ANNUAL REPORT
2022

FOODS OF NORWAY

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

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

CONTENTS

EXECUTIVE SUMMARY

With seven years of research activities under our belts, Foods of Norway as a centre has now reached many milestones and documented a lot of exciting results. Thanks to the dedicated partners in the centre and its many talented researchers and technicians, we have been able to continue our path toward more sustainable feed resources for fish and livestock.

The Norwegian government presented in October 2022 its long-term plan for research and higher education. One of the missions is sustainable feed, which is within Foods of Norway's core goals and ambitions.

After the successful industrial scale-up of yeast produced from sugars from Norwegian spruce trees, two large-scale feeding trials with yeast were carried out in 2022: one trial with salmon in seawater and a field trial with piglets. The results are promising, and we expect more valuable findings throughout 2023. Rising prices of sugars in recent years have made the production of yeast to a feed ingredient more challenging, and the focus has turned towards the mycoprotein PEKILO®, which can utilize cheaper materials from tree biomass. Two trials with Atlantic salmon have been conducted, and results show that fish perform well and that the PEKILO® has immunomodulating effects. We are optimistic about using PEKILO® as a high-quality sustainable protein source in feed for fish and farm animals.

Studying the potential of seaweed is also a major part of our research. We have obtained interesting results with seaweed in diets for dairy cows, where cows fed the seaweed-based ration had higher feed intake and milk yield, and produced milk with a higher fat and iodine content. A trial with Atlantic salmon using fucoidan (a complex carbohydrate) extracted from sugar kelp shows promising results and suggests that fucoidan is an interesting candidate for functional feeds.

Two PhD students successfully completed their degrees this year. Jeleel Opeyemi Agboola defended his thesis on nutritional and functional properties of yeasts in diets for Atlantic salmon. Based on his PhD work, he won the prestigious Nutreco 2022 Young Researchers Prize. Ingrid Marie Håkenåsen studied novel protein sources in diets for weaned piglets and how they affect growth performance, gut function and health.

Foods of Norway is also building recognition in the media and with authorities and interest groups as a valuable knowledge provider. The centre has participated in the Norwegian environmental organization Bellona's report "Råvareløftet", which sheds light on a wide range of candidates for new, alternative feed ingredients.

We are looking forward to continuing our work in 2023. Among many other exciting events, we will continue assessing feed efficiency in salmon, and perform sustainability and economical assessment of the large-scale feeding trials. The centre period has been extended to the end of 2024, which will give us opportunities to fulfill our goals and ambitions.

Centre Director,
Professor Margareth Øverland

Margareth Øverland

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.

RESEARCH PLAN

The Norwegian fish-farming and livestock industries rely heavily on imported protein-rich feed ingredients, such as soy-based products. Heavy use of such ingredients raises some ethical concerns, however, as it puts increased pressure on natural resources and leads to greater competition for human food.

The sustainability of future livestock and farmed fish production will depend on increased use of local and novel feed ingredients.

These novel ingredients should have a low environmental impact and should be produced from local resources and waste streams that are not suitable for human consumption. At the same time, we need to use our feed resources more efficiently, for example by genetic improvement of animals and optimal feed resource allocation across species.

Norway has limited land area for cultivating food and feed crops, but possesses considerable natural bioresources such as trees, grass, macroalgae, and by-products from fish, animals and plants. These have great potential as a basis for producing novel feed ingredients.

Foods of Norway develops sustainable feed ingredients from selected renewable bioresources which are available in sufficient quantities to support large-scale production at a competitive cost.
The centre consists of six integrated work packages with several sub-tasks, each led by an NMBU researcher and in close collaboration with our industry partners. The research is multidisciplinary and there are close synergies across the work packages.

Trials with salmon fed yeast at LetSea's fish farm at Dønna (top), and beef cattle fed seaweed at a farm in Vestfold, Norway (right).

Photos: BioMar (top) and Nortura (right).

Photos: EniferBio (left) and Seaweed Solution (below).

The research plan for the next two years will focus on evaluating microbial ingredients such as the mycoprotein PEKILO® that have a higher protein content and can grow on cheaper forestry-based side streams than yeast. Researchers in the centre are now studying the nutritional value and beneficial effects on health, as well as sustainability and techno-economical properties of these microbial ingredients.

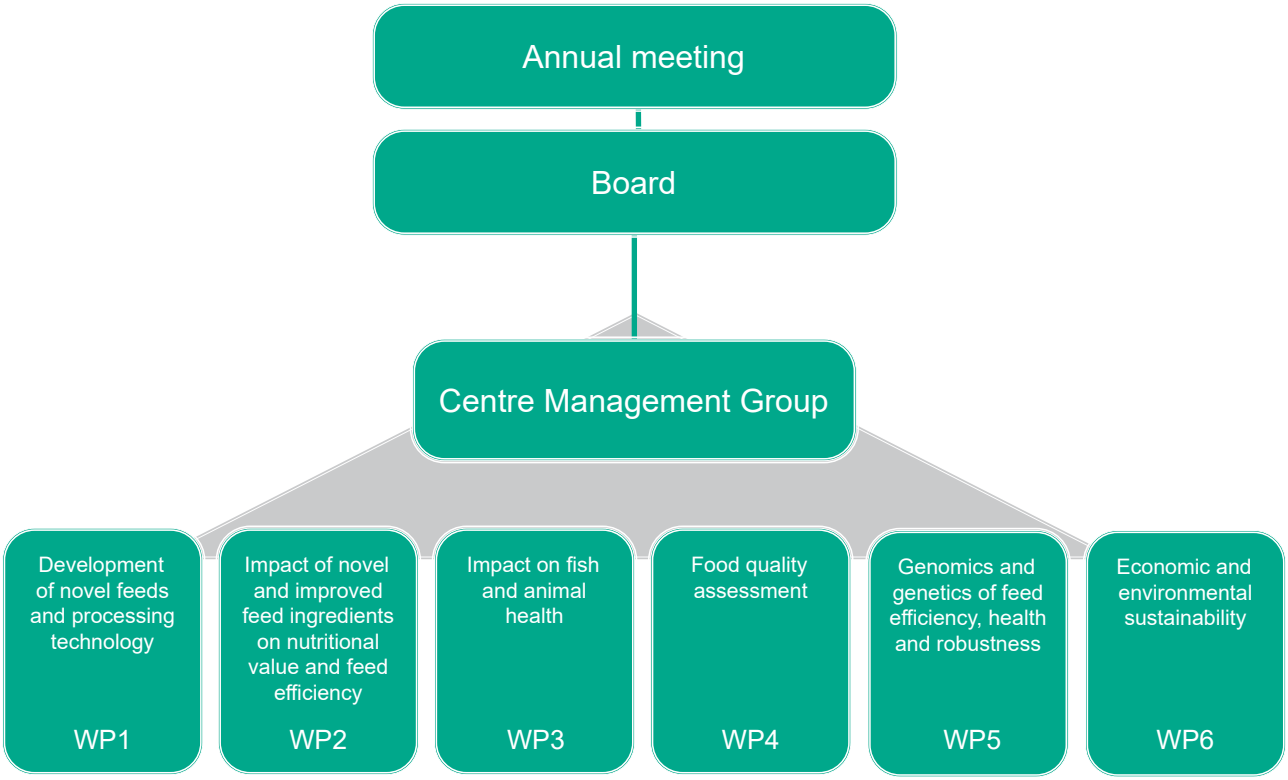
Foods of Norway researchers are investigating low-processed seaweed (sugar kelp) as a functional ingredient to improve the meat quality of beef cattle and yield and quality of milk from dairy cows. Fucoidan, extracted from sugar kelp, is evaluated in functional feeds for Atlantic salmon and broiler chickens with focus on immunomodulating properties and gut microbiota composition to improve health and robustness. Different technologies are being evaluated to preserve the nutritional value and functional properties of seaweed during storage.

Foods of Norway has a special focus on improving the feed efficiency and robustness of farm animals and fish. Improvements in feed efficiency have a large impact on feed resource utilization, feed costs and the environment. We have developed novel indicator traits for individual feed efficiency in salmon, based on stable isotope profiling. By using natural isotopes, phenotyping is applicable in practice. Over the next year there will be a final verification experiment with large salmon. Also, over the next two years we will assess whether the indicator traits can be applied to dairy cows and pigs.

ORGANISATION

The Board is the ultimate decision- making body of the Consortium. The board's main responsibility is to ensure that the intentions and plans underlying the contract for the establishment of the centre are fulfilled.

The centre director is 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 convenes once a year.



THE BOARD

Knut Røflo

Chair until Nov 2022

Felleskjøpet Fôrutvikling (FKF)

Vegard Denstadli

Chair from 10 Nov 2022

BioMar

Kari Kolstad

Deputy chair

NMBU / Faculty of Biosciences

Eirik Selmer-Olsen

Member

Tine

Hege Rivedal-Ødegaard

Member

Denofa

Cecilie Hultmann

Member

Nortura

Eli Grindflek

Member

Norsvin

Gudbrand Rødsrud

Member

Borregaard

Solveig Fossum-Raunehaug

Member

NMBU / Research Department

Sigrid Gåseidnes

Member

NMBU / Faculty of Chemistry, Biotechnology and Food Science

CENTRE MANAGEMENT GROUP

Margareth Øverland
Centre Director

Professor, NMBU
Faculty of Biosciences

Svein Jarle Horn
Leader WP1

Professor, NMBU
Faculty of Chemistry, Biotechnology and Food Science

Liv Torunn Mydland
Leader WP2

Researcher, 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 comprises three faculties at NMBU and 20 partners in industry and innovation. We also work closely with several international partners and collaborators.

Supporting partners

NORGES BONDELAG

NORSK LANDBRUKSSAMVIRKE

NHO Mat og Drikke

Innovation Norway

Academic partners and collaborators

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
- eniferBio
- 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

Photo: Shutterstock

COOPERATION BETWEEN PARTNERS

In a centre for Research-based Innovation (CRI), industry participation is very important. Foods of Norway collaborates across three sectors – agriculture, aquaculture and forestry.

The aim is to promote discussion and close collaboration, leading to new research ideas and innovation potential across the sectors. To achieve this collaboration, Foods of Norway hosts joint partner meetings and frequent meetings between academia and industry partners.

In May 2022, a partner meeting was held with these main topics: policy makers on circular economy, industry's sustainability strategies, and substrate availability for production of microbial ingredients. A workshop was also organized to discuss prioritization and use of raw materials in future research projects.

Two trials with the microbial protein PEKILO® for salmon were carried out in 2022. The trials were conducted in cooperation with the NordicFeed project. Borregaard provided the forestry-based fermentation substrate (BALI sugar), while the fermentation to produce PEKILO® was done by eniferBio.

After the successful industrial scale-up of yeast produced from sugars from Norwegian spruce trees in 2021, the yeast was evaluated in two large-scale feeding trials in 2022 in collaboration with NMBU and industrial partners. BioMar carried out a trial with yeast in diets for Atlantic salmon in seawater, and Felleskjøpet Fôrutvikling carried out a field trial with yeast in diets for piglets at a Norwegian pig farm. Both trials investigated growth performance, animal health and welfare, as well as the sustainability and economic impact of using yeast as a feed ingredient.

A field trial with seaweed in feed rations for beef cattle has been performed, in a collaboration between Nortura, Seaweed Solutions, Felleskjøpet and NMBU. The cattle were fed a ration containing 1% blanched sugar kelp to evaluate whether the seaweed could improve meat quality.

A pilot trial with dairy cows that were fed a total mixed ration with 1% blanched sugar kelp was performed by TINE and NMBU in collaboration with Seaweed Solutions and Felleskjøpet Fôrutvikling to evaluate whether brown seaweed can result in more efficient milk production, as well as to improve the iodine content of milk.

To further evaluate methods developed by scientists from NMBU and AquaGen on improved feed efficiency in salmon, AquaGen kick-started phenotyping of stable isotopes from 1000 individuals from their slaughter test.

The collaboration model will continue to drive Foods of Norway's activities to ensure innovation and commercialization.

INTERNATIONAL COOPERATION

Foods of Norway continued to work closely with several of our international collaborators in 2022

International collaboration results in important knowledge. Foods of Norway has three international partners: the University of Copenhagen (UC), the Canadian company Lallemand, and the Finnish partner eniferBio. In 2022, collaboration with UC has mainly been through an experiment with yeast as a protein source in diets for broiler chickens, resulting in a manuscript with joint authorship. The collaboration with Lallemand includes evaluating results from field trials with yeast in diets for Atlantic salmon and piglets on growth performance, health, welfare and sustainability.

The Finnish start-up company eniferBio has produced a microbial ingredient (PEKILO®) from forestry side streams that was used in two experiments with Atlantic salmon focusing on nutritional value and health benefits. The diets for these trials were produced at the Swedish University of Agricultural Sciences (SLU), which will also perform rainbow trout experiments with PEKILO® in a collaborating project.

Researchers from NMBU, in close collaboration with Seaweed Solutions and Nortura, have continued their cooperation with IRTA (Institute of Agrifood Research and Technology) in Spain on the publication of previous experiments on chemical properties in cured legs of lamb (fenalår) from animals fed seaweed.

There has been collaboration with Aarhus University on the publication of results from an experiment with yeast in diets for piglets on metabolite profile in urine and plasma to seek an in depth understanding of the metabolic fate of yeast-based diets.

Postdoctoral fellow Purushothaman Kathiresan spent three months at the National University of Singapore, where he carried out proteome analysis on gastro-intestinal samples from Atlantic salmon fed yeast under field conditions, with focus on immunomodulation.

Photo: Shutterstock

International ongoing spin-off projects

NORDICFEED

NORDICFEED (Bio-conversion of non-food bio-resources to novel feeds for salmonids – a Nordic approach) aims to enhance the performance, health and robustness of rainbow trout and Atlantic salmon at various life stages and environmental conditions. The project's goal is to develop optimized feed formulations based on sustainable microbial feed ingredients from locally available waste streams. International partners: Swedish University of Agricultural Sciences, Natural Resources Institute Finland, Vattenbrukscentrum Norr AB, Sweden, and eniferBio Oy Ltd, Finland.

Resilient Salmon

The project Resilient Salmon (Trained immunity and nutritional programming for resilient salmon) investigates beneficial effects on animal health by using bioactive feed components from yeast from woody biomass and brown seaweeds. Specifically, the project investigates growth performance, stress and health responses in Atlantic salmon from two genetic backgrounds - with low and high levels of resilience. The fish are fed today's standard feed and tomorrow's feed with yeast, both in freshwater and during seawater transfer. International partners are University of Santiago, Chile; Pontifical Catholic University of Valparaiso, Chile; and University of Wisconsin-Madison, USA.

OIL4FEED

The OIL4FEED project (Oil from oleaginous microbial biomass derived from Norwegian resources to replace fish/plant oils in fish feed) aims to develop a process for producing microbial oils from animal fat by-products and second-generation sugars derived from Norwegian woody feedstock.
This will allow a new value chain from Norwegian by-products to microbial feed oils to be established for the first time in Norway, increasing the financial and environmental sustainability of Norwegian aquaculture, agriculture, forestry and food industries. OIL4FEED will deliver a complete set of new insights into the effect of microalgal/fungal oil on the growth performance and health of fish. The project is led by the Faculty of Science and Technology, and its international partner is California Center for Algae Biotechnology, USA.

SafeKelp

The SafeKelp project (Safe kelp for food and feed – controlling the transfer of iodine and arsenic through the value chain) aims to follow the presence of iodine and arsenic throughout the value chains from cultivation to human consumption, with the aim to manage feed/food safety of this valuable resource. The project focuses on the species Saccharina latissima (sugar kelp) and Alaria esculenta (winged kelp), both cultivated in Norway, and S. japonica which is cultivated in China. The project is a collaboration between Norwegian (NMBU, Sintef Ocean, Institute of Marine Research) and Chinese partners (Institute of Oceanology, Chinese Academy of Sciences and Yellow Sea Fisheries Institute, and Chinese Academy of Fishery Sciences).

Photo: Shutterstock

RESEARCH HIGHLIGHTS IN 2022

The main goal of Foods of Norway is to develop novel protein sources in diets for livestock and fish. The centre focuses on the use of woody biomass and seaweed, both abundant resources in Norway and which do not compete with resources for human food. This is a sustainable approach to some of the challenges we see in agriculture and aquaculture today.

1 Biomass processing and production of microbial ingredients

In Foods of Norway enzyme technology and fermentation processes are used to produce microbial biomass from underutilized bioresources as a novel feed ingredient for the aquaculture and agriculture industries.

A novel pathway for improved value creation of our natural bioresources is to develop processes to convert these into microbial ingredients, such as yeast. Developing these processes and documenting the use of yeast as a novel protein source in animal feeds are some of the centre's main areas of research.

After the successful large-scale production of 1,600 kilos of autolyzed C. jadinii yeast grown on spruce sugars in 2021, the yeast was included in feed and used in large-scale feeding trials in 2022 (see next page). Additionally, the fermentation research focus moved from yeast to filamentous fungi, and procedures to grow fungi in bioreactors were successfully established.

Hydrolysis equipment in Borregaard's biorefinery demo plant used for converting cellulose to sugars (top), and sampling of salmon at LetSea's fish farm at Dønna (right).

Photos: Martin Lersch/Borregaard (top) and BioMar (right)

2 Testing the impact of novel feed ingredients

Foods of Norway evaluates novel feed ingredients for nutritional value, growth performance and the health of livestock and fish, and the quality of fish, meat and milk products.

Large-scale demonstration of yeast as a feed ingredient

Two large-scale feeding trials with yeast in diets for salmon and piglets have been performed during 2022. BioMar carried out the salmon trial during the grow-out phase in seawater where the fish were fed diets with 0, 6, 12 and 18% yeast respectively. Felleskjøpet Fôrutvikling performed the field trial with piglets that were fed a diet with 0 or 8% yeast. Growth performance, animal health and welfare were registered. Results are being analysed; so far, they look promising. Data will also undergo a sustainability and economic assessment of using yeast as a feed ingredient.

Trial with piglets fed yeast.

Photo: Foods of Norway

Evaluation of nutritional value and health effects of PEKILO®

The centre has been evaluating the mycoprotein PEKILO® produced by EniferBio using a side stream from Borregaard in two trials with Atlantic salmon. The results show that fish liked the feed, grew well and had a high feed efficiency. A laboratory-scale experiment with immune cells isolated from salmon head kidney and spleen that were exposed to PEKILO® has also been carried out. Results showed that PEKILO® gave a strong immune-stimulating response, especially when the cells were also exposed to a common salmon pathogen (*Moritella viscosa*). The results suggest that PEKILO® has a positive effect on health, verified in an ongoing experiment with salmon during sea water transfer.

Evaluation of brown seaweed as a functional feed ingredient

The centre has conducted a trial to evaluate the immunomodulating effects of fucoidan, a bioactive component extracted from sugar kelp, in salmon. Results showed that moderate dosage of fucoidan gave a strong immune-stimulating effect. Fucoidan also led to changes in gut microbiota with a dose-dependent increase in genus Bacillus, which some species are associated with positive health effects in fish. These results suggest that fucoidan is an interesting candidate for functional feeds, but the effects depend on the processing method and the dosage used.

Saccharina latissima - or sugar kelp.
Photo: Foods of Norway

A field experiment with beef cattle was successfully conducted. The cattle were fed a total mixed ration of silage, concentrate and 1% blanched sugar kelp on a dry matter basis. Results showed that feeding seaweed tended to increase tenderness, reduce cooking loss and to increase the iodine content of the meat. Results were similar to those in an earlier trial with lambs.

A pilot trial with dairy cows that were fed a total mixed ration with 1% blanched sugar kelp was performed. Results show that cows fed the sugar kelp had increased feed intake, milk yield, milk fat content and energy corrected milk yield. Taken together, supplementing diets with seaweed holds promise with respect to milk yield and milk composition.

3 Genomics and genetics

Methods for direct selection for improved feed efficiency based on individual metabolic efficiency have been developed.

The centre has developed a method for selecting salmon with high feed efficiency which is based on adding isotopes to feed to measure feed efficiency characteristics of salmon in early life. The next step is to evaluate the use of a method based on natural isotopes in feed and tissue samples from salmon, as an alternative and cheaper method to measure feed efficiency. In 2022, AquaGen kick-started phenotyping of stable isotopes from 1000 individuals from their slaughter test .

NEW SPIN-OFF PROJECTS IN 2022

One spin-off project was granted funding in 2022.

ForestFeed

A new spin-off project, ForestFeed (A Nordic blue-green value chain from forest to fish filet), was granted funding at the end of 2022. The project will take the technology developed in Foods of Norway and the NordicFeed project further by upscaling production of the sustainable novel feed ingredient, PEKILO®, based on low-cost local forestry by-products to enhance diets for rainbow trout and Atlantic salmon production. PEKILO® will also be evaluated in a large-scale trial under field conditions with Atlantic salmon together with Biomar. The project will also valorize bioactive components from PEKILO® to high-value products with functional properties. The immunomodulating properties of these will be evaluated in functional feed for salmon.

ForestFeed is led by NMBU (Margareth Øverland) and financed by the Bioeconomy in the North program (BIN). Partners are eniferBio, Agricultural University of Sweden, Institute for Food and Environmental Research e.V. Germany. Associate partners are Biomar and AV Group Inc, Canada.

Photo: Shutterstock

Farmed salmon can grow on Norwegian spruce trees instead of Brazilian soybeans

Norwegian spruce can mitigate Brazilian deforestation. Farmed salmon will soon eat feed that comes from Norwegian forests instead of soybeans that have been transported halfway around the world.

Even if Norwegian salmon feed based on soybeans did not contribute to deforestation, the feed must still be transported from Brazil to Norway, and that is not a climate-friendly option.

Photo: Knut Werner Alsén

It could have been taken directly from the Norwegian government's political platform, known as the Hurdal Platform – or from the Government's long-term plan for research, for that matter, but NMBU's Professor Margareth Øverland and her colleagues began their work long before either of these documents had been written.

More feed

"The whole point of Foods of Norway is to increase food production in Norway while reducing the nation's climate footprint. More food means more feed," Professor Øverland explains. She is the centre director of the research centre Foods of Norway, where scientists based at Ås cooperate with scientists, enterprises and organisations all over the world. When the Government now states that all livestock and fish feed must come from sustainable sources, Øverland is already well on the way to providing a solution.

Fungus from spruce

Norwegian farmed salmon is currently fed soybeans imported from Brazil. Foods of Norway wants to replace the high-mileage soybeans with Norwegian spruce. “We have been working with Borregaard of Norway since 2015 to produce yeast based on Norwegian spruce,” she says. The yeast is turned into fish feed.

Rising prices in recent years have made their work a little harder. When the price of sugar rises and the world wants more bioenergy, making yeast from spruce becomes more expensive. But Foods of Norway’s Finnish partner Enifer Bio has a solution to this problem: PEKILO®. “It is a fungus that can help us to utilise much cheaper residual raw materials from the forest,” says Øverland.

Fungus, either yeast or Pekilo, feeds on Norwegian spruce, and the fungus in turn becomes healthy feed for farmed salmon.

Photo: Foods of Norway

For example, spruce can be used to produce ethanol. Once the product has been extracted and sold at a good price, PEKILO® can feed on the leftovers, grow and become salmon feed.

Healthier salmon

Not only does the new feed contain 65 percent protein, which is the level Norwegian salmon farmers are currently struggling to achieve from sources other than imported soybeans. It is also super-digestible and improves the salmon’s health. The professor explains: “It has a digestibility approaching 90 per cent, and we can make it from cheaper raw materials. It has a beneficial effect by stimulating the immune system, and we can see that the fish like this feed a lot. They grow well and show better food utilisation.”

NMBU researchers will now be taking a closer look at the health effects. In a world where it is important to produce feed that is cheap enough to compete with imported soybeans, it would help a lot to demonstrate that the feed also keeps the salmon healthier. If this can be documented, fish farmers, and therefore also feed manufacturers, will be willing to pay more.

Sustainability

Microbes and yeast are the future of food production. “They have high nutritional value, grow very quickly compared with terrestrial plants and can convert all sorts of raw materials into high-quality proteins that can be used as animal feed. At the same time, they are also more sustainable,” says Øverland. “The residual raw materials used by microbes and yeast do not take up farmland, and they do not compete with food for human consumption,” she emphasises.

In the climate debate, such competition has been an important argument in favour of consuming less meat: Concentrate feed is made from raw materials that could have been used for human food. “Yeast contains a number of substances that bring health benefits. We need to focus on those benefits going forward, because that will add value,” she says.

Faster growth

So far, trials have shown that salmon fed yeast and PEKILO® are not only healthier, but they grow faster. “We have carried out growth trials that show a positive effect on growth, feed uptake and feed utilisation,” says Øverland.

The focus is now on achieving cheap large-scale production of the novel feed resource. The aquaculture industry will only use PEKILO® or other forms of feed ingredients originating from the forest if the feed can be produced in large quantities and is available at a price no higher than that of imported soybeans.

“We are working on cheaper solutions that will produce feed ingredients with a higher protein content, higher digestibility and beneficial health effects. The industry is waiting for Foods of Norway to come up with answers. Everyone needs new raw materials,” says Øverland.

The scientists have achieved promising results in their laboratory. The next step is to produce sufficient quantities to make industrial production viable.

Photo: Foods of Norway

Feed from the sea gives healthier farm animals and tastier meat

Everything from sheep to salmon to chickens that eat seaweed can benefit.

Sheep like seaweed, and consumers like the meat of sheep that have been fed seaweed.

Photo: Foods of Norway

Seaweed has a long tradition as animal feed in coastal areas, but new technology can broaden the use of seaweed in a variety of livestock and fish.

“Seaweed is good for sheep, for example. The meat will often have a more aromatic, saltier flavour than meat from other lambs,” says Margareth Øverland, professor at the Norwegian University of Life Sciences (NMBU).

Happy and sustainable

She is talking about high-quality meat from happy sheep – but sustainability is an underlying factor. Øverland is the centre director of the research centre Foods of Norway at NMBU, where scientists cooperate with business and industry partners to produce more environmentally friendly feed for fish and livestock. One place to look is just beneath the surface of the sea. “Seaweed grows much faster than terrestrial plants. All it needs is seawater and sunlight. Moreover, seaweed has a beneficial effect on the environment, as it can recycle nutrients from the aquaculture industry that would otherwise be lost,” Øverland explains.

Øverland and her colleagues are initially looking at brown seaweed and how it can be used in feeds for a variety of animal species, from chickens to farmed salmon. Simply feeding them seaweed and letting the chickens or salmon eat it as is, is not going to work, however. Species with a single stomach, such as fish, chickens and pigs, are not able to get much nutrition from the seaweed.

Seaweed can provide good salmon, sheep and cattle feed.

Photo: Seaweed Solutions

Healthier salmon

"The initial nutritional value is very low. Targeted processing is required to turn seaweed into feed," she says. This involves extracting the active substances. Sugar and nutrients are then used to produce yeast, which in turn becomes a protein-rich feed ingredient. And what is left of the plant can be used as fertiliser.

"We see that seaweed extract has a highly beneficial effect on fish health, especially in connection with the transfer of salmon to seawater," Øverland says. Seaweed extract has anti-inflammatory properties and gives the fish a healthier gut flora.

"We have great faith in this as a good solution for the aquaculture industry, where the fish is exposed to a high level of stress. Salmon experience changes in their environment and feed, pathogens and stress from being handled in connection with vaccination or delousing. This could impair growth and cause considerable losses, particularly in seawater," she says.

Perhaps seaweed extract can reduce stress and strengthen the immune system, thus making the salmon more robust and better able to withstand these challenges. Lower mortality means better financial results for fish farmers. In Øverland's words: "This shows very interesting potential."

Unprocessed for ruminant animals like sheep

Some farm animals can eat seaweed in an unprocessed state. "We have added seaweed to feed for ruminants without processing it. Ruminants are much better equipped to utilise the seaweed's nutritional value, as they come with their own natural 'bioreactor,'" she says.

Scientists have fed lambs seaweed grown on the island of Frøya in Norway. The company Seaweed Solutions has farmed seaweed, cut it up, frozen it and sent it to Ås, where it was sun-dried. The end-product had a dry matter content of about 30 per cent. This is roughly equivalent to the sheep's normal winter feed of silage stored in round bales or silos.

"We found that the sheep liked this feed very much. There was no negative effect on their growth, and the meat was of high quality," says Øverland.

Good meat, more milk

The sheep were not the only ones to enjoy their feed. So did the people who ate the high-quality meat from the lambs. "There was less loss in cooking, and the meat was more tender. It also improved storage stability," she says.

Cattle fed seaweed appear to produce meat that is more tender and of higher quality. Photo: Foods of Norway

The researchers had consumers taste meat from lambs that had been fed seaweed and lambs that had not, and there was a clear distinction. The meat of lambs that had been fed seaweed had a more aromatic, saltier flavour. It is juicier, redder, it can be stored for longer, and it also has a higher content of nutrients such as iodine and selenium.

Trials where cattle and goats have been given feed containing seaweed indicate similar effects: tenderer meat, less loss in cooking, and more and healthier milk.

Øverland gave a presentation of the project at the SIG Seaweed conference in Trondheim. "One thing that came out of the conference is that Norway is in a good position to develop a seaweed-based industry, and there is considerable interest in seaweed farming, but access to sales channels presents a bottleneck," she says.

Most of the seaweed presently farmed is used for human consumption. If it could also be used in animal feed, that would open up possibilities for new products and sales channels, and production could be increased considerably.

Can fish grow on trees? Yes!

Yeast produced from tree sugars can be used as a valuable feed ingredient to promote growth and health in Atlantic salmon, new research shows.

New research shows that salmon eat well when given the yeast-based feed.

Photo: Bente Paulson

This exciting new insight is part of the recently submitted PhD thesis of Jeleel Opeyemi Agboola, a doctoral fellow at the centre for research-based innovation Foods of Norway hosted by the Norwegian University of Life Sciences (NMBU).

The thesis aimed to investigate whether yeasts produced from sugars from Norwegian spruce trees can promote growth performance, health and robustness of Atlantic salmon. It concludes that not only can yeast be a valuable alternative feed resource to traditional sources of protein, it can also make us less dependent on imports, and even have beneficial health effects for the fish.

The main motivation for Jeleel is contributing to global food security. Fish is the most important protein source in the world, and the global aquaculture industries are growing rapidly. In Norway, yeast grown on spruce tree extracts would be a step towards a more sustainable industry, as this can be a local feed ingredient produced from natural resources not suitable for direct human consumption.

Jeleel Opeyemi Agboola.

Photo: NMBU

Additional benefits

Jeleel's results show that yeast can be used as a high-value protein source, without compromising the growth or health of fish. However, yeast from trees can as of now only be produced in low quantities, which is challenging in terms of profitability. This is why an important part of Jeleel's work is uncovering the additional benefits of yeast for fish health.

"Additional health effects will add a premium on the cost of this alternative ingredient. However, yeasts need to be produced in commercial quantities. So, using the yeast as a protein source in feed for salmon is possible, but there is a need for a consistent supply," Jeleel explains.

For instance, as part of his research, Jeleel and his team investigated whether yeast produced from wood sugars could improve the health of salmon during their most vulnerable stage of life, the transition from freshwater to seawater.

Jeleel Opeyemi Agboola with the yeast-based feed, produced at NMBU.
Photo: Bente Paulson

Official mandate

Professor Margareth Øverland was Jeleel's main supervisor at NMBU. She is also the head of Foods of Norway, a centre aiming to produce sustainable feed ingredients from local resources for livestock and fish.

"In our work we follow the entire value chain from tree biomass to the final products. Jeleel's research has provided important insight into how yeast grown on sugars from Norwegian spruce trees can affect growth performance and health of the fish. This is valuable input for the next steps in making sustainable feeds from Norwegian natural resources," she says.

The exciting results from his PhD work have spurred Jeleel to continue his work with aquaculture development, especially within nutrition and health.

"The Norwegian government has given us a clear mandate, as it has stated that by 2030 all feed ingredients should come from sustainable resources. Part of the industry is already taking this target on board as part of the way forward for Norwegian aquaculture. This will take time, and we need to generate even more knowledge about the impact of novel feed ingredients on fish growth performance and health," Jeleel says.

"But in the end, the quality of the fish fillet is at the top of the pyramid," he says.

In an additional finding, Jeleel's research showed how some antinutritional factors related to soybean meal in the feed can be counteracted by the bioactive components in yeast, which is linked to the effects the yeast-based feed has on the immune system of fish.

"This is an interesting observation. Going forward, we see that these findings must be validated by further research to understand the mechanism of how yeasts can improve the immune response of fish, and in that way affect overall fish health," Jeleel says.

RECRUITMENT

Foods of Norway increased its staff in 2022.

Ruth Tamara Montero Meza

Researcher

Fish Nutrition and Health

Jamie Hooft

Researcher

Fish Nutrition and Health

Line Degn Hansen

Postdoctoral Fellow

Molecular Biology

Ingjerd Dønnem

Administrative coordinator

Centre Management Group

KNOWLEDGE SHARING

Foods of Norway scientists are frequently invited to scientific meetings and conferences, often as keynote speakers or panel participants, and to meetings with stakeholders from the aquaculture, forestry and agricultural industries, as well as with politicians and regulatory authorities.

In 2022, Foods of Norway researchers gave talks at several important scientific conferences around the world. A group from the centre went to Sorrento, Italy, for the International Symposium on Fish Nutrition and Feeding (ISFNF) in June. Some of the scientists also travelled to Madrid to present their research at the International Symposium on Mucosal Health in Aquaculture in October. Other participation includes contributions from the centre at Arendalsuka in Norway, the Seaweed4Health Conference in Ourense, Spain, and the International Society of Fish and Shellfish Immunology in Bodø.

The Foods of Norway delegation in Sorrento, Italy.

Photo: Foods of Norway

Centre director Margareth Øverland participated in several events on behalf of the consortium. She was invited as a keynote speaker at the 2nd International Symposium on Mucosal Health in Aquaculture in Madrid, where she presented "Role of functional aquafeeds on mucosal immunity: From bioactive components to a resilient salmon." She was also a speaker at Aquaculture Canada and WAS North America 2022 in Canada with the presentation "Green & blue: Forest by-products – a promising feed resource for Atlantic salmon" and the SIG Seaweed 7 Conference in Trondheim with the presentation entitled "Seaweed as a feed resource." Professor Øverland also participated in several major Norwegian events looking at novel feeds in the blue and green sectors.

Byron Morales-Lange and Ruth Tamara Montero Meza presented at the 4th Congress of the International Society of Fish and Shellfish Immunology 2022 in Bodø.

Photo: Margareth Øverland

COMMUNICATION AND DISSEMINATION

Foods of Norway's research and innovations are continuously highlighted by domestic and international media, and in 2022 the dissemination of news was the result of both reactive and proactive communication activities.

The centre has had well deserved attention in the media. In March, the national broadcaster NRK visited the centre's labs during final sampling from the field trial with salmon that were fed diets containing yeast derived from Norwegian spruce trees, and in April NRK was invited to the farm in Vestfold to hear about the results from the field trial with seaweed for beef cattle. Proactive communication efforts from the centre also resulted in several articles in relevant news outlets.

In many of the centre's communication activities during 2022, 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 going forward is to continue 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

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.

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

Fredrik Hansen
Journalist

Helena Rønning
Journalist

Article from NRK Vestfold og Telemark 7 May 2022

Salmonexpert Bolsa Laboral Mitos y Verdades Nosotros

STEEN® www.steen.be *Tu solución innovadora para procesar pescado*

Dr. Byron Morales, científico chileno involucrado en la investigación y que actualmente trabaja en la NMBU. Foto: Byron Morales.

Levaduras en dietas: ¿cuáles serían sus efectos …mones?

…que la inclusión de levaduras en dietas para salmones, podría … procesos de estrés agudo para los peces, evitando pérdida de

Article from Salmonexpert.cl 17 May 2022

forskning.no Kultur Helse Miljø Samfunn Teknologi Naturviten Podcast Nyhetsbrev

Selv om norsk laks spiser soya som ikke er et resultat av avskoging, så skal fôret uansett fraktes fra Brasil til Norge. Det er ikke nødvendigvis så klimavennlig. (Foto: Knut Werner Alsén)

Oppdrettslaks skal spise norsk gran, ikke brasiliansk soya

Norsk gran kan erstatte brasiliansk avskoging. Snart spiser oppdrettslaksen fôr som stammer fra den norske skogen, i stedet for soya som er fraktet rundt halve verden.

Georg Mathisen
FRILANSJOURNALIST

NMBU – Norges miljø- og biovitenskapelige universitet

Article from Forskning.no 13 November 2022

IN NUMBERS: COMMUNICATION OUTPUT IN 2022

983
Facebook followers

40
Articles in editorial media

354
Average reach of our Facebook posts

Articles in editorial media	Norwegian	38
	International	2
Newsletter*	Sent out	1
	Subscribers	176
Facebook	Followers	983
	Average reach	354
	Average engagement (post clicks / reactions, comments & shares)	50
Twitter	Followers	454
	Impressions	842

*Created in June 2022, in accordance with GDPR

List of personnel 2022

Key researchers	
Name	**Main research area**
Margareth Øverland	Centre director; Feed ingredient evaluation
Svein Jarle Horn	Bioprocessing, applied enzymology
Liv Torunn Mydland	Process; feed ingredient evaluation
Charles Press	Veterinary pathophysiology, veterinary immunology
Henning Sørum	Bacteriology, pre- probiotics, microbiota, antibiotic resistance, fish diseases
Siv Skeie	Product quality
Gunnar Klemetsdal	Genetics; nutrition; feed efficiency
Hanne Fjerdingby Olsen	Economics and sustainability

Permanent research staff		
Name	**M/F**	**Topic**
Bjørg Egelandsdal	F	Product quality of meat
Nils Petter Kjos	M	Pig nutrition
Egil Prestløkken	M	Ruminant nutrition

Postdoctoral researchers with financial support from the centre budget		
Name	**M/F**	**Topic**
Vladana Grabez	F	Meat quality, proteomics
Hanne Dvergedal	F	Feed efficiency in fish
Özgun Candan Onarman Umu	F	Gut microbiota
Sergio Da Rocha	M	Microbiology and immunology assessment
Peng Lei	F	In vitro screening of feed components for health effects
Brankica Djordjevic	F	Fish nutrition and health
Khaled Itani	M	Yeast in diets for broiler chickens
Ghulam Qasim Khan	M	Ruminant nutrition, upgrading nutritional value of grass
Ove Øyås	M	Bioinformatics
Dimitrios Papoutsis	M	Meat quality
Ruth Tamara Montero Meza	F	Immunology
Jamie Hooft	F	Feed processing, fish nutrition
Jeleel Opeyemi Agboola	M	Downstream processing of yeast, salmon nutrition and health

Postdoctoral researchers working on projects in the centre with financial support from other sources			
Name	**M/F**	**Funding**	**Topic**
Jørgen Ødegaard	M	NMBU	Genomics of feed efficiency
Byron Morales Lange	M	NFR	Mucosal immunity
Davide Porcellato	M	NMBU	Milk microbiota
Purushothaman Kathiresan	M	NMBU	Fish health
Line Degn Hansen	F	NFR	Fermentation

PhD students with financial support from the centre budget		
Name	**M/F**	**Topic**

Martine Olsen	F	Influence of feed on milk quality
Jeleel Opeyemi Agboola	M	Downstream processing of yeast, salmon nutrition and health

PhD students working on projects in the centre with financial support from other sources			
Name	**M/F**	**Funding**	**Topic**
Eirin Stork	F	NMBU	Product quality of milk
Mette Hofossæter	F		Animal health
Dominic Duncan Mensah	M	NMBU	Fish nutrition and health
Ingrid Marie Håkenåsen	F	Industry	Nutrition, novel protein sources, nutrition effect on performance, gut function and health

Master degrees		
Name	**M/F**	**Topic**
Mary Ueland	F	Effect of dietary inclusion of *S. latissima* on milk production and composition in lactating NRF cows
Kant Owusu Fokuo	M	Seaweed pretreatment methods for longer-term storage; effect on nutrients, bioactive compounds and general sensory characteristics
Jenny Dahlberg	F	Hepatic metabolic modulation in Atlantic salmon fed different functional diets during freshwater and seawater phase

PhD degrees		
Name	**M/F**	**Topic**
Jeleel Opeyemi Agboola	M	Can fish grow on trees? Nutritional and functional properties of yeasts in diets for Atlantic salmon (Salmo salar)
Ingrid Marie Håkenåsen	F	Novel protein sources in diets for weaned piglets – effect on growth performance, gut function, and health

Visiting researchers				
Name	**Period**	**M/F**	**Affiliation**	**Topic**
Lele Fu	28.02.22-15.02.23	F	Institute of Hydrobiology, Wuhan	Health effects of organic acids in fish feed
Chunyu Ge	28.02.22-15.02.23	F	Chinese Academy of Agricultural Sciences, Beijing	Insects as an alternative protein source in fish feed

Statement of accounts

Foods of Norway costs 2022 (1000 NOK)

Host NMBU	Industry partners (Norway)	International partners	Equipment	Total costs
14 184	3 510	185	0	17 879

Foods of Norway funding 2022 (1000 NOK)

Host NMBU	Industry partners (Norway)	International partners	Research Council	Total funding
2 199	4 685	285	10 710	17 879

Publications list 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. (2022). 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, 23(3), 1675. https://doi.org/10.3390/ijms23031675

- Agboola J., Chikwati E. M., Hansen, J.Ø. Kortner T. M. Mydland LT., Krogdahl, Å Djordjevic B., Schrama J W., Øverland, M. 2022. 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 555:738214. https://doi.org/10.1016/j.aquaculture.2022.738214

- Bekkelund, A., Kjos, N.P., Øverland, M. 2022. Effects of dried chicory and Jerusalem artichoke on skatole-producing microbial populations of entire male pigs. Livestock Science 261, 104957. https://doi.org/10.1016/j.livsci.2022.104957

- 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; 1- 27. https://doi:10.1111/raq.12766

- Dvergedal, H., Ødegård, J., Galloway, T., Sharma, S., Juarez, M., Klemetsdal, G., 2022. Verifying the relationship between δ13C isotope profile variables and individual feed conversion ratio in large rainbow trout (Oncorhynchus mykiss). Aquaculture 558, 738355. https://doi.org/10.1016/j.aquaculture.2022.738355

- Grabež, V., Egelandsdal, B., Cruz, A., Hallenstvedt, E., Mydland, L. T., Alvseike, O., Kåsin, K., Ruud, L., Karlsen, V., Øverland, M. (2022). Understanding metabolic phenomena accompanying high levels of yeast in broiler chicken diets and resulting carcass weight and meat quality changes. Poultry Science, 101 (5), 101749. https://doi.org/10.1016/j.psj.2022.101749

- Grabež, V., Coll-Brasas, E., Fulladosa, E., Hallenstvedt, E., Håseth, T.T., Øverland, M. Berg, P., Kidane, A., and Egelandsdal, B. (2022). Seaweed Inclusion in Finishing Lamb Diet Promotes Changes in Micronutrient Content and Flavour-Related Compounds of Raw Meat and Dry-Cured Leg (Fenalår). Foods, 11, 1043. https://doi.org/10.3390/foods11071043

- Iakhno, S., Delogu, F., Umu, O.C.O., Kjos, N.P., Håkenåsen, I.M., Mydland, L.T., Øverland, M., & Sørum, H. 2022. 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, 4:62. https://doi.org/10.1186/s42523-022-00217-5

- Kidane, A., Vhile, S.G., Ferneborg, S., Skeie, S.B., Olsen, M.A., Mydland, L.T., Øverland, M., Prestløkken, E. (2022). 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, 105 (3), 2343-2353. https://doi.org/10.3168/jds.2021-20139.

- Morales-Lange, B., Djordjevic, B., Gaudhaman, A., Press, C.M., Olsen, J., Mydland LT., Castex, M, Øverland, M. 2022. 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 13:836810. DOI: https://doi.org/10.3389/fphys.2022.836810
- Møller, H., Samsonstuen, S., Øverland, M., Modahl, I.S., Olsen, H.F. (2022). Local non-food yeast protein in pig production – environmental impacts and land use efficiency. Livestock Science 260, 104925. https://doi.org/10.1016/j.livsci.2022.104925
- Weththasinghe, P., Rocha, S.D.C., Øyås, O., Lagos, L., Hansen, J.Ø., Mydland, L.T., Øverland, M. (2022). 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, 4, 9. https://doi.org/10.1186/s42523-021-00161

FOODS OF NORWAY

Annual report 2022

Norwegian Centre for Research-based Innovation

The Research Council of Norway

NMBU Faculty of Biosciences
Oluf Thesens vei 6, Campus Ås
Telephone:+47 67 23 26 00
E-mail: fon@nmbu.no

www.foodsofnorway.net