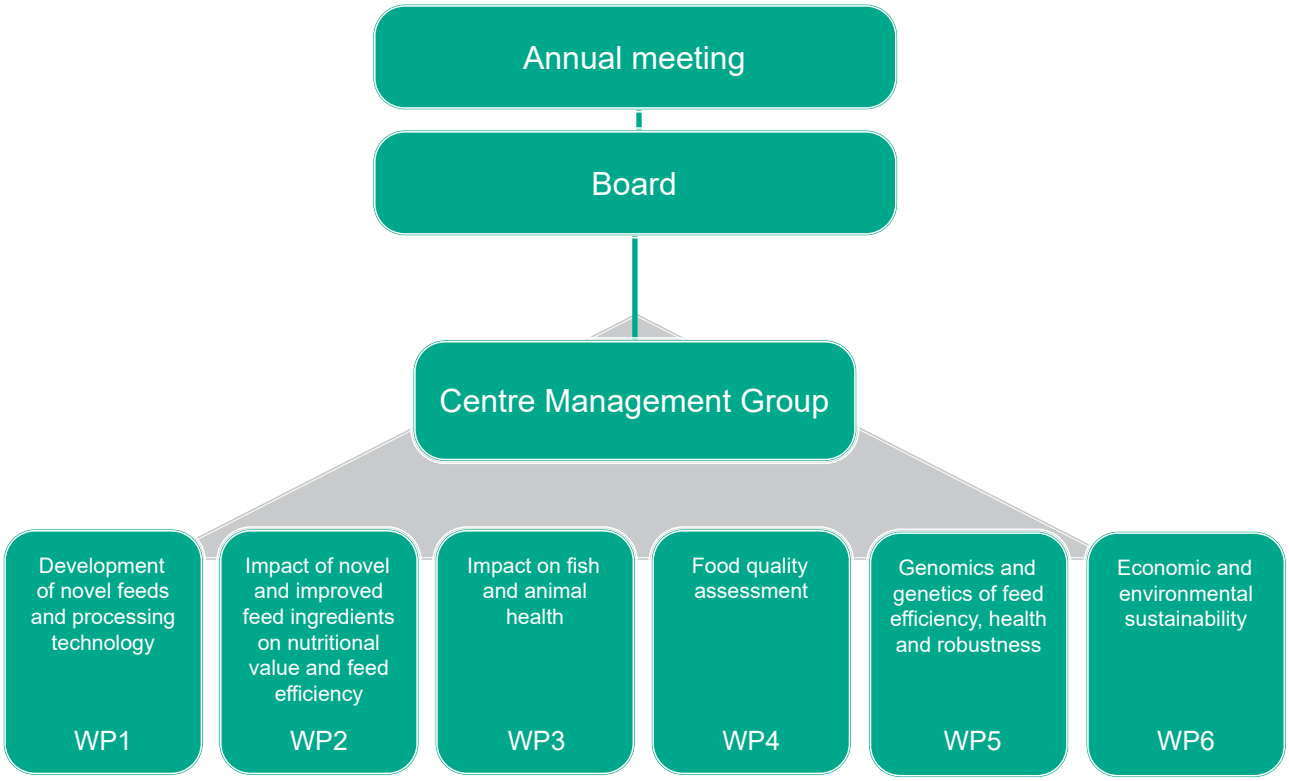
The secondary objectives are to

- **EXPLOIT** modern biorefining technologies to develop high-value feed ingredients from lignocellulosic biomass.
- **USE** innovative bioprocessing to develop novel feed ingredients from local natural bioresources such as macroalgae and animal and plant co-products.
- **IMPROVE** efficiency of existing feed resources through innovative bioprocessing.
- **ALLOCATE** feed resources across species (fish, pigs, broiler chickens and dairy cows) for optimal production economy and minimal environmental impact.
- **PROVIDE** knowledge to ensure that the novel feed ingredients support production of high quality Norwegian food products.
- **IDENTIFY** biomarkers for optimal utilization of novel feed resources for use in future fish and animal breeding programs.

BASIC FACTS ABOUT THE CENTRE

The Board was the ultimate decision- making body of the Consortium. The board's main responsibility was to ensure that the intentions and plans underlying the contract for the establishment of the centre are fulfilled. All industry and reseach partners were represented in the board.

The centre director was in charge of the operation of the centre, assisted by the centre management group that consists of the centre director, the work package leaders, centre coordinator and administrator. The Annual Meeting was held once a year.



THE BOARD 2015-2024

Period	Board	Period	Board
2023-2024	**Chair: Vegard Denstadli (Biomar)** Eirik Selmer Olsen (TINE) Cecilie Hultmann (Nortura) Bjørg Heringstad (Geno) Hege Rivedal Ødegaard (Denofa) Gudbrand Rødsrud (Borregaard) Solveig Fossum- Raunehaug (NMBU) Sigrid Gåseidnes (NMBU) Kari Kolstad (NMBU) Ole Jørgen Marvik (Innovasjon Norge) Tina Rebecca Hov-Gylthe (RCN)	2021-2022	**Chair 2021: Knut Røflo (Felleskjøpet Fôrutviling (FKF))** **Chair 2022: Vegard Denstadli (Biomar)** Eirik Selmer Olsen (TINE) Cecilie Hultmann (Nortura Eli Grindflek (Norsvin) Hege Rivedal Ødegaard (Denofa) Gudbrand Rødsrud (Borregaard) Solveig Fossum- Raunehaug (NMBU) Sigrid Gåseidnes (NMBU) Kari Kolstad (NMBU) Ole Jørgen Marvik (Innovasjon Norge) Siri Anzjøn (RCN)
2019-2020	**Chair: Knut Røflo (FKF)** Eirik Selmer Olsen (TINE) Morten Sollerud (Norilia) (2019) Cecilie Hultmann (Nortura (2020) Nina Santi (AquaGen) (2019) Eli Grindflek (Norsvin) (2020) Christine Tørklep (Denofa) (2019) Hege Rivedal Ødegaard (Denofa) (2020) Ragnhild Solheim (NMBU Ågot Aakra (NMBU) Kari Kolstad (NMBU) Ola Hedstein (Norsk landbrukssamvirke) (2019) Ole Jørgen Marvik (Innovasjon Norge) (2020) Siri Anzjøn (RCN)	2017-2018	Chair: Knut Røflo (FKF) Eirik Selmer Olsen (TINE) Morten Sollerud (Norilia) Nina Santi (AquaGen) Gudbrand Rødsrud (Borregaard) Ragnhild Solheim (NMBU Ågot Aakra (NMBU) Kari Kolstad (NMBU) Ola Hedstein (Norsk landbrukssamvirke) Siri Anzjøn (RCN)
2015-2016	**Chair: Knut Røflo (FKF)** Eirik Selmer Olsen (TINE) Morten Sollerud (Norilia) Nina Santi (AquaGen) Gudbrand Rødsrud (Borregaard) Ragnhild Solheim (NMBU Are Aastveit (NMBU) Torstein Steine (NMBU) Ola Hedstein (Norsk landbrukssamvirke) Kirsti Anker-Nilssen (RCN)		

CENTRE MANAGEMENT GROUP

Margareth Øverland

Centre Director

Professor, NMBU
Faculty of Biosciences

Gro Steine

Centre Coordinator until 2022

Head of Department
Faklty of Biosciences

Svein Jarle Horn

Leader WP1

Professor, NMBU
Faculty of Chemistry, Biotechnology and Food Science

Liv Torunn Mydland

Leader WP2

Professor, NMBU
Faculty of Biosciences

Charles McLean Press

Leader WP3

Professor, NMBU
Faculty of Veterinary Medicine

Siv Borghild Skeie

Leader WP4

Professor, NMBU
Faculty of Chemistry, Biotechnology and Food Science

Gunnar Klemetsdal

Leader WP5

Professor, NMBU
Faculty of Biosciences

Hanne Fjerdingby Olsen

Leader WP6

Postdoctor, NMBU
Faculty of Biosciences

PARTNERS

The Foods of Norway consortium comprised three faculties at NMBU and 20 industry and innovation partners. We also worked closely with several international partners and collaborators.

FOODS OF NORWAY

Industrial partners

Borregaard
Felleskjøpet
Nortura
BioMar
AquaGen
geno
Norsvin
enifer
Viken Skog
denofa
ANIMALIA
LALLEMAND
TINE
norilia
Seaweed Solutions

Supporting partners

NORGES BONDELAG
NORSK LANDBRUKSSAMVIRKE
NHO Mat og Drikke
Innovation Norway

Academic partners and collaborators

NMBU Norwegian University of Life Sciences
SLU
AARHUS UNIVERSITY
THE UNIVERSITY OF WESTERN AUSTRALIA
UNIVERSIDAD DE CHILE
UNIVERSITY OF COPENHAGEN
USDA
UNIVERSITY OF MINNESOTA

Academic partners

- NMBU's faculties of
  - Biosciences
  - Chemistry, Biology and Food Science
  - Veterinary Medicine
- University of Copenhagen

International collaboration

- Aarhus University
- Swedish University of Agricultural Sciences
- University of Minnesota
- University of Western Australia
- University of Chile
- US Department of Agriculture (USDA - ARS)

Industrial partners

- Animalia
- AquaGen
- BioMar
- Borregaard
- Denofa
- enifer
- Felleskjøpet Fôrutvikling
- Geno
- Lallemand
- Norilia
- Felleskjøpet Agri
- Norsvin
- Nortura
- TINE
- Viken Skog
- Seaweed Solutions

Supporting partners

- Innovation Norway
- NHO Mat og Drikke
- The Federation of Norwegian Agricultural Cooperatives
- The Norwegian Farmers' Union

COOPERATION WITHIN THE CENTRE

The centre was organised with the aim of strong interaction between the academic and industrial partners. Foods of Norway collaborated across three sectors – agriculture, aquaculture and forestry.

The centre management group have met about once a month to plan and organise the centre activities. The WP-leaders have been responsible for developing the Annual Work plans in close collaboration with the industry and research partners involved in the work packages. The WP-leaders have coordinated the progress and made sure the deliverables agreed on are produced.

Industry participation have been very important. The aim has been to promote discussion and close collaboration, leading to new research ideas and innovation potential across the sectors. To achieve this collaboration, Foods of Norway have hosted annual partner meetings and frequent smaller meetings between academia and industry partners. These meeting have been important arenas for knowledge sharing and discussion on scientific results with potential for application in the industry. Throughout the centre period there have been regular visits to partners and personnel mobility that have stimulated the development of scientific activity highly relevant to industry.

The final seminar of Foods of Norway

Photo: Janne Karin Brodin

RESULTS - KEY FIGURES

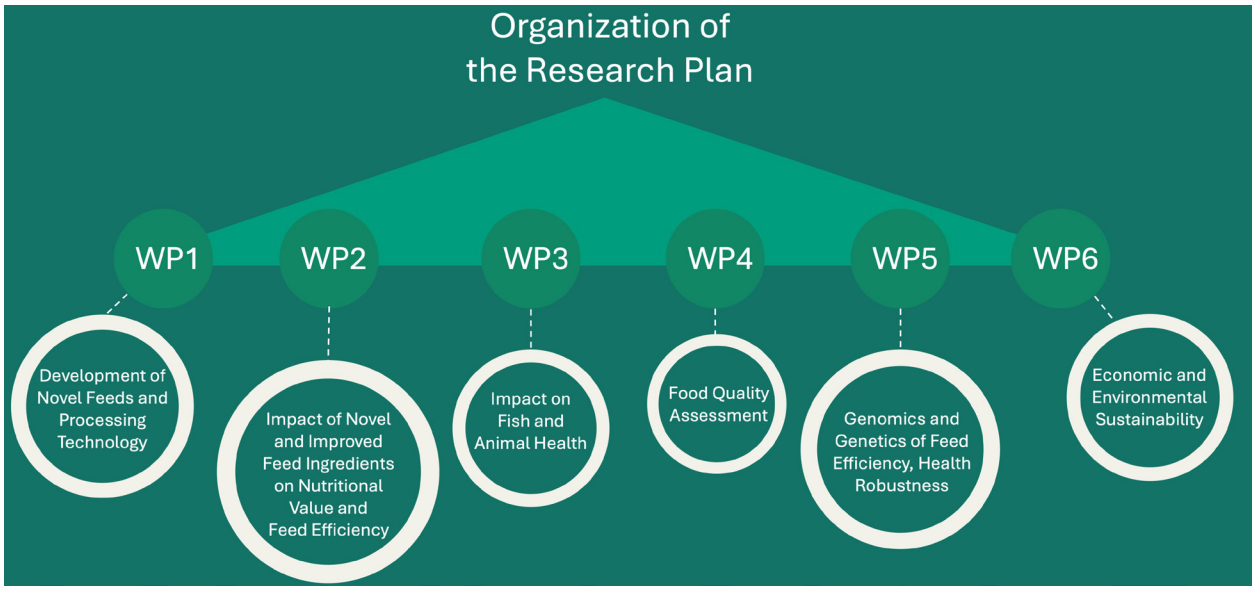
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Scientific publi¬cations (peer reviewed)		4	2	10	16	14	10	13	9	6	3	**87**
Dissemination measures for users	41	50	35	49	57	6	11	23	10	14	2	**298**
Dissemination in mass media	72	74	33	52	64	7	7	10	5			**324**
Dissemination measures for the general public	4	5	4	5	1	9	4	6	7			**45**
PhD degrees completed				1	4	1	1	2	1	1	1	**12**
Master's degrees		1	2	1	10	5	3	3	1	6	1	**33**
Number of new/improved methods/ models/proto-types finalised				13	5	9	5	7				**39**
Number of new/improved products/ processes/ ser¬vices finalised				2		1		1	1			**5**
New business activity										1		**1**



RESEARCH

Our research has focused on harnessing Norway's abundant natural resources, such as woody biomass, seaweed and grass to create innovative feed solutions that support the environment and the food production sector. This section describes the key research achievements and highlights that have led to innovations.

The research plan for Foods of Norway was organized into six integrated work packages, each led by an NMBU researcher and developed in close collaboration with industry partners. This multidisciplinary approach fostered strong synergies across the work packages. Following the midterm evaluation, the centre emphasized strengthening internal communication to enhance coherence within and between work packages, while also fostering closer collaboration with less active industrial partners.



The original research plan outline for Foods of Norway:

This research plan aimed to develop innovative feed solutions based on natural bioresources and improved feed utilization through a holistic, multi-disciplinary approach, involving advanced biotechnological tools, genetics, detailed evaluations of nutritional value, health effects, and product quality, as well as comprehensive environmental and economic assessments.

1. Bioprocessing and Feed Technology Toolbox (WP 1):
   - Focus on using industrial enzymes for biomass processing (e.g., sugars, peptides, lipids) in collaboration with Seaweed Energy Solution AS, Norilia, and other ongoing projects.
   - Targeted biomasses include macroalgae, microbial products, and animal co-products.
   - Improve nutritional value and aerobic stability of grass-silage via mechanical, chemical, enzymatic, and microbial treatments.
   - Utilize state-of-the-art equipment for producing tailored feed additives and diets.
2. Evaluation Pipeline for Novel Feed Ingredients (WP 2):
   - Multi-step evaluation of feed ingredients:
     1. Chemical characterization and microbial analysis.
     2. Short-term in vivo digestibility and palatability testing in salmonids and farm animals.
     3. Intermediate-term in vivo experiments with multiple animal species (cattle, pigs, broiler chickens, salmonids).
     4. Long-term in vivo growth experiments and field trials.
   - Collection of blood, tissue, and other samples for a wide range of analyses within the field of nutrition, metabolism, health, product quality, and genetics.

3. Nutrition, Metabolism, and Health Toolbox (WP 2 & WP 3):
   - Utilize various analytical methods (e.g., chromatography, 'omics-techniques, metagenomics) to study nutrient utilization, metabolic pathways, microbiota, immune responses, and gastrointestinal health.
   - Focus on understanding gut homeostasis and interactions between feed and animal health.

4. Food Product Quality Toolbox (WP 4):
   - Sensory, chemical, nutritional, and microbial analyses of food products (e.g., milk, fish, meat) and the influence of altered feed on the processing and quality of meat and milk products.

5. Genomics, Bioinformatics, and Modelling (WP 2, 3, 4, 5, & 6):
   - Leverage high-throughput data analysis and bioinformatics to identify biomarkers and improve understanding of feed responses.
   - Develop dynamic models (e.g., gut homeostasis) for better understanding of diet-related health impacts on fish and animals.

6. Economic and Environmental Assessments (WP 6):
   - Use Eco-Efficiency Analysis (EEA) to assess the environmental impacts and costs of feed ingredients, considering the entire life cycle.
   - Perform sensitivity and economic analysis to identify opportunities for improving feed resource production efficiency.

The research plan was highly ambitious and comprehensive, encompassing numerous initiatives aimed at developing feed ingredients across the entire value chain—from bioresource sourcing to the final meat product. After the mid-term evaluation, we prioritized several key areas of research to increase the focus and impact of outcomes. These prioritized areas included:

1. **Advancing Feed Solutions** through biotechnological innovations and improved feed efficiency, including the use of cutting-edge biotechnologies like enzymatic and fermentation processes to convert natural bioresources into high-value feed ingredients. Key areas of exploration include utilizing forest-side streams and animal by-products such as chicken hydrolysates as input factors for the production of microbial proteins.
2. **Enhancing the Nutritional Value** of grass silage by developing methods to increase the nutritional value of grass silage and new methods for predicting the nutritional value of grass.
3. **Integrating Seaweed into Feed Applications** for ruminants, along with the use of innovative biorefinery processing methods to isolate bioactive components from seaweed.
4. **Optimizing Feed Efficiency** by evaluating methods to select for improved feed utilization across various animal species.
5. **Using a Systems Biology Approach** to assess the impacts of these novel feed solutions on animal health, metabolism, overall productivity, and product quality. Additionally, environmental and economic assessments were prioritized, with life cycle analyses evaluating the ecological footprint and economic viability of these new feed solutions.

By concentrating on these key areas, we aimed to drive significant advances while maximizing both economic and environmental sustainability.

To strengthen collaboration and address cross-cutting issues, a “task force” was introduced following the suggestion in the midway evaluation. This served as a platform for industry partners and work package leaders to address topics such as sustainability, economics, regulatory considerations, commercialization, and business planning. This task force became an integral part of Work Package 6, aligning with the centre’s overarching goals.

To address comments from the midterm evaluation, Foods of Norway set a publication target of 75 peer-reviewed articles—a target that has already been surpassed. The center has currently published 87 articles and is expected to reach a total of close to 100 publications.

To increase international engagement, we have shared our key results with scientists and stakeholders worldwide, including those in North and South America, Europe, China, and Australia. We have also reached out to the public through various channels, such as keynote presentations and scientific presentations at international conferences, emphasizing depth and excellence in science.

We have also actively sought international funding by applying for several EU projects. Additionally, two Nordic projects, NordicFeed and ForestFeed, have been funded by NordForsk and the Bioeconomy in the North program. These projects aim to develop microbial ingredients from bioresources and food waste in the Nordic region.

The center has also been active in training of young scientist and many of these now hold key positions in relevant industries. For more information see training of research.

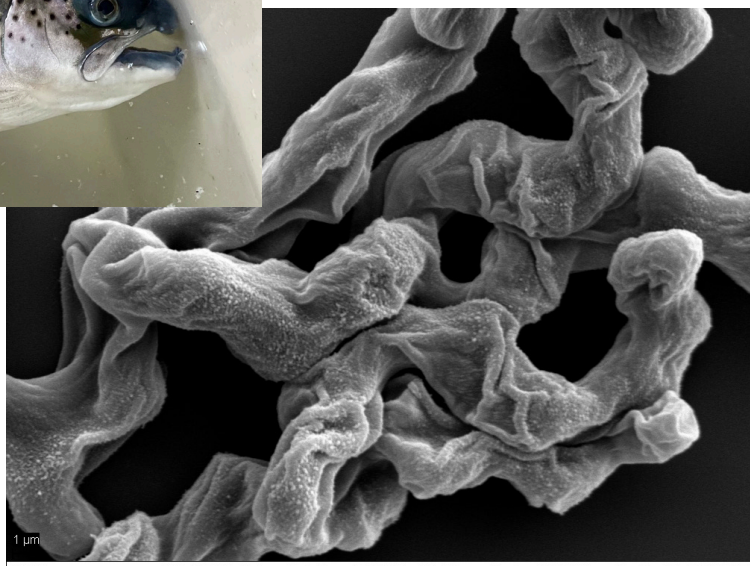
Research achievements

Foods of Norway focused on developing sustainable microbial ingredients, such as yeast and mycoproteins, for farm animal and fish feed. The center initially worked on identifying the best yeast strains and optimizing production processes for high yield and cost-efficiency. However, rising sugar costs led to a shift toward the mycoprotein PEKILO®, which utilizes more affordable forestry-based side-streams and had a higher nutritional value. Researchers evaluated PEKILO®'s nutritional value, health benefits, sustainability, and techno-economic feasibility.

The center also focused on enhancing the nutritional value of grass silage through enzyme treatments to improve digestibility, and refining seaweed cultivation and processing methods to create new feed resources. Biorefinery processes were applied to enhance seaweed's nutritional value and extract bioactive compounds, such as fucoidan, for use in functional feeds for salmon, chickens, and ruminants. Efforts were also made to maintain the nutritional value of seaweed during storage.

Improving feed efficiency and robustness in farm animals and fish remained a key goal. Novel indicator traits for feed efficiency in salmon were developed using stable isotope profiling, enabling more practical phenotyping.

Salmon fed yeast grown on spruce sugar. Photo: BioMar



Microscopy imaging of PECILO® Photo: Dominic Duncan Mensah

Microbial Ingredients and Biomass Processing

A central research focus was unlocking the potential of local bioresources, including forest-side streams and animal by-products, to produce microbial ingredients like yeast and fungi. This work involved scaling up yeast production from laboratory experiments to larger fermentation processes at Borregaard's facilities. Yeast strain C. jadinii, which efficiently utilized sugars from Norwegian spruce trees, was particularly successful.

The effects of C. jadinii yeast as a novel protein source was extensively evaluated in diets for farm animal and salmon, including effect on growth performance, health, growth, and product quality.

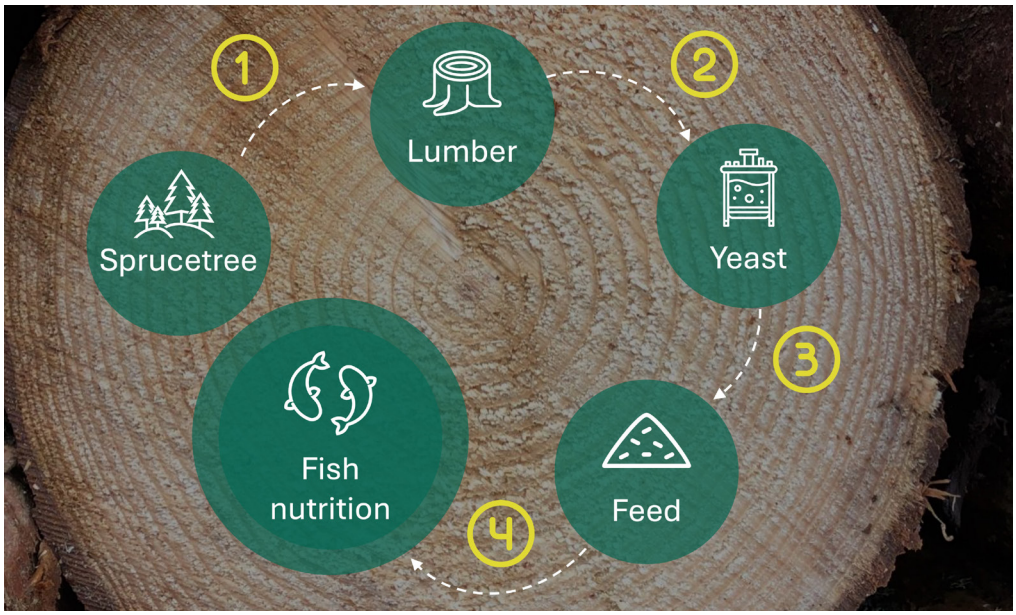
Key findings include:

Yeast in Feed:

- Salmon: Up to 12% yeast in diets maintained excellent growth, health, and product quality, especially under challenging soybean-based diets.
- Broiler Chickens: Up to 30% of protein replaced by yeast supported high growth and health.
- Piglets: Up to 40% of protein from yeast maintained excellent growth performance, improved gut digestive function, enhanced bacterial composition, reduced the incidence of diarrhea, and overall health was improved.
- Dairy Cows: Yeast had no negative effects on milk quality or cheese yield; cheese yield was higher with yeast than with barley-based diets.

In 2021, Lallemand produced 1,600 kg of autolyzed C. jadinii yeast from wood sugars prepared in Borrgeaard's demo-plant, which was applied in large-scale trials with salmon and piglets, demonstrating its practical application in animal feed.

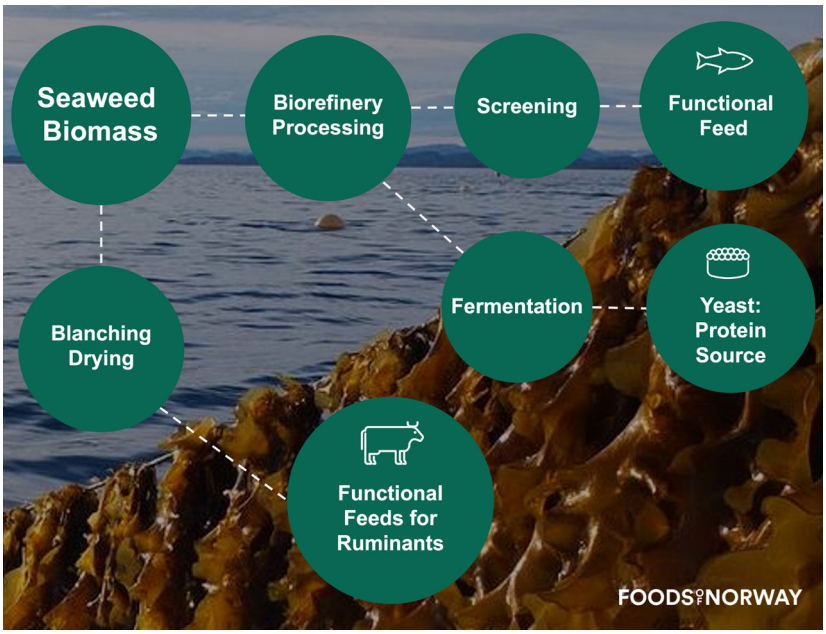
Recent efforts shifted to the production of PEKILO®, a fungal protein derived from forestry side-streams. In salmon diets, PEKILO® showed excellent growth performance, improved gut health and immunity, and reduced environmental impact of salmon production, demonstrating its potential as a sustainable feed ingredient.



Advanced Seaweed as Feed ingredient

Biorefinery methods were also applied to seaweed, enhancing its nutritional value and enabling the extraction of functional compounds like fucoidan, which showed promising effects in feeds for salmon and chickens. Low processed seaweed, such as dried or blanched forms, was tested as a functional ingredient for ruminants.

Fucoidan extracts improved salmon health and robustness during seawater transfer. Sun dried or blanched sugar kelp in lamb, beef cattle, and dairy cow diets improved meat tenderness in lamb, and increased feed intake and boosted milk yield and milk fat content in dairy cows.



Enhancing Grass Silage for Livestock

In collaboration with TINE, the center developed innovative methods to enhance the nutritional value of grass silage. By using a combination of organic acids and novel enzymes, we can more effectively break down the fibers in grass silage which increases digestibility and the feed value of the grass. We found an increase in the digestibility of the organic matter in the grass. A few percentages units increase will have a considerable sparing effect of imported concentrate, enabling greater use of local feed resources and reducing reliance on imports. Additionally, we have created new tools to efficiently predict the nutritional value of grass, supporting the increased incorporation of grass silage into feed rations.

Improving Feed Efficiency

Improving feed efficiency and robustness in farm animals and fish has been a central focus. Enhanced feed efficiency significantly impacts resource utilization, cost reduction, and environmental sustainability. The centre developed novel indicator traits for individual feed efficiency in salmon using stable isotope profiling, enabling practical phenotyping through natural isotope analysis.

The centre has developed a method to select salmon with increased feed efficiency. The method is based on the use of natural isotopes in feed for the property to be analyzed in slaughter tests. This has been evaluated in rainbow trout, and a validation experiment with large salmon have been conducted. After completing the validation experiment with large salmon, the method can potentially be included in AquaGen's breeding program from 2025 onwards.

Key Takeaways

Through innovative research, Foods of Norway has advanced sustainable feed production using local bioresources. From spruce-derived yeast to fungi and seaweed, these ingredients have proven to enhance the health and productivity of livestock and fish, while offering a more sustainable alternative to traditional feed ingredients. These breakthroughs contribute to more sustainable food production, supporting both farmers and the environment.

Highlights of scientific results

Foods of Norway has made substantial efforts in creating sustainable and resource-efficient feed and feed ingredients from Norwegian bioresources. These advances have laid the foundation for innovations that support both the blue and green sectors. The center has delivered key breakthroughs in the development of new feed ingredients, improving feed efficiency, and applying novel technologies.

1. WOOD-BASED MICROBIAL INGREDIENTS (MI):

INNOVATION: The center has pioneered the production of high-quality microbial proteins derived from local forestry side streams. This feed sources serves as an environmentally friendly alternative to traditional ingredients like soy.

PROCESS: Cellulose and hemicellulose from woody biomass are degraded into soluble sugars using enzymatic hydrolysis. These sugars are used to cultivate yeast in bioreactors, producing microbial protein of high nutritional value.

IMPACT: This innovation helps reduce feed-food competition, lowers dependence on imported feed raw materials, conserves agricultural land, and enables year-round production independent of climate conditions. By recycling renewable biological residuals, it contributes to a circular bioeconomy, reducing waste and creating valuable feed alternatives.

2. INNOVATIONS IN SEAWEED BIOREFINING:

INNOVATION: Foods of Norway has successfully integrated seaweed, a macroalgae abundant along the Norwegian coast, into feed rations. Seaweed is rich in health-promoting substances and offers a sustainable feed option.

BENEFITS: Seaweed only need seawater and sunlight to grow, making it an environmentally sustainable and renewable resource. This innovation provides nutritional and environmental benefits to both aquaculture and livestock production.

IMPACT: By utilizing local, underused marine resources, seaweed represents a promising solution for sustainable food production.

3. IMPROVED NUTRITIONAL VALUE OF GRASS SILAGE:

INNOVATION: The center has developed methods to enhance the nutritional value of grass silage for ruminants. By adding organic acids and enzymes to degrade the fibers in grass, the nutritional value of late-harvested grass is improved.

IMPACT: This innovation increases feed efficiency, making more nutrients available to livestock, improving productivity, increases robustness in difficult climatic and topographical conditions, gives a concentrate sparing effect, and optimizing feed quality for ruminants such as dairy cows.

4. FEED EFFICIENCY IN SALMON AND FARM ANIMALS:

INNOVATION: Researchers have developed a method to track individual feed utilization in large groups of farmed animals, such as salmon. By using stable isotopes as markers, the amount of feed consumed relative to growth rate is determined for each animal. This method, is however, very expensive. Thus, we are working on a more cost-efficient method, but this remains to be verified.

IMPACT: This breakthrough enables better understanding and optimization of feed use, allowing for improved feed efficiency and maximizing yield from every unit of feed in fish farming and animal husbandry.

CONCLUSION: The achievements highlighted here represent the culmination of years of research at Foods of Norway, which have led to groundbreaking innovations in feed and feed ingredients. These developments not only offer environmentally sustainable solutions for aquaculture and livestock farming but also present substantial opportunities for industrial activity, reinforcing the center's mission to foster sustainable food production for the future.

Awards

Jeleel Opeyemi Agboola, researcher in Foods of Norway, won Nutreco's 2022 Young Researchers Prize. The prize-winning project was Jeleel's PhD work "Can fish grow on trees? Yeast as a future feed ingredient".

PhD student Dominik Mensah received a prize for the 2nd best oral presentation at the ISFNF meeting in Puerto Vallarta, Mexico in 2023..

In 2023 Foods of Norway was awarded its own postage stamp. Norway Post and the Research Council of Norway wanted to honor the centre's successful work in developing sustainable feed resources.

Foods of Norway was honored with its own postage stamp.
Photo: Janne Brodin

Keynotes

Following is a highlight of keynote talks at international conferences given by centre director Margareth Øverland:

- 2024: Managing the Feed/Food divide. Pre-Symposium, Circular Feed Ingredients, Optimising Nutrient Use Through Aquaculture, IFFO, ISFNF, Puerto Vallarta, Mexico
- 2023. Foods of Norway: A Norwegian perspective on the raw material feed crisis. AquaNor presentation, Trondheim, Norway.
- 2022. Foods of Norway. Seaweed as a feed resource. 7th SIG Seaweed Conference, Trondheim, Norway.
- 2022. Role of functional aquafeeds on mucosal immunity: From bioactive components to a resilient salmon. The 2nd international symposium of Mucosal Health in Aquaculture Madrid.
- 2021. Microbial ingredients from blue and green biomass for aquafeeds. The 15th symposium of world's Chinese scientists on nutrition and feeding on nutrition and feeding of fin fish and shellfish, Qingdau, China.
- 2020. The 5th International Feed Processing Technology Symposium, Nanjing, China,
- 2019. The 70th EAAP meeting. Seaweed as a feed resource for farmed animals. Ghent, Belgium.
- 2018. EURAGRI conference - "Cross Sectoral Opportunities in the Bio-economy and the Implementation of the global Sustainable Development Goals"., Oslo, Norway.
- 2016. Global forum for innovations in agriculture 2016. Abu Dhabi.

INTERNATIONAL COOPERATION

Foods of Norway have worked closely with several international collaborators

International collaboration plays a key role in advancing knowledge and innovation. Foods of Norway has built a strong foundation for expanding our global activities through personnel exchanges, the creation of new network, and participation in conferences and research projects.

International industry partners:

Lallemand (Canada): The global leader in fermentation technology has worked with us on experiments with yeast in diets for Atlantic salmon, piglets, broiler chicken and dairy cows. The research focused on improving growth, health, welfare, and sustainability in animal farming.

Enifer (Finland): Enifer produces a microbial ingredient (PEKILO®) from forestry side streams. We have used this in experiments with Atlantic salmon to investigate its nutritional value and health benefits.

Academic international partners:

University of Copenhagen (Denmark): We have worked closely on experiments exploring yeast as a functional ingredient for piglets and broiler chicken, leading to joint research papers.

Aarhus University (Denmark): Our partnership has involved studying the effects of yeast-based diets on piglets, particularly focusing on metabolite changes in urine and plasma.

Swedish University of Agricultural Sciences (SLU): Our cooperation has focused on improving fermentation of yeast and producing extruded diets for Atlantic salmon.

University of Minnesota (USA): The university has supported our efforts to improve the nutritional value of plant-based ingredients like rapeseed meal using solid-state fermentation technology.

Institute of Agrifood Research and Technology (IRTA): This partnership studied the chemical properties in cured legs of lambs of animals fed seaweed-based feeds.

Universidad Católica de Valparaiso (Chile): Postdoctoral fellow Byron Maximiliano Morales Lange from Chile spent two years as a guest researcher in Foods of Norway and then continued as a researcher in the Foods of Norway team at NMBU. Important research topics has been fish immunology and development of important immunological biomarkers.

University of Chile (Chile): The university has worked with us to develop new methods for processing of macro-algae using enzymes.

National University of Singapore (Singapore): We've collaborated to analyze gastrointestinal samples by proteome analysis from Atlantic salmon fed yeast, focusing on how yeast affects their immune response.

EU framework program:

Sustainability of pig production through improved feed efficiency (SUSPIG) (2017-2020). ERA-NET SUSAN. INIA, in collaboration with NMBU, Norsvin, INRA, SLU, Newcastle University, and the Institute de Porc. This project aimed to share research and experience on local feed resources for pigs, with a focus on evaluating their impact on economy, society and the environment.

AntiVirFish (2022-2023). A collaboration between Universidad Miguel Hernandez de Elche (Spania), NMBU and the Norwegian Veterinary Institute. The project aims to investigate whether identified antiviral proteins can be used as a treatment for salmon, with the goal to reducing viral infections and minimizing economic losses.

Other international projects:

Global Research Council Grant: This interdisciplinary project ensures the availability of quality water and food, focusing on sustainable water management and small-scale biointegrated agro-aquaculture systems. It involves partners from Chile, Norway, and Turkey, and aligns with the UN Sustainable Development Goals (SDGs), including zero hunger and responsible production.

NORDICFEED. This project aims to improve the performance, health, and resilience of salmon and rainbow trout by developing sustainable feed ingredients made from local side streams from agriculture and forestry in collaboration with partners from Swedish University of Agricultural Sciences, Natural Resources Institute Finland, Vattenbrukscentrum Norr AB (Sweden) and Enifer (Finland)

Resilient Salmon. This project investigates how bioactive components from yeast and seaweed can enhance growth performance, health and resilience of Atlantic salmon, particularly under different environmental conditions. Our partners are University of Santiago (Chile), Pontifical Catholic University of Valparaiso (Chile) and University of Wisconsin-Madison (USA).

SafeKelp. The SafeKelp project focuses on controlling iodine and arsenic levels in seaweed-based feed and foods, ensuring safety from cultivation to human consumption. It involved partners from Norway (NMBU, Sintef Ocean, Institute of Marine Research) and China (Institute of Oceanology, Chinese Academy of Sciences and Yellow Sea Fisheries Institute, and Chinese Academy of Fishery Sciences).

ForestFeed. This project explores how bioeconomy solutions from the Nordic region can turn wood side-streams into valuable nutrients for the aquaculture industry, thereby strengthening both the forestry and aquaculture sector. Partners include Swedish University of Agricultural Sciences; Enifer, Finland; Institute for Food and Environmental Research, Germany.

Other international cooperation:

International exchange of researchers: Visiting researchers from around the world and exchanges with other research institutions have been vital for sharing ideas and staying updated on global scientific developments.

International courses and conferences: Foods of Norway has contributed to an international knownledge-sharing through:

- Participation in the International PhD course on fish nutrition at Wageningen University (Netherlands).
- Regular participation in global conferences, such as Aquaculture Europe, ISFN, ICoMST, International Feed Processing Technology Symposium (2020), International Symposium Mucosal Health in Aquaculture (2019, 2022) and others.

The Foods of Norway delegation in Sorrento, Italy, 2022. Photo: Foods of Norway

- Key-note presentations by our centre director, Margareth Øverland and work package leaders in the centre, at various international conferences.
- Hosted a workshop on microbial feed ingredients alongside the NordicFeed and ForestFeed projects in 2023.
- Arranged NOVA course in "Immunonutrition in Aquaculture: From novel feeds to overall health" in 2024/2025.

Workshop on microbial feed ingredients in 2023, organized by Food of Norway, and the projects NordicFeed and ForestFeed. Photo: Ingjerd Dønnem

TRAINING OF RESEARCHERS

Since the beginning of the centre period Foods of Norway has recruited 14 PhD candidates, whereas 7 candidates have been financed from the centre budget and 7 have worked on projects in the centre with financial support from other sources. Of these candidates, 12 have so far completed their PhD degree. In addition, Foods of Norway has recruited 8 Postdocs and supervised 33 master students. The recruited PhD candidates and Postdocs are very closely balanced in terms of gender.

Our PhD students are taking external doctoral courses at national and international universities. PhD students are also carrying out part of their research at international universities. PhD students take an active part in the centre's research activities alongside experienced senior researchers and bioengineers. Researcher training at the PhD level also comprises presenting work at conferences and other events. The centre has one industrial PhD.

All PhD students were recruited based on international calls. Some were recruited while writing their master thesis, by involving them in centre-related research activities and working in close collaboration with researchers and bioengineers in the centre, and thereby motivating them to apply for PhD positions within the Centre and associated projects.

The professors teaching courses in MSc programs have taken topics from Foods of Norway into various master courses. Also, the centre has participated in a master course at NMBU's School of Economics and Business where master students have worked on four cases related to Foods of Norway's work on sustainability and consumer behaviour. The centre contributed with two supervisors, one researcher and one scientist from a user partner. A Nova-course in Immunonutrition in Aquaculture have been arranged in 2024.

Employment of PhD-candidates

Most of the PhD candidates who have worked at SFI Foods of Norway have continued their career in industry, and many of them with industry partners of the centre.

Employment of PhD candidates (number)							
By centre company	By other company	By public organisations	By university	By research institute	Outside Norway	Other	Total
5	2			1	2	2	12

We have asked a selection of our candidates to reflect on their experiences from being a PhD candidate in Foods of Norway. What are they doing today? And why are their results important to the industry?

David Lapeña Gomez

Date of dissertation: 13.09.19
Current position: Infors HT
Title of thesis: Production of yeast from spruce sugars and hydrolysates of protein-rich by-products as feed ingredient
Supervisors: Professor Vincent Eijsink (main supervisor), professor Svein Jarle Horn.

Why did you choose to do a PhD in Foods of Norway?

I found the project very interesting from a scientific and industrial point of view, NMBU well was funded, and my supervisors were and are great scientists.

Why is your project important to the industry?

While the topic was not new from an industrial point of view, it provided depth and know-how about the topic as a whole; from the by-products used to generate the microbes used as an alternative protein, till the impact those feed ingredients have in animals.

Describe your experience from being a PhD candidate in Foods of Norway

It was a great experience. I always felt supported by my supervisors and colleagues.

Where did you start to work after completing your PhD-degree?

I was working as research scientist within Foods of Norway for a couple of years, and then I started to work for Infors HT. We used Infors bioreactors and incubator shakers for our fermentations for Foods of Norway.

Ana Rita Girio da Costa Cruz

Date of dissertation: 15.11.19
Current position: Product developer in Felleskjøpet Fôrutvikling
Title of thesis: Yeast (Cyberlindnera jadinii): an alternative protein source in pig and poultry feed
Supervisors: Professor Margareth Øverland (main supervisor), Professro Liv Torunn Mydland, Professor Anne-Helene Tauson, NMBU, Dr. Hallgeir Sterten.

Why did you choose to do a PhD in Foods of Norway?

I first learned about Foods of Norway through a job application at Felleskjøpet Fôrutvikling, and this is where the opportunity of a phD project in cooperation with the university came up. I was really interested in working with the industry, and that's what "reeled" me in, but to be given the opportunity to work with Foods of Norway and contribute to the research of new protein sources was a bonus, as it is such an impactful subject.

Why is your project important to the industry?

My project was in short about yeast as a locally produced protein source for monogastric animals. The subject of local protein sources was and still is highly relevant for the Norwegian feed industry and the nutrition of production animals. Feed protein-rich raw materials are mostly imported, thus it is still possible to greatly improve the sustainability of animal diets.

The protein source I studied in my project is unfortunately not in use in Norwegian feed today, due to cost restrictions and difficulty in upscaling the production of the yeast. The knowledge acquired during the project was nonetheless useful to understand the effects of the yeast in practical conditions, and its limitations as a raw material in practice.

Describe your experience from being a PhD candidate in Foods of Norway

Perhaps the best part of being an "industrial PhD" student was to be able to move between the two worlds - academic and industrial-, find common interests between them and be a sort of a "bridge" in the communication between the two. I learned a lot, met many great competent people and gave a contribution to science. I am very thankful for all the support I received from teachers, supervisors and colleagues at NMBU and Felleskjøpet.

Where did you start to work after completing your PhD-degree?

When I completed my phD, I started working right away at Felleskjøpet Fôrutvikling in Trondheim, as a product developer for poultry feed. I have so far worked with laying hens, broiler chickens and pigs. Here new challenges and great learning possibilities await every day.

Jeleel Opeyemi Agboola

Date of dissertation: 24.05.22
Current position: Scientist in BioMar
Title of thesis: Can fish grow on trees? Nutritional and functional properties of yeasts in diets for Atlantic salmon (Salmo salar)
Supervisors: Professor Margareth Øverland (main supervisor), Dr. Jon Øvrum Hansen, Dr. Magnus Øverlie Arntzen.

Why did you choose to do a PhD in Foods of Norway?

My overarching goal in life is to contribute my part towards ensuring food security by enhancing the productivity and sustainability of aquaculture. One way to achieve this is to increase the use of sustainable novel ingredients in aqua feeds. So, when the opportunity came to explore this area of research during my PhD, I quickly grabbed it with both hands. My PhD gave me the opportunity to gain technical experts and develop innovative solutions that are important to improve aquaculture practices, ensuring they are more efficient and environmentally sustainable. My goal was to support the growing global demand for food by advancing aquaculture as a reliable and responsible source of nutrition, ultimately contributing to a more secure and sustainable global food system.

Why is your project important to the industry?

Aquaculture is the fastest growing food sector globally, crucial for fish consumption. Despite its potential, it faces challenges, including the ongoing quest for sustainable novel resources to be used in fish feeds. My PhD research showed that microbial biomass from wood and chicken by-products can be sustainable ingredients for fish like Atlantic salmon. These sustainable alternatives address environmental impact and resource availability issues, reducing reliance on finite marine resources. Sustainable ingredients help preserve marine ecosystems, lower the industry's carbon footprint, and stabilize feed supply. My research promotes long-term productivity and environmental responsibility in aquaculture.

Describe your experience from being a PhD candidate in Foods of Norway

My PhD program was highly rewarding and intellectually stimulating, offering valuable opportunities for impactful research in sustainable aquaculture. I benefited from a supportive academic environment, knowledgeable faculty mentorship, and collaboration with fellow researchers. The program deepened my expertise and reinforced my passion for global food security. Overall, it was enriching both professionally and personally, preparing me well for future challenges in the field.

Where did you start to work after completing your PhD-degree?

BioMar – working as a Scientist within the global R&D team.

COMMUNICATION AND DISSEMINATION

Foods of Norway's research and innovations have been continuously highlighted by domestic and international media, and dissemination of news have been a result of both reactive and proactive communication activities.

The centre has had well deserved attention in the media. Proactive communication efforts from the centre also resulted in articles in relevant news outlets.

In many of the centre's communication activities cooperation between partners has been central and has strengthened both message and delivery, adding value to the centre as a knowledge provider.

The centre's communication strategy has been to focus on main target audiences: decision and policy makers, farmers' associations, other stakeholders, and the general public in Norway. The centre also aims to continue building the brand as a knowledge provider for feed and food industries as well as agriculture and aquaculture industries in Norway and abroad.

Fôret laks med kortreist gran: – Bedre helse og mer robust

Lakseprodusenter satser på norsk granskog for å gjøre norsk laks mer klimavennlig. Foreløpig er resultatene lovende. Nå skal nye undersøkelser gi viktige svar.

Sofie Retterstøl Olaisen
Journalist

Lars-Petter Kalkenberg
Journalist

Marie Staberg
Journalist

Vi rapporterer fra **Dønna**

Publisert 31. mars 2022 kl. 14:32
Oppdatert 18. apr. 2022 kl. 16:02

På Dønna i Nordland undersøker forskere og sjømatbedrifter nå hvordan laks som har spist fôr av gran har klart seg, etter et halvt år i sjøen.
FOTO: LARS-PETTER KALKENBERG / NRK

Article from NRK Nordland, 31 March 2022

PhD student Ingrid Marie Håkenåsen presented her work with yeastbased feed for weaning pigs at Forsker Grand Prix in Oslo, in September 2020. Photo: Ynge Vogt.

Khrono 10 år

LANSERING

NMBU og NTNU får egne frimerker

I fire år har Posten hatt en frimerkeserie gående med søkelys på norsk forskning, innovasjon og teknologi.

Frimerkedirektør Halvor Fasting og professor og leder for Foods of Norway, Margareth Øverland, avduket denne uken et nytt frimerke på NMBU. Foto: Posten

Article from the launch of Foods of Norway's postage stamp, September 2023

iLaks.no NYHETER KOMMENTARER KONTAKT OSS STILLINGER OCTAVIAN FORLAG

NMBU-forskere viser til lovende resultater med gjærsopp-fôr

Nyheter av redaksjonen - 25 april 2024

Tømmer kan brukes til så mangt.

iLaks har tidligere skrevet om det finske bioteknologifirmaet Enifer, som i januar sikret seg tolv millioner euro for å gjøre opp produksjonen av sitt Pekilo-protein. Proteinet lages ved hjelp av soppgjæring, og kan brukes som ingrediens i fiskefôr.

Auksjon av befrukt torskerog

Meld på

Article in iLaks, April 2024

Har utviklet nytt Fôr av NORSK gran:

Garanterer enda bedre juleribbe

Etter mer enn seks års forskning og teknologiutvikling mates nå norsk gris på kraftfôr basert på norske grantrær. Dette skal redusere behovet for soya, bedre dyrehelsen og ribbekvaliteten.

GLADE GRISER: Grisene på Vormsund liker det nyutviklede fôret. Foto: Goran Jorganovich / TV 2

Ronnie Baraldsnes Goran Jorganovich (foto)

Publisert 12.12.2021 11:19

Article from TV2, December 2021

New study by Enifer and NMBU shows that farmed fish grow better and healthier with fungi produced from Nordic forestry by-products than with soybeans

THU, OCT 26, 2023 08:00 CET

Report this content

As the global demand for fish consumption continues to surge, fish farmers are constantly looking for ways to improve their cultivation techniques. A new study conducted by researchers at the Norwegian University of Life Sciences (NMBU) shows that using Enifer's proprietary PEKILO®Aqua mycoprotein had a significant positive impact on salmon's natural immune system and growth.

Espoo, Finland (October 26th, 2023) Finnish biotech startup Enifer has contributed to a new study on farmed salmon that was done in collaboration with the Norwegian University of Life Sciences (NMBU). The study utilized Enifer's PEKILO®Aqua mycoprotein, and it was conducted by a group of researchers led by Professor Margareth Øverland. The study shows that

Article from news.cision, October 2023

Norsk biff kan bli mørere med nytt dyrefôr

Forskere håper biffen i kjøttdisken kan bli bedre når dyrene legger om til et kosthold med tare. Det kan også gjøre fôret mer kortreist.

Fredrik Hansen
Journalist

Helena Rønning
Journalist

Vi rapporterer fra **Sandefjord**

Publisert 7. mai 2022 kl. 18:48

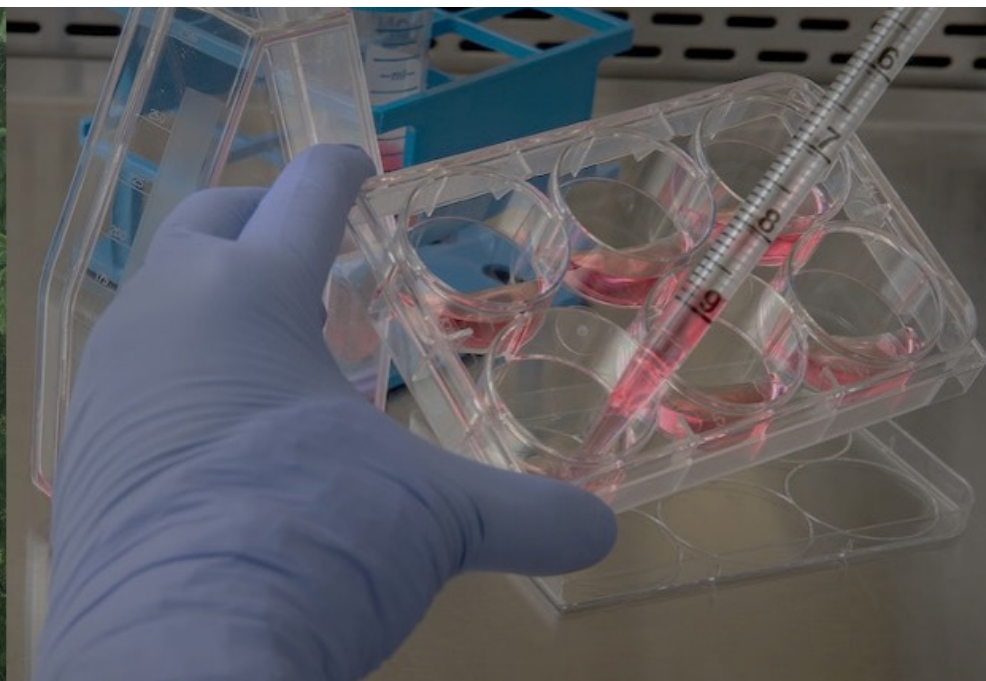
KOS: Arnt Inge Flood Johansen tar seg en tur inn til oksene på gården. Han leverer kjøtt til Nortura.
FOTO: FREDRIK HANSEN / NRK

Article from NRK Vestfold og Telemark, May 2022

EFFECT OF THE CENTRE FOR THE HOST INSTITUTION AND RESEARCH PARTNERS

Foods of Norway has reinforced NMBU's global leadership in sustainable food production and biotechnology by driving innovations aligned with the university's research priorities in circular bioeconomy, advanced biotechnologies, agriculture and aquaculture.

1. **Circular Bioeconomy:** By transforming renewable bioresources like wood biomass, seaweed, and animal and marine by-products into sustainable feed ingredients through biorefinery processing and fermentation technology, the center reduces reliance on imported feed raw materials and promotes resource efficiency and helps facilitate a circular economy.
2. **Advanced Biotechnologies:** Leveraging microbial fermentation, biorefinery processes, and nutritional programming, Foods of Norway enhances feed efficiency, improves animal and salmon health, and minimizes environmental impacts, setting global standards for sustainability.
3. **Animal Nutrition:** The center develops alternative proteins and functional feeds that improve farm animal and salmon growth, gut health, and resilience, directly addressing sustainability challenges in agriculture and aquaculture.
4. **Improvement in feed efficiency:** The center develops innovative methods to enhance feed efficiency in Atlantic salmon, with applications for other farm animals, increasing resource utilization and reducing the environmental impact of fish and meat production.
5. **Global Collaboration:** Foods of Norway fosters international partnerships across academia, industry, and policy, creating a synergistic ecosystem that enhances NMBU's reputation as an innovation hub.
6. **Education and Outreach:** By integrating research outcomes into education and training, the center equips future scientists to advance sustainable feed and food systems.



Through its interdisciplinary approach, Foods of Norway supports NMBU's sustainability mission and offers scalable solutions for a sustainable global food system.

CAPACITY BUILDING:

NMBU has made strategic investments in national infrastructure, including advanced laboratories, bioreactors, and testing facilities to enable cutting-edge research. The Center for Fish Research and the biorefinery laboratory, for examples, supports the development of sustainable feed ingredients. These state-of-the-art facilities enhance NMBU's capacity for interdisciplinary research in biotechnology, circular bioeconomy, and aquaculture nutrition, strengthening its position as a leader in sustainable innovation.

INTERDISCIPLINARY COLLABORATION:

Foods of Norway has fostered collaboration across NMBU faculties, including Faculty of Life Sciences, Faculty of Chemistry, Biotechnology and Food Science, and Faculty of Veterinary Medicine, to develop integrated solutions for sustainable feed and food systems. By combining expertise in biotechnology, nutrition, genetics, health, and product quality of food, the center has advanced innovations like microbial-based feed ingredients, functional feeds from seaweeds and methods of improved feed efficiency. This interdisciplinary approach promotes synergy, enabling holistic research that addresses sustainability challenges in both aquaculture and livestock production.

INFLUENCE ON STRATEGY DEVELOPMENT:

- The center's successes have inspired new strategic initiatives at NMBU, including expanded research themes in circular bioeconomy, biotechnology, and sustainable agriculture and aquaculture. These achievements have shaped long-term goals focused on innovation, interdisciplinary collaboration, and global leadership in sustainable food systems.
- A key reason for establishing Foods of Norway in 2014 was its pioneering focus on bioeconomy and the utilization of local bioresources. At that time, concepts like "bioeconomy" and "circular economy" were still in their infancy within the Norwegian research landscape. These ideas had not yet gained widespread recognition, nor had their transformative potential for sustainable feed production been fully explored. Foods of Norway positioned itself as a frontrunner, aiming to demonstrate how the integration of advanced biorefinery technologies and innovative feed solutions could advance aquaculture and agriculture.
- This forward-thinking approach placed emphasis on leveraging renewable local resources, such as forest by-products, marine biomass, and agricultural residues, to develop sustainable alternatives to traditional feed ingredients. By doing so, Foods of Norway contributed to laying the groundwork for bioeconomic strategies that are now central to Norway's research and policy agendas.

EFFECT OF THE CENTRE FOR INDUSTRY AND SOCIETY AT LARGE

In Foods of Norway, innovation is a result of close integration between industry and academic partners throughout the research process.

The centre has worked hard to ensure that at least one industry partner has been involved in every experiment conducted within the centre. There has been a diverse portfolio of research projects, focusing on our business and industrial partners' innovative ideas. Many projects have yielded valuable results, although it takes time for these innovations to reach full-scale implementation. Some results are already in use, while others require further testing and evaluation by the partners. Even though Foods of Norway has concluded, collaborations continue, allowing more innovative results to be implemented

This section includes feedback from some of our partners, starting with general comments we have received from many partners, followed by specific feedback from each partner.

Feedback from the partners

A major benefit for the industry partners has been the strengthening of their knowledge base. Gaining expertise and understanding would not have been possible without participating in the centre. Some partners have recruited PhD-candidates or researchers who were trained at the centre. Participating in the centre, partners has enabled partners to expand their network. Several user partners have formed new collaborations with leading research institutions, opening the door to further technological advancements. Collaboration and communication between blue and green value chains has increased. Additionally, cross-industry partnerships with logistics firms have improved operational efficiency throughout the entire value chain.

Biomar

Biomar is one of the leading suppliers of high-performance feed to the global aquaculture industry, focusing on developing efficient, sustainable and healthy feed solutions. The raw materials studied at the centre are of interest for local sustainable solutions in Norway's aquaculture industry. Participating in Foods of Norway has strengthened BioMar's connection with fish researchers and kept them updated on relevant activities. The centre has also provided Biomar with expertise in immunology, gene expression, and process technology.

Borregaard

Borregaard has been developing alternative products from hemicellulose and cellulose for many years, focusing on hydrolyzing these polysaccharides into monosaccharides for conversion into chemicals, materials, and animal feed. They collaborated with the Center of Excellence, Aquaculture Protein Center, at NMBU on single-cell proteins and developed the BALI technology for co-producing water-soluble lignins and sugar streams from lignocellulosic biomass.

Key conclusions from their work with Foods of Norway include:

- Yeast as Animal Feed: Yeast produced from sugar hydrolysates can replace soy in animal feed, offering good amino acid composition, health benefits, and reduced environmental impact.
- Cost and Protein Content: Yeast is less attractive due to low protein content and high production costs unless low-cost sugar streams are available. Prices for sugar hydrolysates are currently high due to their use in biofuels.
- Pekilo Protein: Pekilo protein from filamentous fungus is more attractive due to higher protein content and ability to grow on various sugar sources, including those unsuitable for ethanol production. This makes it a cost-effective option.
- Regulatory and Market Risks: Rapidly changing regulations and market conditions, such as those for biofuels, can impact the feasibility of development programs. However, trends suggest that prices will normalize, making environmentally friendly proteins for animal feed more relevant.

Borregaard considers this a successful technology development project with potential for future scaling when market conditions are favorable.

The work with Foods of Norway itself did not lead to innovations at Borregaard, but it was part of a larger biorefining development program that resulted in several innovations, including two process patents, new processes, products, and important clarifications. Also, Borregaard as a possible future employer for students and postdocs at NMBU has become much clearer because Borregaard has become much more visible to these candidates through the center.

Felleskjøpet

Foods of Norway has been an important center for Felleskjøpet, as it has significantly influenced the R&D activities, involving substantial resources and participation in various work packages. It has potentially impacted their innovation strategy by focusing on new, sustainable raw materials and technological opportunities for future use. The center has not directly improved the sustainability of Felleskøpet's products, processes, or services, as no new commercial products have emerged from the center yet. But participating in the centre has strengthened Felleskjøpet's knowledge base to a large extent.

Seaweed Solution

Seaweed Solutions core focus is and has been the cultivation of kelp as a raw material with a focus on production biology and technology. Participation in the Foods of Norway centre has expanded Seaweed Solutions' R&D activities to include processing and applications, especially in fish and animal feed. The company has also become more market-oriented through interactions with other industry partners. Participating in the centre has contributed to detailed information on the chemical composition and seasonal variation of seaweed, new preservation methods, new processes and product streams, and data on using seaweed as a functional feed ingredient. Although direct commercialization has not yet occurred, participation in the centre has strengthened the company's market position in the seaweed industry, making it a more attractive supplier and partner in R&D projects, and potentially contributing to increased revenue and securing financing.

AquaGen

An important goal of AquaGen's breeding work is to increase feed utilization of salmon through breeding. Feed utilization is a very important trait in aquaculture, both in terms of sustainability and economy. Through participation in the centre, AquaGen has contributed to and become part of a larger research programme developing methods for direct selection of improved feed efficiency. The methods are using naturally occurring stable isotopes in feed to measure individual feed efficiency. While effective, the method is costly and limited to short trial periods. Another method using stable isotopes in body tissue without experimental feed is more cost-effective and relevant, showing promising results. Participating in the centre has enhanced AquaGens understanding of feed utilisation and fish metabolism, and if the methodology for recording individual feed utilization proves effective, it could help reduce the ecological footprint of aquaculture and be applied to other fish species and livestock.

Enifer

Enifer is working on transforming circular economy by-products into planet friendly mycoprotein. Participation in the centre has significantly advanced the testing and validation of the company's new protein ingredient for salmon nutrition, which would have been impossible without this collaboration. The results have guided their R&D efforts. Their product is a more sustainable alternative to current feed ingredients. The new research data and validation have facilitated progress towards industrial-scale production and commercialization. The feed ingredient's health benefits, particularly its impact on the immune response, have improved its positioning as a raw material. Research on optimal inclusion levels has been valuable for product development in the aquafeed industry. Besides significantly strengthening the knowledge base and network, the participation is expected to strengthen their market position and support the introduction of a sustainable feed ingredient.

Success stories

Advancements at Bio-3's Microbial Protein Facility in Averøy

Bio-3's microbial protein production facility in Averøy is currently under development, with significant progress driven by collaborative efforts within the Foods of Norway Centre. Set to begin construction in 2025 and become operational by 2027, the facility will have an initial annual production capacity of 30,000 tons of PEKILO. Foods of Norway has played a crucial role by providing critical data on the use of PEKILO in salmon diets. Additionally, Foods of Norway facilitated a strong collaboration between Bio-3 and Enifer, enabling both companies to effectively work together toward upscaling innovative feed solutions for the aquaculture industry.

A key element of this collaboration has been the provision of detailed research on the use of PEKILO (filamentous fungi, P. variotii) in the diets of Atlantic salmon, supported by Borregaard's valuable forestry-based streams and Enifer's expertise in fermentation technology. Foods of Norway's research has addressed critical factors such as pellet quality, nutrient digestibility, growth performance, nutrient retention, health effects, and the environmental impact of diets incorporating these microbial-based ingredients. These findings have been published in peer-reviewed journals, showcasing the promising potential of microbial proteins in aquaculture.

Building on these positive results, Bio-3 has made the strategic decision to focus on PEKILO as its primary product, positioning the company to strengthen its role in the growing market for sustainable protein alternatives. Foods of Norway also facilitated the licensing agreement for the fermentation technology used in Bio-3's production process, linking consortium partners Enifer and Bio-3.

This ongoing collaboration is proving essential in advancing Bio-3's production capabilities and supporting the company's long-term growth and sustainability goals. It underscores the importance of innovative research and cross-industry cooperation in driving success in sustainable food production.

Bio-3's microbial protein production facility in Averøy. Illustration: Bio-3

Innovative biorefinery processing of bioactive products from seaweed

Advancements in Seaweed-Based Feed Research by Foods of Norway

Norway's long coastline offers a great opportunity to harvest and cultivate seaweed, a unique resource that can be used in food, animal feed, and biochemicals and more. Not only is seaweed full of potential, but it also helps the environment by absorbing nutrients from the ocean, binding CO2, and reducing greenhouse gas emissions, all which is important to secure a more sustainable livestock production. At Foods of Norway, we've been looking into how brown algae like sugar kelp can be used in feed for livestock, from goats to dairy cows. The seaweed farming company Seaweed Solution have supplied the seaweed for our experiments. After testing sun-dried and blanched sugar kelp, we've seen some exciting results. One experiment involved 24 lambs, fed with either a control feed or one with 2.5% or 5% dried sugar kelp for five weeks. We found that the lambs like the feed, with no negative effects on growth or meat quality. In fact, the meat from the lambs fed seaweed was more tender, had a better color, and a longer shelf life. Consumer taste panels noted that the meat had an aromatic, and slightly salty flavor. The seaweed-fed lambs also had higher levels of iodine and selenium in their meat, making it even more nutritious.

Based on these results, we also tested sugar kelp in diets for beef cattle. Even with just 1% of blanched sugar kelp in their diet, we saw improvements in meat tenderness and less cooking loss, with no impact on growth or meat quality. We also observed an increase in iodine levels in the beef. For dairy goats and cows, our trials showed that adding sun-dried or blanched kelp to their feed could boost milk production and increase iodine content in the milk. Goats fed with 5% sundried kelp produced significantly more milk, with higher levels of protein, fat, and lactose. A follow-up study with dairy cows fed balanced seaweed showed similar results with better feed intake, higher milk yield and a slight increase in fat content.

All in all, our research confirms that seaweed is a interesting, sustainable feed solution that improves the quality of both meat and milk. With its many advantages, seaweed is playing an increasingly important role in both Norway's agriculture industry while helping the environment.

Saccharina latissima - or sugar kelp. Photo: Seaweed Solution

Beef cattle fed sugar kelp. Photo: Margareth Øverland

Innovative methods to improve feed efficiency in Atlantic salmon and livestock

Feed efficiency in salmon breeding – the stable isotope approach - the journey

In Norway close to one billion salmon are kept in aquaculture, where most of the production is exported, relying heavily on imported feed. Then, reducing feed costs through saving of feed from improving the feed efficiency becomes important. Feed efficiency can be understood as the ratio between the growth of the fish to the feed given. Improving this ratio with one percent through genetics has been calculated to have a discounted net-value of around one billion NOK, illustrating the considerable importance of improving feed efficiency in aquaculture breeding.

In aquaculture, recording individual feed intake—and thus feed efficiency— is nearly impossible. Instead, stable isotopes footprints in fish tissues serve as indicators. In juvenile pre-smoltified salmon, we found that growth-to-isotope ratios in the fillet correlated to feed efficiency, suggesting that efficient fish had lower maintenance requirement. A large family experiment (2,300 fish) confirmed a near perfect genetic correlation (0.99) between isotope measure and tank level feed efficiency, with moderate heritability (0.06-0.09). We refined methods from isotopes in the feed to natural fractionation and recently conducted verification experiments using metal bids to track individual feed intake. The experiments, spanning freshwater trial with juveniles to 2 kg salmon in sea water (completed in January 2025) will determine if stable isotope profiling can be integrated into AquaGen's breeding program for improved feed efficiency.

Studying 2300 fish at pre-smolt stages in freshwater.
Photo: Janne Brodin

Our approach has been to decompose feed efficiency into its components, phenotype them, and demonstrate their genetic variation. In addition to maintenance requirement, digestive efficiency has been explored and found to be genetically determined. Regarding deposition efficiency, our research has identified a relationship between feed efficiency and stable isotope levels in the viscera (fat surrounding the internal organs), suggesting it as a candidate phenotype. Finally, we have shown that feed efficiency has a relationship to the metabolome of the fish.

Photo: Margareth Øverland

We have applied these findings to livestock, demonstrating that stable isotopes can serve as indicators of feed efficiency in both meat-producing animals like sheep and in dairy cattle. Ongoing research is now assessing their value in crossbred pig. Finally, stable isotopes are being explored as a novel method to determine feed value of individual ingredients or complete feed rations.

FUTURE PROSPECTS

Advancing Sustainable Feed Research and Industry Collaboration

As the operational period of the Foods of Norway Centre concludes, the host institution is committed to preserving and expanding the expertise and infrastructure developed during this time. To ensure long-term sustainability and maximize the impact of the Centre's work, we have outlined strategic initiatives to secure new funding from sources such as the Research Council of Norway, the Research Fund for the Fisheries and Aquaculture Industry (FHF), EU Horizon projects, Nordic funds like Nordforsk and Bioeconomy in the North, and European Research Council grants. These initiatives focus on advancing sustainability in the aquaculture and agriculture sectors, particularly through sustainable feed ingredients, improving animal and fish health and resilience, and developing feed solutions derived from local bioresources.

Building on the Centre's strong reputation and continued potential, we will actively pursue additional funding through national and international channels, such as Horizon Europe. These resources will support the ongoing development of sustainable feed and food production systems, ensuring continued innovation and a positive impact on the sector's future. We also plan to expand our research into cutting-edge fields such as biotechnology in feed production, AI for feed traceability, and the integration of industrial symbiosis and renewable energy into feed systems.

While several applications for EU funding and innovation grants are still in progress, our research has already made significant strides in developing sustainable feed practices. Moving forward, we aim to transition these projects into industrial applications by collaborating with key partners across the fermentation and feed industries in Norway, the EU, and South America. Notably, we work closely with leading companies in both the green and blue sectors, such as Biomar, Cargill, Cermaq, Skretting, and Eide Fjordbruk, to apply our research to practical, large-scale solutions. Additionally, we are collaborating with a strong consortium of research groups and industries from Spain to apply for funding to develop novel monitoring systems and next-generation oral vaccines to improve fish health and reduce mortality. We are also working with a strong consortium of research groups in Chile to apply for funding to develop novel feed resources for the salmon industry.

Expanding and Strengthening Networks: The Centre has fostered valuable connections between academia, industry in both the blue and green sectors, government, and NGOs. We will continue to strengthen and expand these networks, particularly by facilitating the development of a feed ingredient industry in Norway, promoting the increased use of local feed resources such as grass silage and grains for pigs, poultry, and ruminants, improving feed efficiency in farmed animals and fish through genomic selection, and working to reduce the environmental footprint of both salmon and farm animal production.

Safeguarding Infrastructure and Data: The infrastructure developed during the Centre's operation, including specialized laboratories and research databases, will be maintained and utilized for future research. The host institution will ensure these assets remain central to ongoing academic and industrial projects, with secure archiving and data accessibility for the broader scientific community.

In conclusion, while formal funding from the Research Council comes to an end, our research will continue to evolve, supported by ongoing projects, industry collaborations, and strategic funding applications. With these initiatives, Norway will remain at the forefront of sustainable feed development, positioning itself as a global leader in feed science.

CONCLUSIONS

Since the start, Foods of Norway has achieved key breakthroughs in developing novel feed ingredients from natural bioresources, improving feed efficiency, and applying innovative technologies. After the mid-term evaluation, the research plan was adjusted to align with priorities in key research areas. By concentrating on the areas, we ensured more focused and impactful outcomes.

The research work has been organised into six integrated work packages, each led by a NMBU researcher collaborating closely with industry partners. A multidisciplinary approach has fostered strong synergies across the work packages. The management group, which included the centre director, the six work package leaders, centre coordinator, and an administrator, worked together effectively throughout the centre period. They organised meetings, followed up deliverables, and maintained close collaboration with the board and individual partners.

To promote collaboration between academia and industry partners, annual partner meeting and frequent smaller gatherings were organised. These meeting have been crucial for knowledge sharing and discussion on scientific results real-world applications. A constant focus on relevance and partner engagement led to the creation of a "task force," designed to help industry partners and work package leaders collaborate on key issues such as sustainability, economics, and business planning.

The centre has also played a significant role in training the next generation of scientist. PhD students actively participated in the centre's research activities alongside senior researchers, bioengineers and industry partners. The centre has provided several Ph.D. candidates and master students, effectively matching the industry recruitment needs. This approach is one of the most effective ways to build expertise.

Communication efforts included dissemination to research fellows through scientific publications, conference presentations, and other channels, as well as outreach to user groups and the general public. Foods of Norway has maintained visibility through its website, annual reports, social media, newsletters, and numerous public events. We are proud of the high number of popular science articles —around 300—and peer-reviewed articles, reaching 87 articles, several of which have appeared in high impact journals.

Foods of Norway has been a strategic asset for NMBU, strengthening the Universty's core areas. In partnership with industry, the centre has successfully fostered collaboration, innovation, and the development of new knowledge for both industry and society.

Foods of Norway has played a crucial role in making the new aquafeed factory a reality by providing critical data on the use of Pekilo in salmon diets. Furthermore, Foods of Norway facilitated a strong collaboration between Bio3 and Enifer, enabling both companies to effectively work together toward upscaling innovative feed solutions for the aquaculture industry.

FINANCING THROUGH THE LIFE OF THE CENTRE

Summary sheet for the main categories of partners (NOK million)

Contributor	Cash	In-kind	Total
Host		44.9	44.9
Research partners		0.7	0.7
Companies	14.0	45.8	59.8
Public partners		0.2	0.2
RCN	96.0	-	96.0
Sum	**110.0**	**91.6**	**201.6**

Distribution of resources (NOK million)

Type of activity	NOK million
Research projects	176.3
Common centre activities	2.5
Administration	22.8
Total	**201.6**

List of personnel

List of Post-docs, Candidates for PhD and MSc degrees during the full period of the centre

Postdoctoral researchers with financial support from the Centre budget					
Name	**Nationality**	**Period**	**M/F**	**Topic**	**Main contact**
Kiira Vuoristo	Finland	2016-2018	F	Biorefining, fermentation technology, enzymology	Vincent Eijsink
Alexander Kashulin-Bekkelund	Norway	2017-2018	M	Microbiology	Charles Press
Fanny Buffetto	France	2018-2020	F	Bioprocessing and valorization of brewers' spent grain	Svein Jarle Horn
Vladana Grabez	Bosnia-Herzogovina	2017-2023	F	Meat quality, proteomics	Siv Skeie
Live Heldal Hagen	Norway	2019-2020	F	Bioinformatics on gut microbiota	Svein Jarle Horn
Ove Øyås	Norway	2019-2022	M	Bioinformatics	Margareth Øverland
Line Degn Hansen	Denmark	2023-2024	F	Fermentation	Svein Jarle Horn

Postdoctoral researchers working on projects in the centre with financial support from other sources						
Name	**Nationality**	**Period**	**M/F**	**Funding**	**Topic**	**Main contact**
Gergely Kòsa	Hungary	2018-2019	M	NFR	Bioprocessing and fermentation processes	Svein Jarle Horn

PhD candidates who have completed with financial support from the Centre budget					
Name	**Nationality**	**Period**	**M/F**	**Thesis title**	**Main thesis advisor**
David Lapeña Gomez	Spain	2015-2019	M	Production of yeast from spruce sugars and hydrolysates of protein-rich by-products as feed ingredient	Vincent Eijsink
Hanne Dvergedal	Norway	2016-2019	F	Novel indicator traits for individual feed efficiency in Atlantic salmon (Salmo salar)	Gunnar Klemetsdal
Jeleel Opeyemi Agboola	Nigeria	2019-2022	M	Can fish grow on trees? Nutritional and functional properties of yeasts in diets for Atlantic salmon (Salmo salar)	Margareth Øverland
Ingrid Marie Håkenåsen	Norway	2017-2022	F	Novel protein sources in diets for weaned piglets- effect on growth performance, gut function, and health	Liv Torunn Mydland

Martine Andrea Olsen	Norway	2018-2023	F	Cheese-making efficiency affected by protein source in concentrate feed for dairy cows and their αS1-κ-casein genotypes	Siv Skeie
Mette Hofossæter	Norway	2016-2024	F	Effects on intestinal health of yeast used as a protein source in diets for Atlantic salmon (Salmo salar)	Charles Press

PhD candidates who have completed with other financial support, but associated with the centre

Name	**Nationality**	**Period**	**M/F**	**Funding**	**Thesis title**	**Main thesis advisor**
Sandeep Sharma	India	2016-2018	M	NMBU	Production of microbial protein from brown seaweed and spruce wood and its use as a novel feed ingredient in aquaculture	Svein Jarle Horn
Ana Rita Girio da Costa Cruz	Portugal	2016-2019	F	Industry PhD. Felleskjøpet/ NFR	Yeast (Cyberlindnera jadinii): an alternative protein source in pig and poultry feed	Margareth Øverland
Håkon Kaspersen	Norway	2016-2019	M	FFL/VI	Quinolone resistant Escherichia coli in Norwegian livestock - A comparative genomics study	Karin Lagesen
Stanislav Iakhno	Russia	2017-2021	M	NMBU	Porcine gut microbiota, short chain fatty acids, and gut health in response to a high yeast inclusion diet	Henning Sørum
Pabhoda Weththasinghe	Sri Lanka	2018-2021	F	NFR/Nordic CoE	Nutritional, health, and technical properties of black soldier fly (Hermetia illucens) in Atlantic salmon (Salmo salar) feeds	Margareth Øverland
Dominic Duncan Mensah	Ghana	2021-2025	M	NMBU	Novel Diets and Fish Health: Evaluating the Immunonutritional Impact of Filamentous Fungus Paecilomyces variotii in Aquafeeds for Atlantic Salmon (Salmo salar)	Liv Torunn Mydland

Master's degrees					
Name		**Period**	**M/F**	**Topic**	**Main Thesis Advisor**
Rouzbeh Keihani	Iran	2016	M	Bioprocessing, fish nutrition and health	Margareth Øverland
Oluwaseun George Shomorin	Nigeria	2016-2017	M	Testing new feed- and feces collection systems for Atlantic salmon	Jon Øvrum Hansen
Ingrid Marie Håkenåsen	Norway	2016-2017	F	Feed intake, nutrient digestibility, growth performance and general health of piglets fed increasing levels of yeast	Liv Torunn Mydland
Ida Steine Oma	Norway	2017-2018	F	Isolation and characterization of bioactive components in macroalgae	Liv Torunn Mydland
Ingvild Solhjem	Norway	2018-2020	F	Feeding behaviour of dairy cows fed a diet with protein derived from yeast (Candida utilis) compared with diets containing soybean meal and barley.	Egil Prestløkken
Elise Hatch Fure	Norway	2017-2019	F	Comparison of in sacco, DaisyII incubator and gas production to evaluate digestibility of silage in ruminants	Egil Prestløkken
Lars Jordhøy Lindstad	Norway	2018-2019	M	Gene Cloning, Purification and Characterization of Novel Hemicellulases for Production of Tailor Made Prebiotics and Biochemicals	Bjørge Westereng
Bjørn Pedersen	Norway	2017-2019	M	Characterization of a thermostable exolytic alginate lyase from hot vents in the Arctic Mid-Ocean Ridge	Vincent Eijsink
Cathrine Nilsen Sebjørnsen	Norway	2014-2019	F	Characterization of Yeast Exopolysaccharides	Magnus Øverlie Arntzen
Ashwath Gaudhaman	India	2019-2021	M	Novel functional ingredients containing yeast cell wall components modulate molecular biomarkers in Atlantic salmon (Salmo salar) when exposed to acute hypoxic stress.	Brankica Djordevic
Daniel Nøkland	Norway	2017-2019	M	Black soldier fly larvae (acid conserved or dry meal) in extruded salmon diets - effects on feed processing, pellet quality, growth, and nutrient digestibility	Jon Øvrum Hansen
Ann Jorun Hansen Hoøen	Norway	2019	F	In vitro digestion/methane potential evaluation of different concentrates used in different forage-to-concentrate ratios.	Alemayehu Sagaye

Guro Holseth Grepperud	Norway	2019	F	Feed intake, digestibility, growth performance and general health of piglets fed increasing levels of black soldier fly larvae meal.	Liv Torunn Mydland
Thea Brustad	Norway	2019-2020	F	Effects of grass ensiling with different acids, chemical stabilizers, lactobacillus spp. and exogenous fibrolytic enzymes on aerobic stability, chemical composition, in vitro rumen degradation of fiber and methane potential	Liv Torunn Mydland
Ingrid Leikvoll	Norway	2017-2019	F	Kvalitetsforandringer tidlig postharvest i brunalgen Saccharina latissima ved bruk av ulike lagringsmetoder	Bjørg Egelandsdal
Pernille Margrethe Olsen	Norway	2019-2019	F	Fermentation for Single Cell Protein Production	Svein Jarle Horn
Mari Brusletten	Norway	2018-2019	F	Fermentation and downstream processing of yeast for production of single-cell proteins and polysaccharides	Bjørge Westereng
Kristin Heggen	Norway	2020	F	Effects of Candida utilis as a protein source and replacement of soybean meal and yeast with barley on feed utilization and nitrogen use efficiency in dairy cow diets	Egil Prestløkken
Ole Berner Bondø	Norway	2020	M	Comparison of in vitro and in vivo digestibility of grass-based silages in ruminants	Egil Prestløkken
Maren Oftebro	Norway	2019-2020	F	Enzymatic saccharification of the polysaccharides in Saccharina latissima (L.)	Svein Jarle Horn
Dominic Duncan Mensah	Ghana	2020-2021	M	Effect of downstream processing of yeast on the gastrointestinal health of Atlantic Salmon during seawater transfer	Jon Øvrum Hansen
Reidun Lund	Norway	2020-2021	F	Effect of functional feed in diets for Atlantic salmon from two family groups with low and high level of resilience on growth performance kept in fresh water and sea water	Jon Øvrum Hansen
Mary Ueland	Norway	2021-2022	F	Effect of dietary inclusion of *S. latissima* on milk production and composition in lactating NRF cows	Liv Torunn Mydland
Kant Owusu Fokuo	Ghana	2021-2022	M	Seaweed pretreatment methods for longer-term storage; effect on	Liv Torunn Mydland

				nutrients, bioactive compounds and general sensory characteristics	
Jenny Dahlberg	Sweden	2022	F	Hepatic metabolic modulation in Atlantic salmon fed different functional diets during freshwater and seawater phase	Brankica Djordjevic
Sana Javed	Pakistan	2022-2023	F	Filamentous fungi (Paecilomyces variotii) as an alternative sustainable ingredient in diets for Atlantic salmon (Salmo salar) : effects on pellet quality, growth performance, nutrient digestibility and utilization, and immune-related biomarkers in the distal intestine during the freshwater phase	Jamie Marie Hooft
July Arinez	Philippines	2023-2024	M	Estimating microbiota effects on feed efficiency	Gunnar Klemetsdal
Daniel Hellum Andresen	Norway	2024	M	Yeast as single cell protein – optimization of medium compositions and process parameters.	Svein Jarle Horn
Malin Neteland	Norway	2024	F	Impact of increasing mycoprotein Paecilomyces variotii (Pekilo) on growth performance, gut histomorphology, blood biochemistry and welfare indicators of post-smolt Atlantic salmon.	Byron Morales-Lange
Thilini Madhushika Hettiarachchi	Sri Lanka	2024	F	Immunomodulatory Properties of Laminarin Derived from Laminaria hyperborea on Atlantic Salmon (Salmo salar) Parrs: First Insights for the Aquaculture Industry.	Ruth Tamara Montero
Erlend Podhorny Økland	Norway	2023-2024	M	Effekt av enzymer på fordøyelighet av ensilert gras	Egil Prestløkken
Muhammad Asad Rasool	Pakistan	2024	M	Effects of high nutrient density diets in Atlantic salmon on growth performance, yield, morphometric parameters, and nutrient retention	Liv Torunn Mydland
Daniel Oluwole Bisiriyu	Nigeria	2024	M	Assessing the potential of *Aurantiochytrium limacinum* as a novel source of DHA for pre-smolt Atlantic salmon (*Salmo salar*): evaluating its impact on fish performance, nutrient digestibility, nutrient retention, and utilization.	Sérgio D. C. Rocha
Martine Karlsnes	Norway	2025	F	Measured and AI predicted length of intestinal villi in pe-smoltified	Gunnar Klemetsdal

				salmon: Genetic parameters and effect on feed efficiency, feed intake and growth.	

Statement of accounts

Funding 2015 - 2024

Activity	RCN	NMBU	København	Viken Skog	Borregaard	SES	Norilla	Yara	FKF	TINE
WP1	17 688	4 492	0	317	7 449	1 426	1 138	916	314	1 872
WP2	37 331	7 854	732	31	0	0	356	406	4 531	3 291
WP3	12 400	6 992	0	0	0	0	126	146	121	425
WP4	11 233	5 607	0	0	0	0	30	34	58	601
WP5	7 885	2 861	0	0	0	0	26	26	50	80
WP6	1 547	1 162	0	292	0	418	542	14	141	49
Management	7 915	15 953	0	0	0	0	140	153	105	380
Sum	**95 999**	**44 921**	**732**	**640**	**7 449**	**1 844**	**2 358**	**1 695**	**5 320**	**6 698**

Activity	Animalia	Nortura	AquaGen	Norsvin	Geno	Agrifirm	Denofa	BioMar	Lallemand	enifer
WP1	303	1 896	384	88	0	425	768	285	607	466
WP2	249	1 883	1 765	520	0	148	747	2 243	119	0
WP3	97	1 670	120	522	0	43	60	80	148	0
WP4	55	1 843	26	178	0	24	13	12	10	0
WP5	23	1 169	8 979	1 534	615	12	12	455	8	0
WP6	99	175	656	238	25	8	32	195	4	0
Management	67	282	98	0	0	67	49	40	35	0
Sum	**893**	**8 918**	**12 028**	**3 080**	**640**	**727**	**1 681**	**3 310**	**931**	**466**

Activity	Norges Bondelag	Norsk Landbruks samvirke	NHO	Innovasjon Norge	**TOTAL**
WP1	133	141	0	104	**41 212**
WP2	8	67	0	0	**62 281**
WP3	0	0	0	0	**22 950**
WP4	0	0	0	0	**19 724**
WP5	0	0	0	0	**23 735**
WP6	115	472	136	96	**6 416**
Management	25	0	18	0	**25 327**
Sum	**281**	**680**	**154**	**200**	**201 645**

Cost 2015 - 2024

Activity	NMBU	København	Viken Skog	Borregaard	SES	Norilla	Yara	FKF	TINE
WP 1	26 996	0	317	7 449	1 426	739	459	48	454
WP 2	48 192	1 858	31	0	0	0	0	4 292	2 109
WP 3	20 854	0	0	0	0	0	0	37	0
WP 4	17 190	0	0	0	0	0	0	37	506
WP 5	11 019	0	0	0	0	0	0	37	0
WP 6	2 850	0	292	0	418	528	0	134	9
Management	25 282	0	0	0	0	0	0	0	0
Sum	**152 383**	**1 858**	**640**	**7 449**	**1 844**	**1 267**	**459**	**4 585**	**3 078**

Activity	Animalia	Nortura	AquaGen	Norsvin	Geno	Agrifirm	Denofa	BioMar	Lallemand	enifer
WP 1	35	860	3	88	0	310	577	133	474	466
WP 2	11	1 036	1 427	520	0	43	579	2 108	0	0
WP 3	29	1 367	0	522	0	5	0	32	104	0
WP 4	35	1 776	0	178	0	2	0	0	0	0
WP 5	11	1 113	8 956	1 534	615	3	0	447	0	0
WP 6	90	147	645	238	25	2	28	191	0	0
Management	2	0	0	0	0	0	0	0	0	0
Sum	**213**	**6 299**	**11 031**	**3 080**	**640**	**365**	**1 184**	**2 911**	**578**	**466**

Activity	Norges Bondelag	Norsk Landbruks samvirke	NHO	Innovasjon Norge	**Total**
WP 1	133	141	0	104	**41 212**
WP 2	8	67	0	0	**62 281**
WP 3	0	0	0	0	**22 950**
WP 4	0	0	0	0	**19 724**
WP 5	0	0	0	0	**23 735**
WP 6	115	472	136	96	**6 416**
Management	25	0	18	0	**25 327**
Sum	**281**	**680**	**154**	**200**	**201 645**

Publications

2025

Mensah, D.D., Montero, R., Morales-Lange, B., Øverland, M., Mydland, L.T. In vitro salmonid models as tools for studying microbial-derived immunostimulants and aquaculture relevant salmonids pathogens: Current status and future perspectives. Aquaculture 2025, Vol. 595, 741695

Mensah, D.D.; Morales-Lange, B.M.; Rocha, S., Øverland, M.; Kathiresan, P.; Hooft, J.M.; Press, C.McL; Sørum, H.; Mydland, L.T. Paecilomyces variotii improves growth performance and modulates immunological biomarkers and gut microbiota in vaccinated Atlantic salmon pre-smolts. Fish and Shellfish Immunology 2025. Vol. 160, 110223.

Hooft, J.M.; Tran, H.Q.; Montero, R. ; Morales-Lange, B.M.; Stejskal, V.; Mydland, L.T.; Øverland, M. Environmental impacts of the filamentous fungi Paecilomyces variotii (PEKILO®) as a novel protein source in feeds for Atlantic salmon (Salmo salar). Aquaculture 2025, Vol. 596, Part 1, 741779

2024

Egelandsdal, B., Grabez, V., Mydland, L.T., Haug, A., Prestløkken, E. Animal breeding and feeding tools may close human nutrition gaps. Frontiers 2024, Vol. 5.

Benhaïm, D., Sauphar, C.P., Berlizot, B.., Ladurée, G., Knobloch, S., Björnsdóttir, R., Øverland, M., Leeper, A.E.J. Effect of soybean meal enhancements on juvenile Arctic charr (Salvelinus alpinus) growth performance, gut microbiome and behavior. Applied Animal Behaviour Science 2024, Vol. 276.

Hooft, J.M., Montero, R.T., Morales-Lange, B., Blihovde, V., Kathiresan, P., Press, C. McL, Mensaha, D.D., Agboola, J.O., Javed, S., Mydland, L.T. Øverland, M. Paecilomyces variotii (PEKILO®) in novel feeds for Atlantic salmon: Effects on pellet quality, growth performance, gut health, and nutrient digestibility and utilization. Aquaculture 2024; Vol. 589, 740905.

Purushothaman, K., Crawford, A.D., Rocha, S.D.C., Göksu, A.B., Morales-Lange, B., Mydland, L.T., Vij, S., Lin, Q., Øverland, M. and Press, C.McL. Cyberlindnera jadinii yeast as a functional protein source: Modulation of immunoregulatory pathways in the intestinal proteome of zebrafish (Danio rerio). Heliyon 2024; 10, e26547

Stork, E., Ekeberg, D., Devle, H.M., Umu, Ö.C.O., Porcellato, D., Olsen, M.A., Vhile, S.G., Kidane, A., Devold, T. Skeie, S.B. Substituting imported soybean meal with locally produced novel yeast protein in concentrates for Norwegian Red dairy cows: Implications for rumen microbiota and fatty acid composition. Journal of Dairy Research 2024, Vol. 91 (2).

Umu, Ö. C.O., Mydland, L.T., Chen, C., Pérez de Nanclares, M., Shurson, G.C., Urriola, P., Sørum, H. Øverland, M. Integrated multi-omics approach reveals novel associations in the rapeseed diet–microbiota–host axis in pigs. ISME Communications 2024, 4(1), ycae061.

Carril, G., Morales-Lange, B., Løvoll, M.T., Inami, M., Winther-Larsen, H.C., Øverland, M., Sørum, H. Salmonid Rickettsial Septicemia (SRS) disease dynamics and Atlantic salmon immune response to Piscirickettsia salmonis LF-89 and EM-90 co-infection. Veterinary research 2024, Vol. 55:102.

2023

Agboola, J., Rocha, S.C., Mensah, D., Hansen, J.Ø., Øyås, O., Lapeña, D., Mydland, L.T., Arntzen, M.Ø., Horn, S.J., Øverland, M.. Efect of yeast species and processing on intestinal microbiota of Atlantic salmon (Salmo salar) fed soybean meal-based diets in seawater. Animal Microbiome 2023, Vol. 5:21.

Dvergedal, H., Ødegård, J., Galloway, T.F., Klemetsdal, G. Isotope fractionation in juvenile and large rainbow trout (Oncorhynchus mykiss): Repeatability of stable isotope measures and their relationship to growth rate. Aquaculture 2023, Vol. 569:739380.

Grabež, V., Devle, H.M., Kidane, A.S., Mydland, L.T., Øverland, M., Ottestad, S., Berg, P., Kåsin, K., Ruud, L., Karlsen, V., Živanović, V. and Egelandsdal, B. Sugar Kelp (Saccharina latissima) Seaweed Added to a Growing-Finishing Lamb Diet Has a Positive Effect on Quality Traits and on Mineral Content of Meat. Foods 2023, 12, 2131.

Grabež, V., Mydland, L.T., Papoutsis, D., Øverland, M., Egelandsdal, B. Effect of low dose blanched Saccharina latissima in finishing bulls' diet on carcass and beef meat quality traits. Frontiers in Animal Science 2023, Vol. 4.

Hofossæter, M.E., Sørby, R., Göksu, A.B., Mydland, L.T., Øverland, M., Press, C.McL. Cyberlindnera jadinii yeast as a functional protein source for Atlantic salmon (Salmo salar L.): Early response of intestinal mucosal compartments in the distal intestine. Fish and Shellfish Immunology 2023, Vol. 137.

Itani, K., Marcussen, C., Rocha, S.C., Katherisan, P., Mydland, L.T., Press, C.McL., Xie, Z., Tauson, A.H., Øverland, M. Effect of Cyberlindnera jadinii yeast on growth performance, nutrient digestibility, and gut health of broiler chickens from 1 to 34 d of age. Poultry Science 2023, Vol. 102.

Leszek, M., Morales-Lange, B., Montero, R., Mydland, L.T., Horn, S.J., Øverland, M. Impact of biorefinery processing conditions on the bioactive properties of fucoidan extracts from Saccharina latissima on SHK-1 cells. Algal Research 2023, Vol. 75.

Olsen, M.A., Ferneborg, S., Vhile, S.G., Kidane, A., Skeie, S.B. Different protein sources in concentrate feed for dairy cows affect cheese-making properties and yield. Journal of Dairy Science 2023, Vol. 106(8).

Rocha, S., C., Morales_Lange, B.M., Montero, R., Okbayohanese, D., Kathiresan, P., Press, C. McL., Mydland, L.T., Øverland, M. Norway spruce extracts (NSEs) as bioactive compounds in novel feeds: Effect on intestinal immune-related biomarkers, morphometry and microbiota in Atlantic salmon pre-smolts. Journal of Functional Foods 2023, Vol. 111. 105888

2022

Agboola, J.O., Mensah, D.D., Hansen, J.Ø., Lapeña, D., Mydland, L.T., Arntzen, M.Ø., Horn, S.J., Øyås, O., Press, C.M., Øverland, M. Effects of Yeast Species and Processing on Intestinal Health and Transcriptomic Profiles of Atlantic Salmon (Salmo salar) Fed Soybean Meal-Based Diets in Seawater. International journal of molecular sciences 2022, Vol. 23(3), 1675.

Agboola J., Chikwati E. M., Hansen, J.Ø. Kortner T. M. Mydland LT., Krogdahl, Å Djordjevic B., Schrama J W., Øverland, M. A meta-analysis to determine factors associated with the severity of enteritis in Atlantic salmon (Salmo salar) fed soybean meal-based diets. April 2022. Aquaculture 2022, Vol. 555:738214.

Bekkelund, A., Kjos, N.P., Øverland, M. Effects of dried chicory and Jerusalem artichoke on skatole-producing microbial populations of entire male pigs. Livestock Science 2022, Vol. 261, 104957.

Colombo, S.M., Roy, K., Mraz, J., Wan, A.H.L, Davies, S.J., Tibbetts, S.M., Øverland, M., Francis, D.S., Rocker, M.M., Gasco, L., Spencer, E., Metian, M., Trushenski, J.T., Turchini, G. Towards achieving circularity and sustainability in feeds for farmed blue foods. Reviews in Aquaculture 2022, Vol. 1- 27.

Dvergedal, H., Ødegård, J., Galloway, T., Sharma, S., Juarez, M., Klemetsdal, G. Verifying the relationship between δ13C isotope profile variables and individual feed conversion ratio in large rainbow trout (Oncorhynchus mykiss). Aquaculture 2022, Vol. 558, 738355.

Grabež, V., Egelandsdal, B., Cruz, A., Hallenstvedt, E., Mydland, L. T., Alvseike, O., Kåsin, K., Ruud, L., Karlsen, V., Øverland, M. Understanding metabolic phenomena accompanying high levels of yeast in broiler chicken diets and resulting carcass weight and meat quality changes. Poultry Science 2022, Vol. 101 (5), 101749.

Grabež, V., Coll-Brasas, E., Fulladosa, E., Hallenstvedt, E., Håseth, T.T., Øverland, M.

Berg, P., Kidane, A., and Egelandsdal, B. Seaweed Inclusion in Finishing Lamb Diet Promotes Changes in Micronutrient Content and Flavour-Related Compounds of Raw Meat and Dry-Cured Leg (Fenalår). Foods 2022, 11, 1043.

Iakhno, S., Delogu, F., Umu, O.C.O., Kjos, N.P., Håkenåsen, I.M., Mydland, L.T., Øverland, M., & Sørum, H. Longitudinal analysis of the faecal microbiome in pigs fed Cyberlindnera jadinii yeast as a protein source during the weanling period followed by a rapeseed- and faba bean-based grower-finisher diet. Animal Microbiome Journal 2022, 4:62.

Kidane, A., Vhile, S.G., Ferneborg, S., Skeie, S.B., Olsen, M.A., Mydland, L.T., Øverland, M., Prestløkken, E. Cyberlindnera jadinii yeast as a protein source in early- to mid-lactation dairy cow diets: Effects on feed intake, ruminal fermentation, and milk production. Journal of Dairy Science 2022, Vol. 105 (3).

Morales-Lange, B., Djordjevic, B., Gaudhaman, A., Press, C.M., Olsen, J., Mydland LT., Castex, M, Øverland, M. Dietary Inclusion of Hydrolyzed Debaryomyces hansenii Yeasts Modulates Physiological Responses in Plasma and Immune Organs of Atlantic Salmon (Salmo salar) Parr Exposed to Acute Hypoxia Stress. Frontiers in Physiology 2022, Vol. 13:836810.

Møller, H., Samsonstuen, S., Øverland, M., Modahl, I.S., Olsen, H.F. Local non-food yeast protein in pig production – environmental impacts and land use efficiency. Livestock Science 2022, Vol. 260, 104925.

Weththasinghe, P., Rocha, S.D.C., Øyås, O., Lagos, L., Hansen, J.Ø., Mydland, L.T., Øverland, M. Modulation of Atlantic salmon (Salmo salar) gut microbiota composition and predicted metabolic capacity by feeding diets with processed black soldier fly (Hermetia illucens) larvae meals and fractions. Animal Microbiome 2022, 4, 9.

2021

Agboola, J. O., Lapeña, D., Øverland, M., Arntzen, M. Ø., Mydland, L. T., Hansen, J. Ø. Yeast as a novel protein source - Effect of species and autolysis on protein and amino acid digestibility in Atlantic salmon (Salmo salar). Aquaculture 2021, Vol. 546, Article 737312.

Agboola, J. O., Schiavone, M., Øverland, M., Morales-Lange, B. M., Lagos, L., Arntzen, M. Ø., Lapeña, D., Eijsink, V., Horn, S. J., Mydland, L. T., François, J. M., Mercado, L., Hansen, J. Ø. Impact of down-stream processing on functional properties of yeasts and the implications on gut health of Atlantic salmon (Salmo salar). Scientific Reports 2021, Vol. 11, Article 4496.

Arntzen, M. Ø., Pedersen, B., Klau, L. J., Stokke, R., Oftebro, M., Antonsen, S. G., Fredriksen, L., Sletta, H., Aarstad, O. A., Aachmann, F. L., Horn, S. J., Eijsink, V. Alginate degradation: Insights obtained through characterization of a thermophilic exolytic alginate lyase. Applied and Environmental Microbiology 2021, Vol. 87(6), e02399-20.

Djordjevic, B., Morales-Lange, B. M., Press, C. M., Olson, J., Lagos, L., Mercado, L., Øverland, M. Comparison of circulating markers and mucosal immune parameters from skin and distal intestine of Atlantic salmon in two models of acute stress. International Journal of Molecular Sciences 2021, Vol. 22(3), 1028.

Djordjevic, B., Morales-Lange, B. M., Øverland, M., Mercado, L., Lagos, L. Immune and proteomic responses to the soybean meal diet in skin and intestine mucus of Atlantic salmon (Salmo salar L.). Aquaculture Nutrition 2021, Vol. 27(6).

Hansen, J. Ø., Lagos, L., Lei, P., Reveco-Urzua, F. E., Morales-Lange, B. M., Hansen, L. D., Schiavone, M., Mydland, L. T., Arntzen, M. Ø., Mercado, L., Benicio, R. T., Øverland, M. Down-stream processing of baker's yeast (Saccharomyces cerevisiae) – Effect on nutrient digestibility and immune response in Atlantic salmon (Salmo salar). Aquaculture 2021, Vol. 530, 735707.

Hansen, J. Ø., Sharma, S., Horn, S. J., Eijsink, V., Øverland, M., Mydland, L. T. Fecal excretion and whole-body retention of macro and micro minerals in Atlantic salmon fed

Torula yeast grown on sugar kelp hydrolysate. Animals 2021, Vol. 11(8), 2409.

Håkenåsen, I. M., Grepperud, G. H., Hansen, J. Ø., Øverland, M., Ånestad, R., Mydland, L. T. Full-fat insect meal in pelleted diets for weaned piglets: Effects on growth performance, nutrient digestibility, gastrointestinal function, and microbiota. Animal Feed Science and Technology 2021, Vol. 281, 115086.

Morales-Lange, B. M., Agboola, J. O., Hansen, J. Ø., Lagos, L., Øyås, O., Mercado, L., Mydland, L. T., Øverland, M. The spleen as a target to characterize immunomodulatory effects of down-stream processed Cyberlindnera jadinii yeasts in Atlantic salmon exposed to a dietary soybean meal challenge. Frontiers in Immunology 2021, Vol. 12, 708747.

Olsen, M. A., Vhile, S. G., Porcellato, D., Kidane, A., Skeie, S. B. Feeding concentrates with different protein sources to high-yielding, mid-lactation Norwegian Red cows: Effect on cheese ripening. Journal of Dairy Science 2021, Vol. 104(4).

2020

Agboola, J. O., Øverland, M., Skrede, A., Hansen, J. Ø. Yeast as major protein-rich ingredient in aquafeeds: A review of the implications for aquaculture production. Reviews in Aquaculture 2020, Vol. 13(2).

Coll Brasas, E., Possas, A., Berg, P., Grabez, V., Egelandsdal, B., Bover-Cid, S., Fulladosa, E. Physicochemical characterisation of restructured Fenalår and safety implications of salt and nitrite reduction. Food Control 2020, Vol. 119.

Dvergedal, H., Harvey, T. N., Jin, Y., Ødegård, J., Grønvold, L., Sandve, S. R., Våge, D. I., Moen, T., Klemetsdal, G. Genomic regions and signaling pathways associated with indicator traits for feed efficiency in Atlantic salmon (Salmo salar). Genetics Selection Evolution 2020, Vol. 52.

Dvergedal, H., Mydland, L. T., Klemetsdal, G. The change in 15N stable isotope content in muscle, liver and mid-intestine in juvenile Atlantic salmon (Salmo salar) under starvation. Aquaculture Research 2020, Vol. 51(12).

Dvergedal, H., Sagaye, A., Klemetsdal, G., Mydland, L. T., Øverland, M., Olsen, H. F. Individual phenotyping of feed efficiency in lambs fed stable isotopes through maize silage. Livestock Science 2020, Vol. 239, 104173.

Dvergedal, H., Sandve, S. R., Angell, I. L., Klemetsdal, G., Rudi, K. Association of gut microbiota with metabolism in juvenile Atlantic salmon. Microbiome 2020, Vol. 8(1), 160.

Girio Da Costa Cruz, A. R., Sterten, H., Steinhoff, F. S., Mydland, L. T., Øverland, M. Cyberlindnera jadinii yeast as a protein source for broiler chickens: effects on growth performance and digestive function from hatching to 30 days of age. Poultry Science 2020, Vol. 99(6).

Gomez, D. L., Kòsa, G., Hansen, L. D., Mydland, L. T., Passoth, V., Horn, S. J., Eijsink, V. Production and characterization of yeasts grown on media composed of spruce-derived sugars and protein hydrolysates from chicken by-products. Microbial Cell Factories 2020, Vol. 19(1), 19.

Grabez, V., Egelandsdal, B., Kjos, N. P., Håkenåsen, I. M., Mydland, L. T., Vik, J. O., Hallenstvedt, E., Devle, H. M., Øverland, M. Replacing soybean meal with rapeseed meal and faba beans in a growing-finishing pig diet: Effect on growth performance, meat quality and metabolite changes. Meat Science 2020, Vol. 166, 108134.

Håkenåsen, I. M., Øverland, M., Ånestad, R., Åkesson, C. P., Meenakshi Sundaram, A. Y., Press, C. M., Mydland, L. T. Gene expression and gastrointestinal function is altered in piglet small intestine by weaning and inclusion of Cyberlindnera jadinii yeast as a protein source. Journal of Functional Foods 2020, Vol. 73, 104118.

Iakhno, S., Umu, Ö. C. O., Håkenåsen, I. M., Åkesson, C. P., Mydland, L. T., Press, C. M., Sørum, H., Øverland, M. Effect of

Cyberlindnera jadinii yeast as a protein source on intestinal microbiota and butyrate levels in post-weaning piglets. Animal Microbiome 2020, Vol. 2, 13.

Lagos, L., Kashulin Bekkelund, A., Skugor, A., Ånestad, R., Åkesson, C. P., Press, C. M., Øverland, M. Cyberlindnera jadinii yeast as a protein source for weaned piglets – Impact on immune response and gut microbiota. Frontiers in Immunology 2020, Vol. 11, 1924.

Lagos, L., Leanti La Rosa, S., Arntzen, M. Ø., Ånestad, R., Terrapon, N., Gaby, J. C., Westereng, B. Isolation and Characterization of Extracellular Vesicles Secreted In Vitro by Porcine Microbiota. Microorganisms 2020, Vol. 8(7), 983.

2019

Campbell, I., Macleod, A., Sahlmann, C., Neves, L., Funderud, J., Øverland, M., Hughes, A. D., Stanley, M. The environmental risks associated with the development of seaweed farming in Europe - prioritizing key knowledge gaps. Frontiers in Marine Science 2019; Vol. 6.

Couture, J., Geyer, R., Hansen, J. Ø., Kuczenski, B., Øverland, M., Palazzo, J., Sählmann, C., Lenihan, H. S. Environmental Benefits of Novel Nonhuman Food Inputs to Salmon Feeds. Environmental Science and Technology 2019; Vol. 53.(4).

Dvergedal, H., Ødegård, J., Mydland, L. T., Øverland, M., Hansen, J. Ø., Ånestad, R. M., Klemetsdal, G. Stable isotope profiling for large-scale evaluation of feed efficiency in Atlantic salmon (Salmo salar). Aquaculture Research 2019; Vol. 50.(4).

Dvergedal, H., Ødegård, J., Øverland, M., Mydland, L. T., Klemetsdal, G. Indications of a negative genetic association between growth and digestibility in juvenile Atlantic salmon (Salmo salar). Aquaculture 2019; Vol. 510.

Dvergedal, H., Ødegård, J., Øverland, M., Mydland, L. T., Klemetsdal, G. Selection for feed efficiency in Atlantic salmon using individual indicator traits based on stable isotope profiling. Genetics Selection Evolution 2019; Vol. 51.

Girio Da Costa Cruz, A. R., Håkenåsen, I. M., Skugor, A., Mydland, L. T., Åkesson, C. P., Hellestveit, S. S., Sørby, R., Press, C. M., Øverland, M. Candida utilis yeast as a protein source for weaned piglets: Effects on growth performance and digestive function. Livestock Science 2019; Vol. 226.

Gomez, D. L., Olsen, P. M., Arntzen, M. Ø., Kòsa, G., Passoth, V., Eijsink, V., Horn, S. J. Spruce sugars and poultry hydrolysate as growth medium in repeated fed-batch fermentation processes for production of yeast biomass. Bioprocess and biosystems engineering (print) 2019.

Hansen, J. Ø., Hofossæter, M. E., Sahlmann, C., Ånestad, R., Reveco Urzua, F. E., Press, C. M., Mydland, L. T., Øverland, M. Effect of Candida utilis on growth and intestinal health of Atlantic salmon (Salmo salar) parr. Aquaculture 2019; Vol. 511.

Hansen, J. Ø., Øverland, M., Skrede, A., Anderson, D. S., Collins, S. A meta-analysis of the effects of dietary canola/double low rapeseed meal on growth performance of weanling and growing-finishing pigs. Animal Feed Science and Technology 2019; Vol. 259.

Reveco Urzua, F. E., Hofossæter, M. E., Kovi, M. R., Mydland, L. T., Ånestad, R., Sørby, R., Press, C. M., Lagos Rojas, L. X., Øverland, M. Candida utilis yeast as a functional protein source for Atlantic salmon (Salmo salar L.): Local intestinal tissue and plasma proteome responses. PLOS ONE 2019; Vol. 14.(12)

Sählmann, C., Djordjevic, B., Lagos, L., Mydland, L. T., Morales-Lange, B., Hansen, J. Ø., Ånestad, R., Mercado, L., Bjelanovic, M., Press, C. M., Øverland, M. Yeast as a protein source during smoltification of Atlantic salmon (Salmo salar L.), enhances performance and modulates health. Aquaculture 2019; Vol. 513.

Shomorin, O. G., Storebakken, T., Kraugerud, O. F., Øverland, M., Hansen, B. R., Hansen, J. Ø. Evaluation of wedge wire screen as a new tool for faeces collection in digestibility assessment in fish: The impact of nutrient leaching on apparent digestibility of nitrogen, carbon and sulphur from fishmeal, soybean

meal and rapeseed meal-based diets in rainbow trout (Oncorhynchus mykiss). Aquaculture 2019; Vol. 504.

Skugor, A., Kjos, N. P., Meenakshi Sundaram, A. Y., Mydland, L. T., Ånestad, R., Tauson, A. H., Øverland, M. Effects of long-term feeding of rapeseed meal on skeletal muscle transcriptome, production efficiency and meat quality traits in Norwegian Landrace growing-finishing pigs. PLOS ONE 2019; Vol. 14.(8)

Vuoristo, K., Fredriksen, L., Oftebro, M., Arntzen, M. Ø., Aarstad, O. A., Stokke, R., Steen, I. H., Hansen, L. D., Schüller, R. B., Aachmann, F. L., Horn, S. J., Eijsink, V. Production, characterization, and application of an alginate lyase, AMOR_PL7A, from hot vents in the Arctic mid-ocean ridge. Journal of Agricultural and Food Chemistry 2019; Vol. 67.(10).

Wang, J., Lei, P., Gamil, A. A. A., Lagos, L., Yue, Y., Schirmer, K., Mydland, L. T., Øverland, M., Krogdahl, Å., Kortner, T. M. Rainbow trout (Oncorhynchus mykiss) intestinal epithelial cells as a model for studying gut immune function and effects of functional feed ingredients. Frontiers in Immunology 2019; Vol. 10.

2018

Chen, C., de Nanclares, M. P., Kurtz, J. F., Trudeau, M. P., Wang, L., Yao, D., Saqui-Salces, M.; Urriola, P.E., Mydland, L. T., Shurson, G.C. Øverland, M. Identification of redox imbalance as a prominent metabolic response elicited by rapeseed feeding in swine metabolome. Journal of Animal Science 2018; Vol. 96 (5).

Kidane, A., Øverland, M., Mydland, L. T., Prestløkken, E. Interaction between feed use efficiency and level of dietary crude protein on enteric methane emission and apparent nitrogen use efficiency with Norwegian Red dairy cows. Journal of Animal Science 2018; Vol. 96 (9).

Lapena Gomez, D., Vuoristo, K., Kòsa, G., Horn, S. J., Eijsink, V. Comparative assessment of enzymatic hydrolysis for valorization of different protein-rich industrial byproducts. Journal of Agricultural and Food Sciences 2018; Vol. 66.

Mosberian Tanha, P., Landsverk, T., Press, C. M., Mydland, L. T., Schrama, J. W., Øverland, M. Granulomatous enteritis in rainbow trout (Oncorhynchus mykiss) associated with soya bean meal regardless of water dissolved oxygen level. Journal of Fish Diseases 2018; Vol. 41 (2).

Mosberian Tanha, P., Schrama, J. W., Landsverk, T., Mydland, L. T., Øverland, M. The effect of plant-based diet and suboptimal environmental conditions on digestive function and diet-induced enteropathy in rainbow trout (Oncorhynchus mykiss). Aquaculture Nutrition 2018; Vol. 24 (1).

Nirea, K. G., de Nanclares, M. P., Skugor, A., Afseth, N. K., Meuwissen, T., Hansen, J. Ø., Mydland,L. T., Øverland, M. Assessment of fecal near-infrared spectroscopy to predict feces chemical composition and apparent total-tract digestibility of nutrients in pigs. Journal of Animal Science 2018; Vol. 96 (7).

de Nanclares, M. P., Marcussen, C., Tauson, A. H., Hansen, J Ø., Kjos, N P., Mydland, L. T., Bach Knudsen, K. E., Øverland, M. Increasing levels of rapeseed expeller meal in diets for pigs: effects on protein and energy metabolism. Animal 2018; Vol. 13 (2).

Sharma, S., Hansen, L. D., Hansen, J. Ø., Mydland, L. T., Horn, S. J., Øverland, M., Eijsink, V.,Vuoristo, K. Microbial protein produced from brown seaweed and spruce wood as a feed ingredient. Journal of Agricultural and Food Chemistry 2018; Vol. 66 (31).

Sharma, S., Neves, L., Funderud, J., Mydland, L. T., Øverland, M., Horn, S. J. Seasonal and depth variations in the chemical composition of cultivated Saccharina latissima. Algal Research 2018; Vol. 32.

Øverland, M., Mydland, L. T., Skrede, A. Marine macroalgae as sources of proteinand bioactive compounds in feed for monogastric animals. Journal of the Science of Food and Agriculture 2019; Vol. 99.

Mosberian-Tanha, P., Schrama, J.W.T., Mydland, L.T., Øverland, M. The effect of plant-based diet and suboptimal environmental conditions on digestive function and diet-induced enteropathy in rainbow trout (Oncorhynchus mykiss). Aquaculture Nutrition 2018, Vol. 24.

2017

Kurtz, J.F., Chen, C., de Nanclares, M.P., Trudeau, M., Yao, D., Saqui-Salces, M., Urriola, P. E., Mydland, L.T., Shurson, G.C., Øverland, M. Effects of rapeseed feeding on swine metabolome. Journal of Animal Science 2017; Vol. 95

Pérez de Nanclares, M., Trudeau, M.P., Hansen, J.Ø., Mydland, L.T., Urriola, P.E., Shurson, G.C., Piercey Åkesson, C., Kjos, N.P., Arntzen, M.Ø., Øverland, M. High-fiber rapeseed co-product diet for Norwegian Landrace pigs: Effect on digestibility. Livestock Science 2017. Vol. 23.

Ravanal, M.C., Sharma, S., Gimpel, J., Reveco-Urzua, F.E., Øverland, M., Horn, S.J., Lienqueo, M.E. The role of alginate lyases in the enzymatic saccharification of brown macroalgae, Macrocystis pyrifera and Saccharina latissimi. Algal Research 2017, Vol.26.

2016

Estensoro, I., Ballester-Lozano, G., Benedito-Palos, L., Grammes, F., Martos-Sitcha, J.A., Mydland, L.T., Calduch-Giner, J.A., Fuentes, J., Karalazos, V., Ortiz, A., Øverland, M., Sitjà-Bobadilla, A., Pérez-Sánchez, J.. Dietary butyrate helps to restore the intestinal status of a marine teleost (Sparus aurata) fed extreme diets low in fish meal and fish oil. PLoS ONE 2016, Vol. 11.(11)

Mosberian-Tanha, P., Øverland, M., Landsverk, T., Reveco, F.E., Schrama, J.W., Roem, A. J., Wittrup_Agger, J., Mydland, L.T. Bacterial translocation and in vivo assessment of intestinal barrier permeability in rainbow trout (Oncorhynchus mykiss)with and without soyabean meal-induced inflammation. Journal of Nutritional Science 2016, Vol. 5.

Westereng, B., Arntzen, M.Ø., Aachmann, F.L., Varnai, A., Eijsink, V., Wittrup_Agger, J. Simultaneous analysis of C1 and C4 oxidized oligosaccharides, the products of lytic polysaccharide monooxygenases acting on cellulose. Journal of Chromatography A 2016, Vol. 1445.

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Final report

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