Seaweed as a feed resource

Prof. Margareth Øverland, Norwegian University of Life Sciences

SIG conference 15 November, 2022

FOODS OF NORWAY aims to feed fish and farm animals using sustainable new ingredients

Duration: 2015-2024; Budget: > NOK 210 million

Norway has a unique opportunity to develop a seaweed industry

Cultivated seaweeds a potential feed resource

Journal of the Science of Food and Agriculture
SCI
Review
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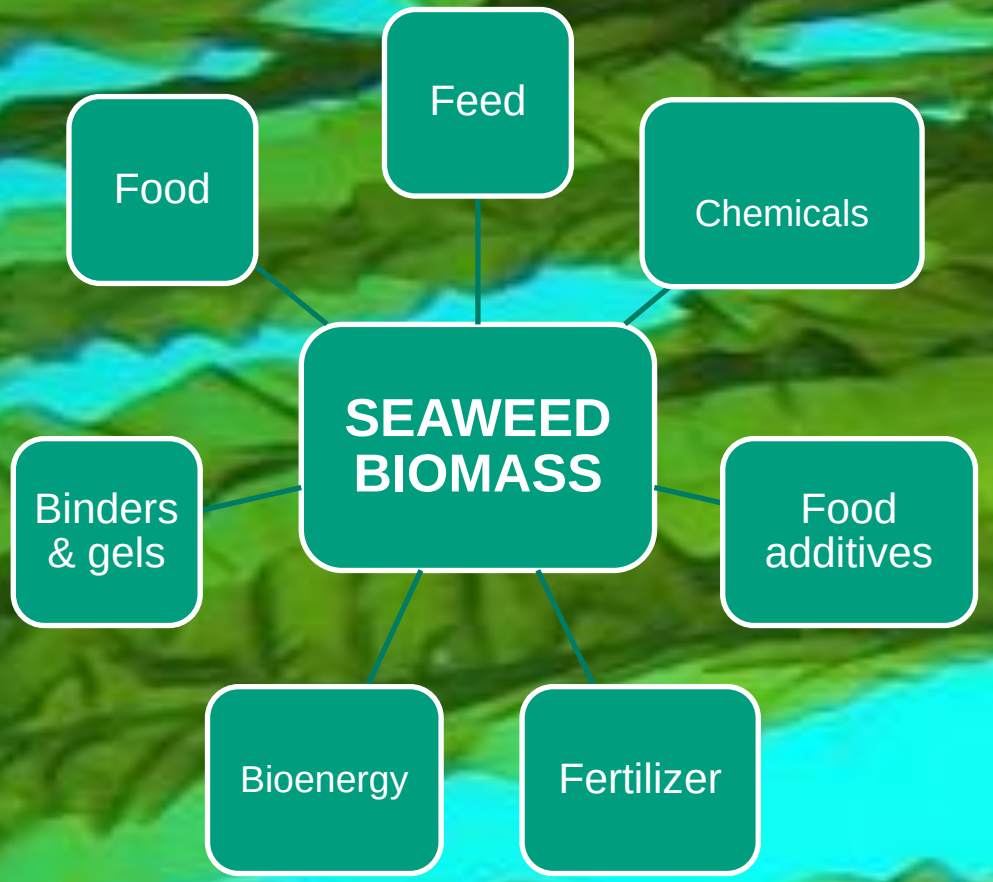
(wileyonlinelibrary.com) DOI 10.1002/jsfa.9143

Marine macroalgae as sources of protein and bioactive compounds in feed for monogastric animals

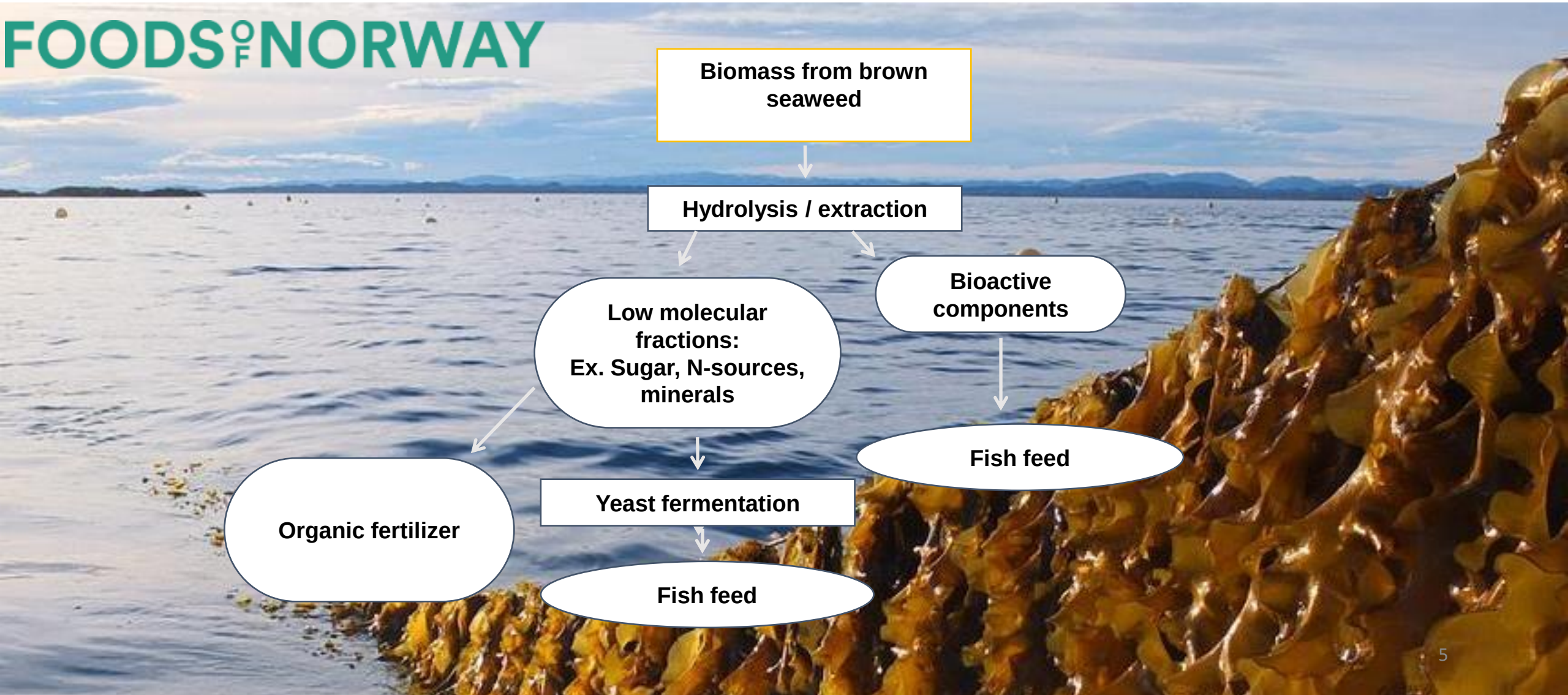
Margareth Øverland,* Liv T Mydland and Anders Skrede

Advantages:

- High biomass production
- Can be cultivated in sea water
- Don’t require any agricultural land, fertilizers, or fresh water
- Binds and recycles nutrients & binds CO_2



Biorefinery processing of seaweed



Co-fermentation of seaweed biomass and spruce trees

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY
Article
Cite This: J. Agric. Food Chem. 2018, 66, 8328−8335
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Microbial Protein Produced from Brown Seaweed and Spruce Wood as a Feed Ingredient

Sandeep Sharma,[†] Line D. Hansen,[†] Jon Ø. Hansen,[‡] Liv T. Mydland,[‡] Svein J. Horn,[†] Margareth Øverland,[‡] Vincent G. H. Eijsink,[†] and Kiira S. Vuoristo*[,†]

Biomass

Spruce trees

Brown seaweed, *Saccharina Latissima*

Brown Seaweed	Spruce wood
Composition	
• **Laminarin** • Mannitol • **Alginate** • Fucoidan • **Minerals** • **Amino acids**	• **Cellulose** • Hemicellulose • Lignin • Extractives
Enzymes	
• **Laminarinase** • β-glucosidases • **Alginate lyases**	• **β-glucanase** • **β-glucosidases** • Auxiliary enzymes

Yeast

Proof of concept:
Yeast grew well on this media

Source: Vaaje-Kolstad, Westereng et al., Science, 2010 ; Shrama, S. et al., 2019, J. of Agriccult & Food Chemistry; Hansen et al., 2022 Animals

Challenges in the aquaculture sector

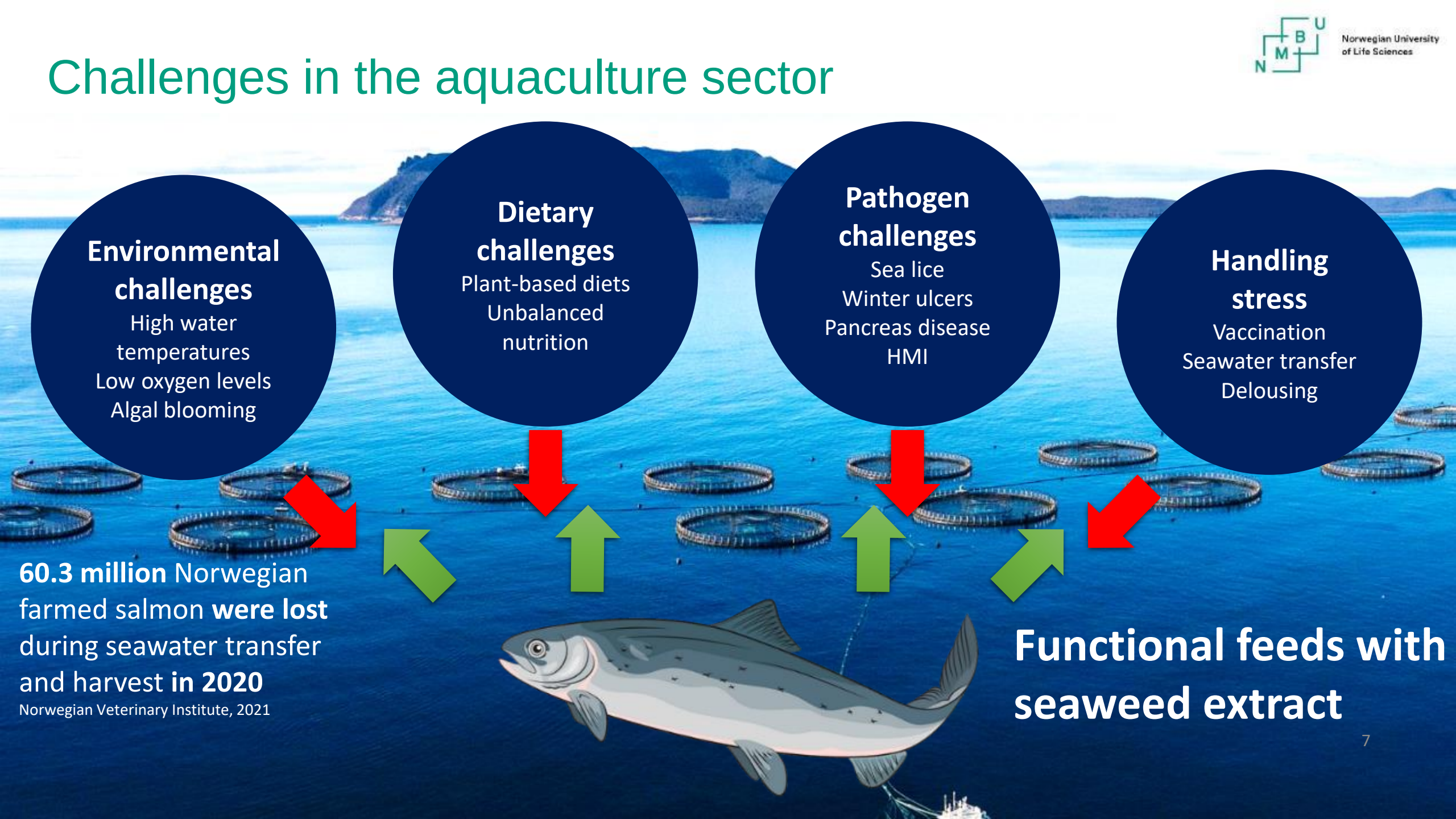
Norwegian University of Life Sciences

Environmental challenges
High water temperatures
Low oxygen levels
Algal blooming

Dietary challenges
Plant-based diets
Unbalanced nutrition

Pathogen challenges
Sea lice
Winter ulcers
Pancreas disease
HMI

Handling stress
Vaccination
Seawater transfer
Delousing

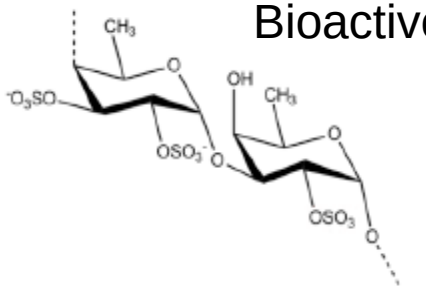


60.3 million Norwegian farmed salmon **were lost** during seawater transfer and harvest **in 2020**
Norwegian Veterinary Institute, 2021

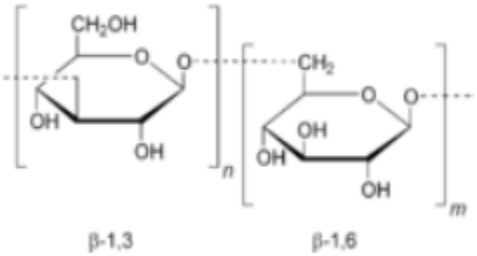
Functional feeds with seaweed extract

Brown seaweed in functional feeds as a feed resource

Bioactive compounds



Fucoidan (sulphated polysaccharide)



Laminaran (β-1,3/1,6-glucan)

Documented functions:

- **Fucoidan:**
  - Immunomodulating
  - Antithrombotic
  - Anticoagulant
  - Antiviral (anti-infectious)
  - Antibacterial / probiotic
  - Antitumor
  - Antioxidant
  - Anti-inflammatory

- **Laminarin:**
  - Immunomodulating
  - Antithrombotic
  - Anticoagulant
  - Antiviral (anti-infectious)
  - Antibacterial / probiotic
  - Antitumor
  - Antioxidan
  - Antiinflammatory

Extraction of bioactive components from seaweed: fucoidan and laminarin

Grinding

Acid extraction

- Polyfenols and alginate

Precipitation

Fractionation

- Filtration & precipitation of alginate

- Fractionation by stepwise filtration

- GEA membran filtration
- Spiral membranes with different MW-cut offs
  - >100 kDa – Fucoidan
  - <100 – 10 kDa - Laminarin

- Chromotografic analysis of sugar, mannitol, uronic acid, sulfer, and molecular weight distribution

- Purification of fucoidan with enzymes and alcohol

- In vitro screening to test bioactivity

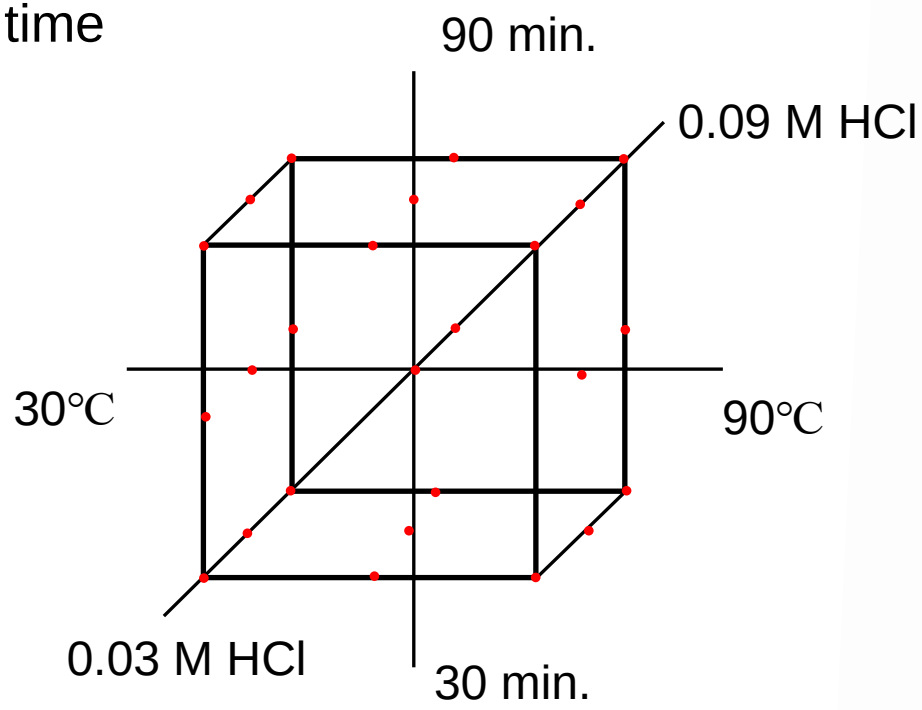
Source: Leszek Michalak et al., in progress ; Foods of Norway team

Extraction of laminarin and fucoidan from seaweed

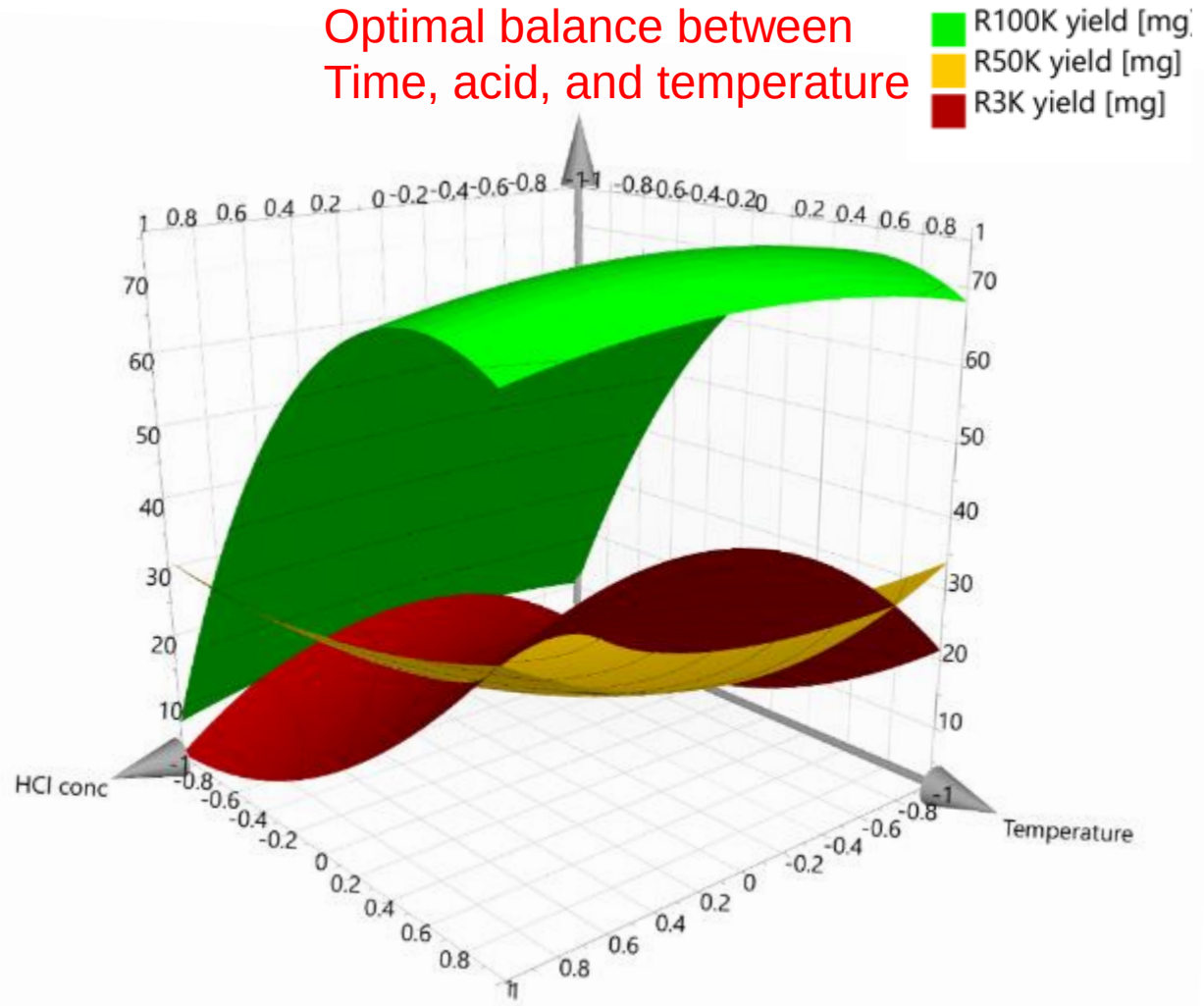
Factorial design:

30 combinations

- acid concentration,
- temperature,
- time



Optimal balance between
Time, acid, and temperature



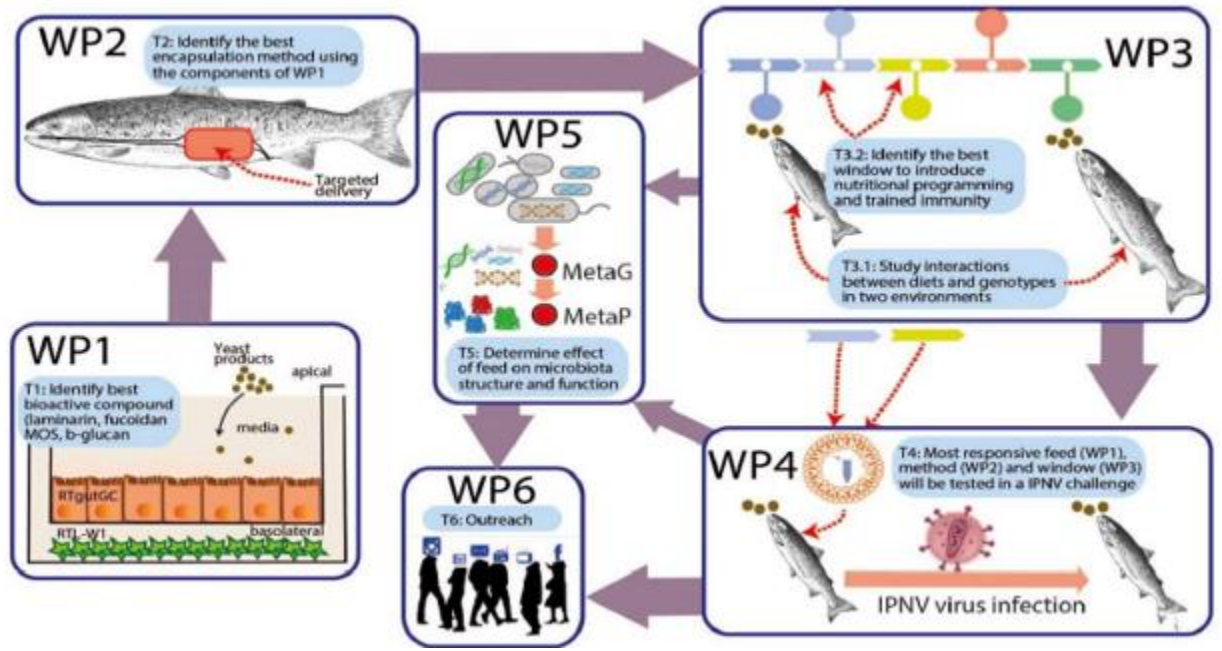
Source: Leszek Michalak et al., in progress ; Foods of Norway team

The RESILIENT SALMON project

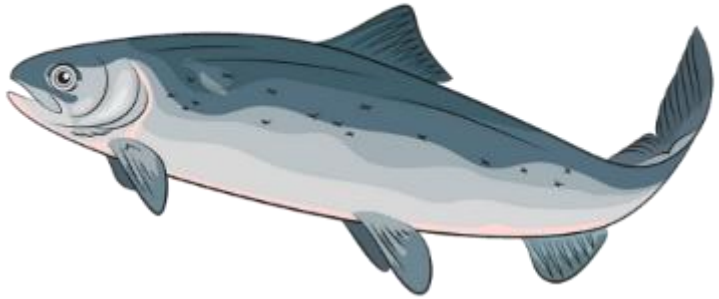
RESILIENT Salmon - **Trained immunity and nutritional programming for resilient salmon**

Finance: 10 Mill NOK ; Time frame: 2019 – 2023 ; Project lead: Prof. Margareth Øverland

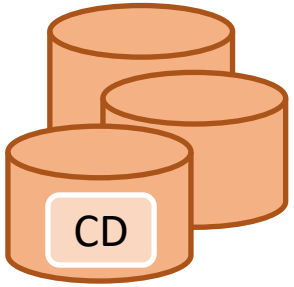
Partners:



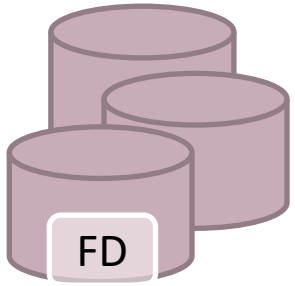
Fish trial with functional feed



Atlantic salmon
28g (pre-smolt)
Feeding period: 34 days



Control basal diet
Commercial-like diet
without functional feed components



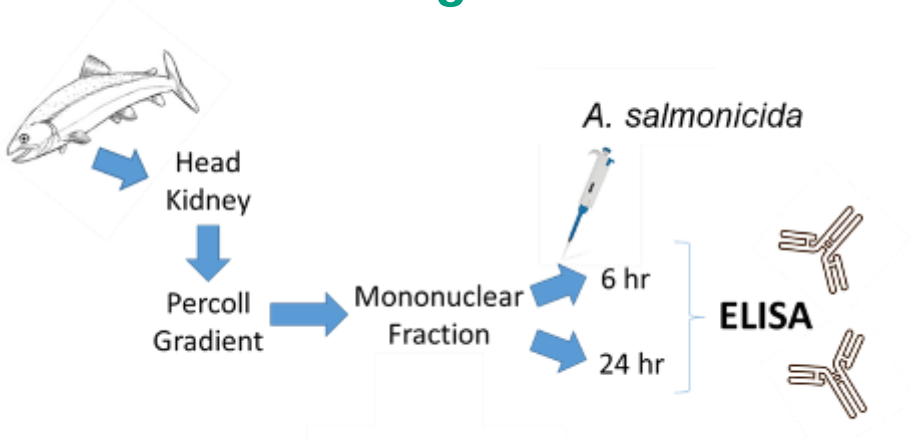
1, 2, 4 g/kg
(0.2%)
S. latissima fucoidan rich extract

Dietary Composition

Fishmeal	34 %
Soy protein concentrate	21 %
Fish Oil	16 %
Wheat gluten	8 %
Pre-gelatinized potato starch	12 %
Pre-mix	9%
Energy	22 Mj/kg

Immunomodulating effect of fucoidan in salmon head kidney

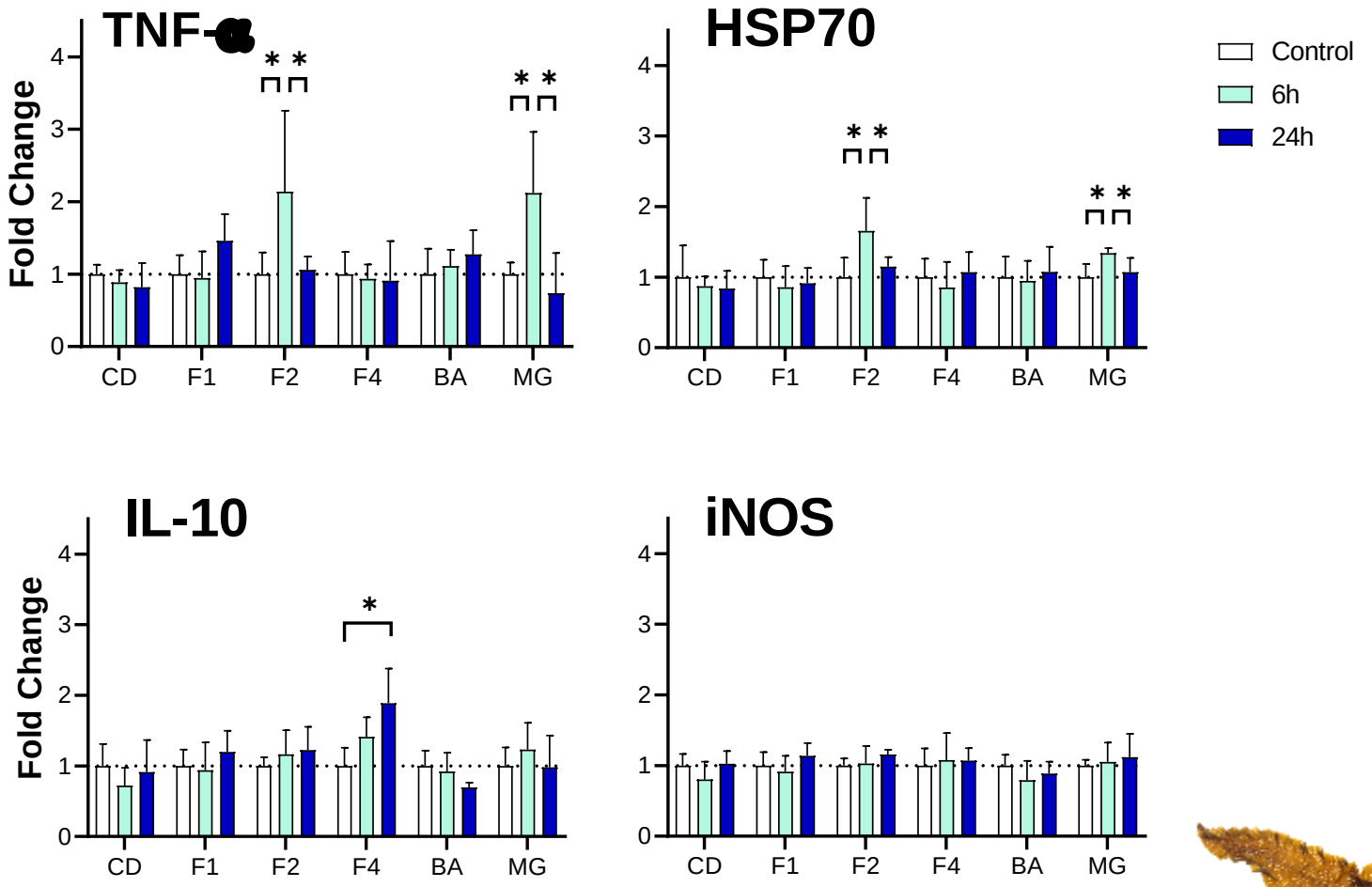
In vitro challenge with HK cells



- Protein production of selected immunobiomarkers by salmon antibodies and indirect ELISA

- Early immune activation with 2g Fuc (TNF- α after 6 h)

- Higher levels of 4g Fuc led to immune suppression (IL-10 after 24h)

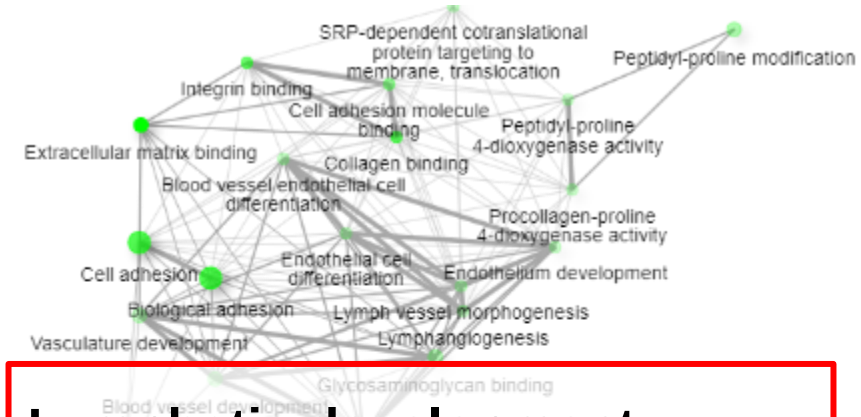


CD: control diet; **F1**: 1g fucoidan/kg; **F2**: 2g/kg; **F4** 4g/kg; **BA**: 2g other Brown Algae extract/kg; **MG**: 2g Macrogard/kg

Fucoidan from sugar kelp, RNAseq: Distal intestine

FD|CD

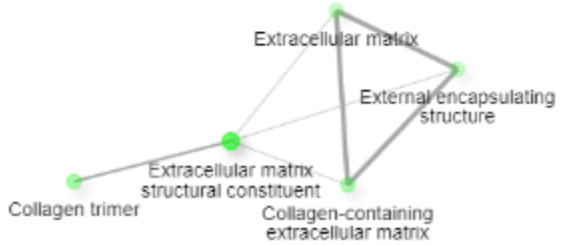
UP

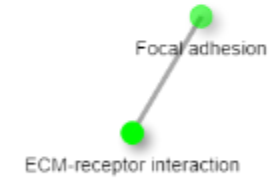


Lymphatic development

Modulation of lymphocytes

Activation of antigen presenting cells





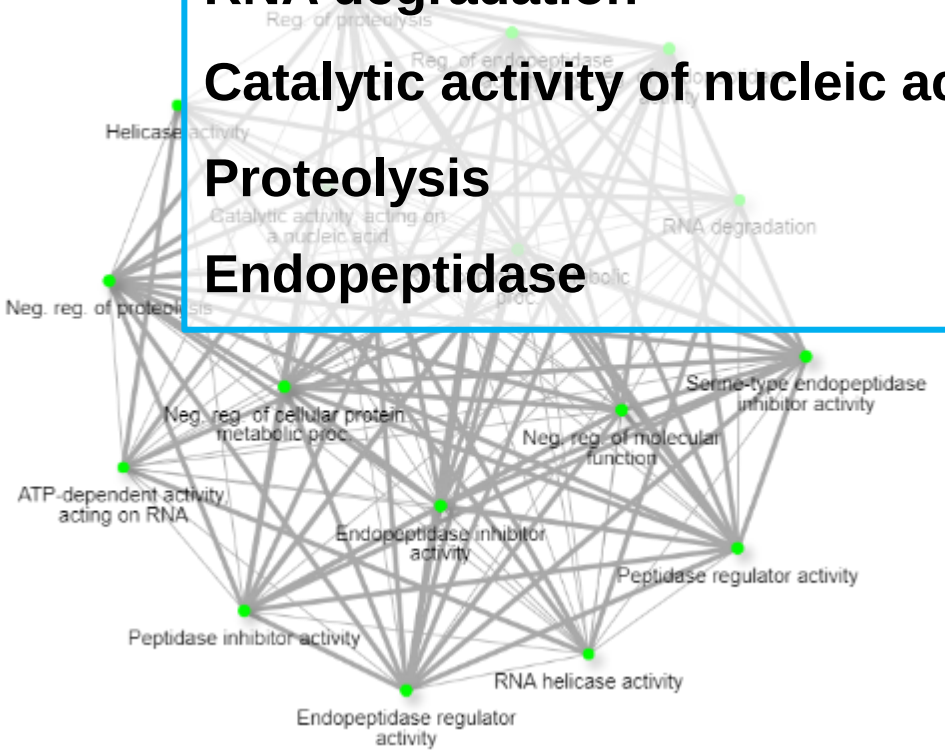
DOWN

RNA degradation

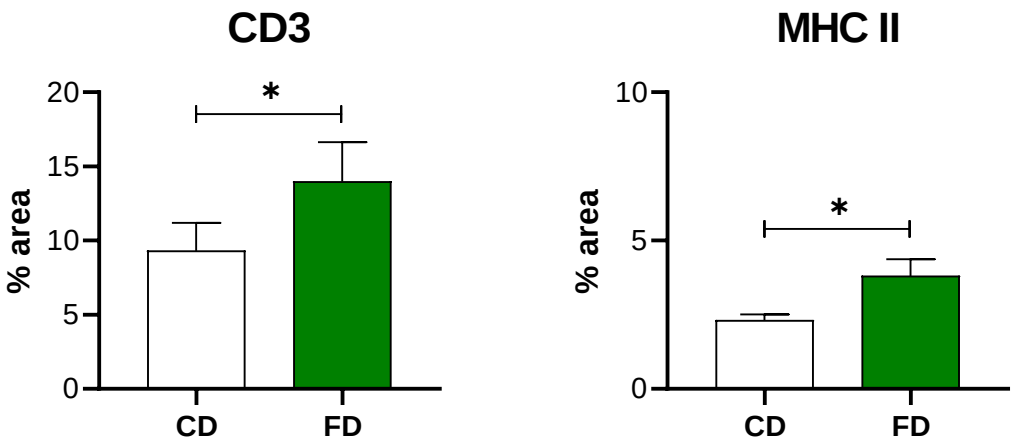
Catalytic activity of nucleic acids

Proteolysis

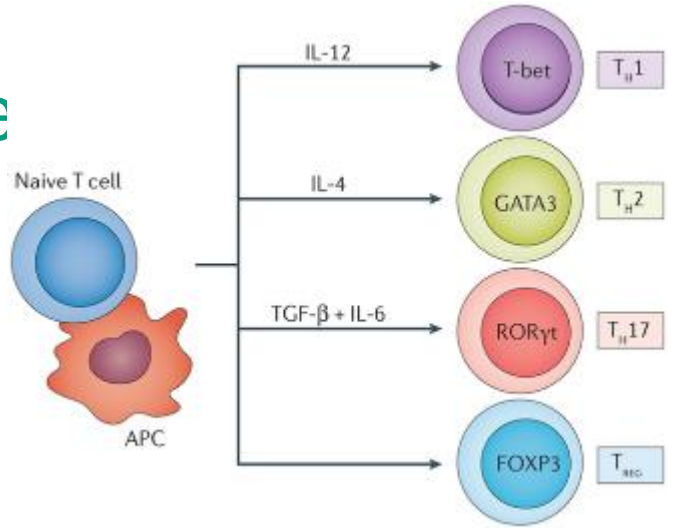
Endopeptidase



Fucoidan from sugar kelp, T-cell activation in distal intestine



Immunocytochemistry

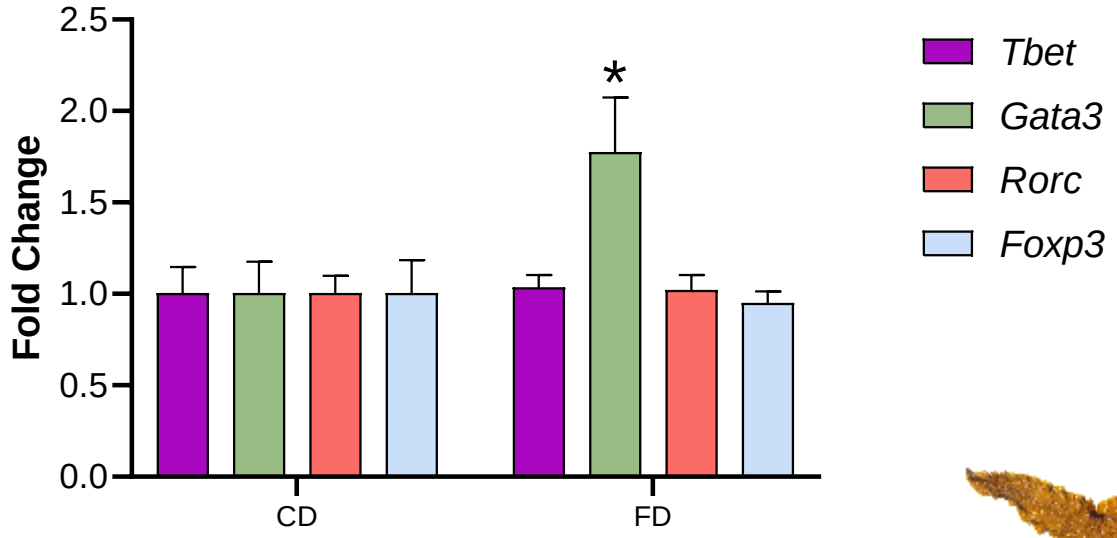


Meng et al., 2016

Directions T-cell activation

Tx Factors

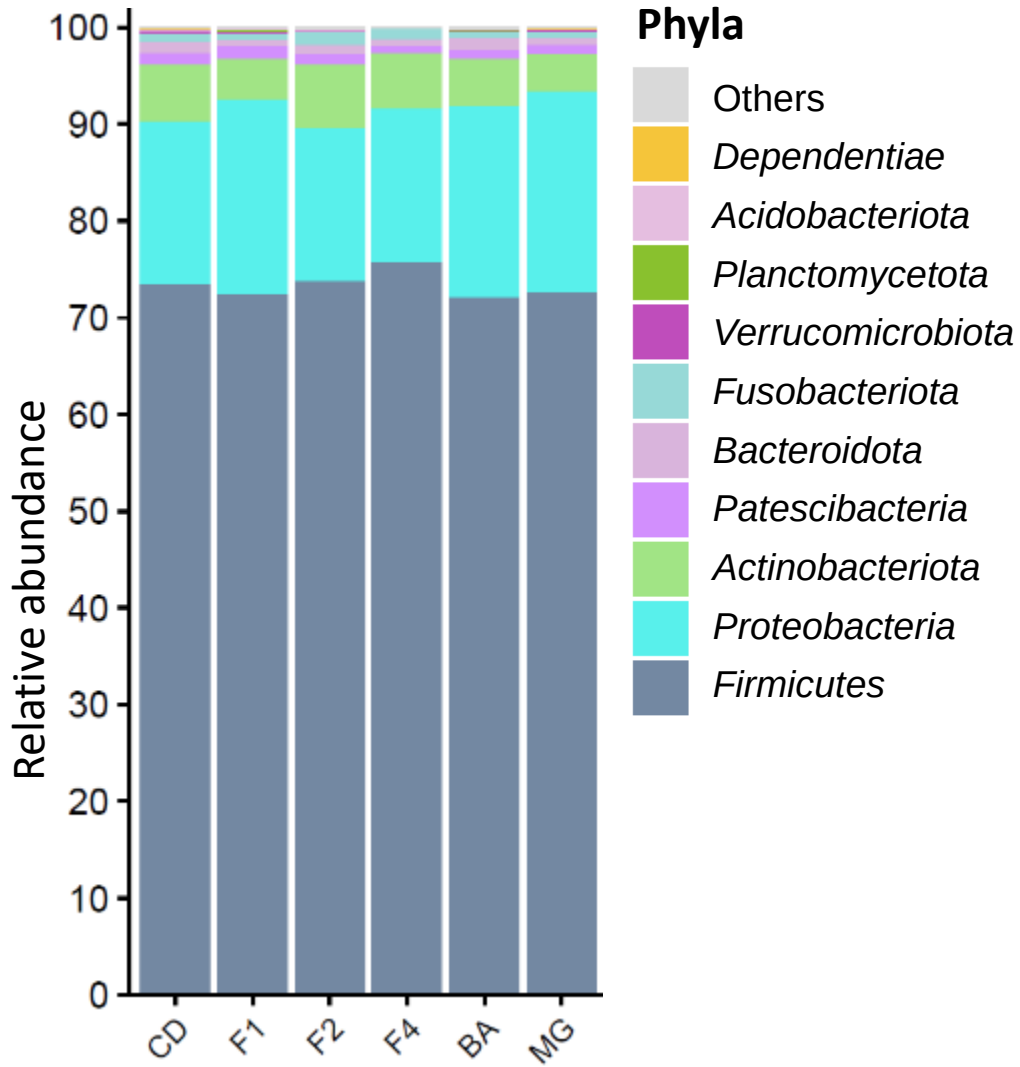
qPCR

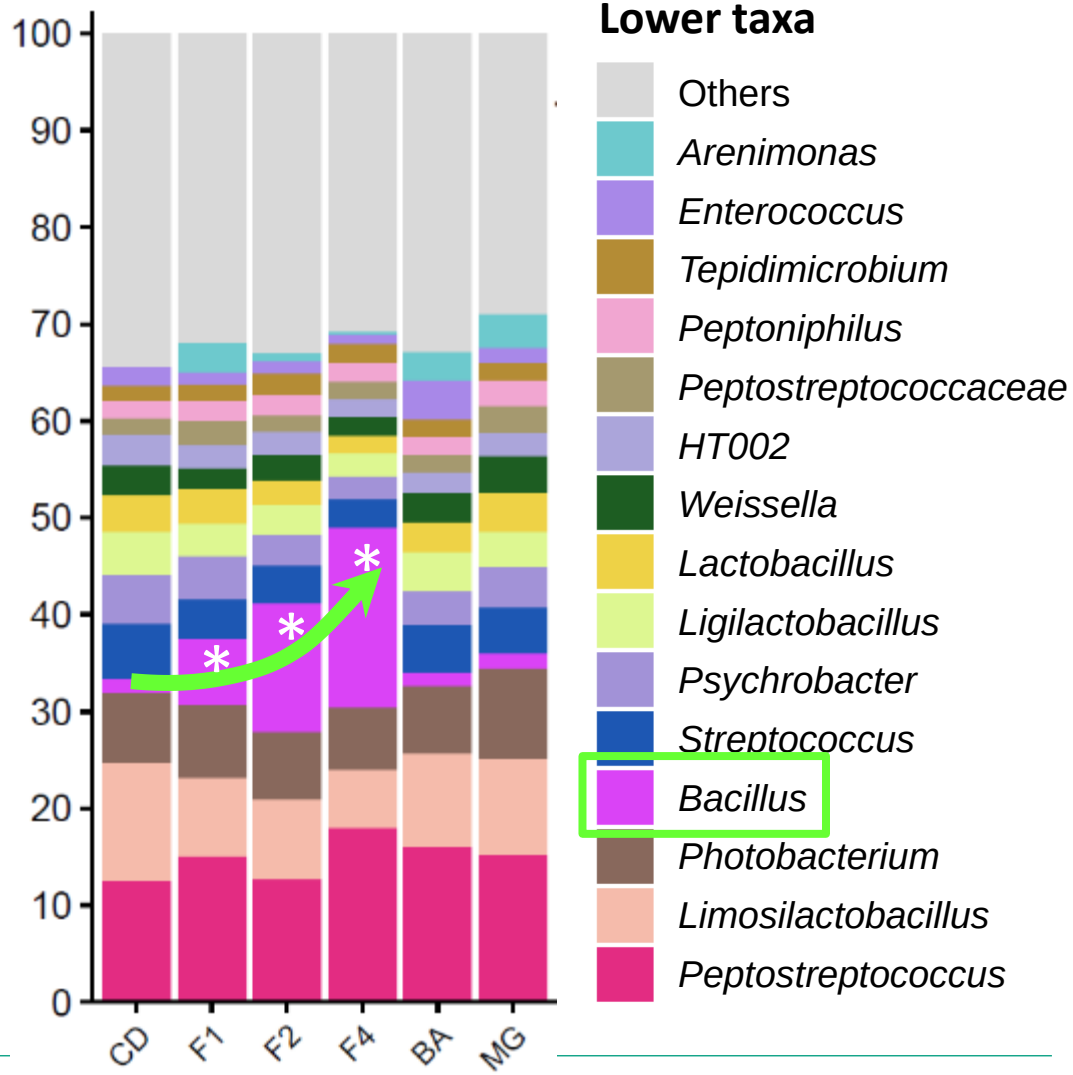


> Fucoidan resulted in T cell activation towards Th2 cells – adaptive immunity

Fucoidan from sugar kelp, gut microbiota in distal intestine

16S rRNA





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Foods of Norway & the Seaweed Biorefinery platform

Immunomodulating properties of fucoidan and laminarin in Atlantic salmon cells

Laminaria hyperborea-derived laminarin – immunomodulatory effects in Atlantic salmon cells

Ruth Montero[1§], Veronica F. Blihovde[1], Lele Fu[2], Leesa J. Klau[3], Olav A. Aarstad[3], Finn L. Aachmann[3], Anne Tøndervik[4], Håvard Sletta[4], Liv T Mydland[1], Margareth Øverland[1]

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NORD universitet

4th Congress of Fish and Shellfish Immunology

Modulatory properties of fucoidan fractions from Sugar kelp (*Saccharina latissima*) on the expression of immune-related biomarkers in Atlantic salmon head kidney cells

Byron Morales-Lange[1§], Leszek Michalak[1], Ruth Montero[1], Sergio Rocha[1], Liv Torunn Mydland[1], Margareth Øverland[1]

[1] *Department of Animal and Aquaculture Sciences, Faculty of Biosciences, Norwegian University of Life Sciences, Oluf Thesens vei 7, 1430 Ås, Norway.*

Seaweed storage

How can we best preserve the seaweed after harvest?
How will this affect the bioactivity of fucoidan?

- Organic acids
- Enzymes
- Lactic acid bacteria
- Other microbes

Chopped seaweed

Storage of vacum packed seaweed

Seaweed in diets for ruminants




Seaweed (Saccharina latissima) in diets for lamb

Feed production

Chopping

Sun drying

Frozen storage

Total mixed ration with grass silage, concentrate and seaweed

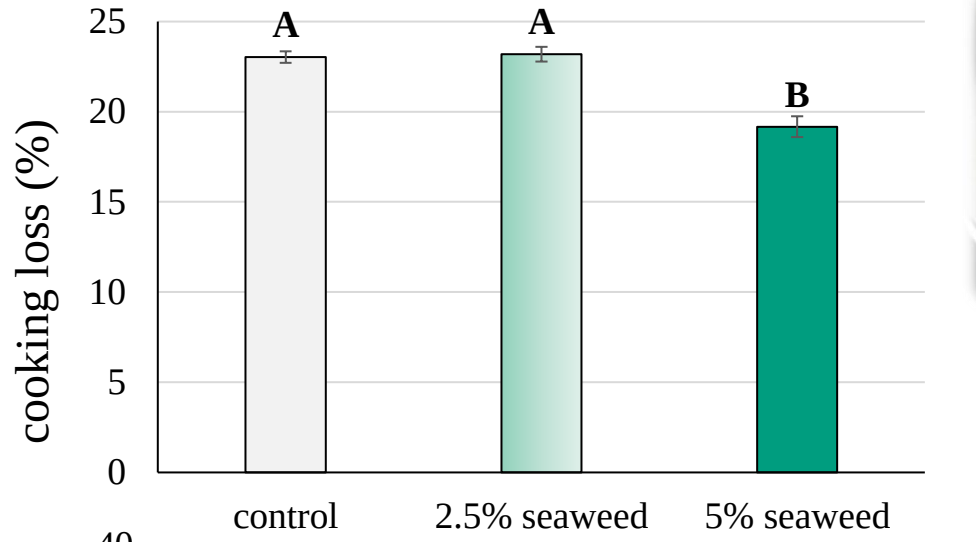
- ✓ Diets: Control, 2.5% and 5% sugar kelp
- ✓ Animals: 8 individually fed lamb per diet
- ✓ Duriation: 4 weeks
- ✓ Slaughther: Rudshøgda, Nortura

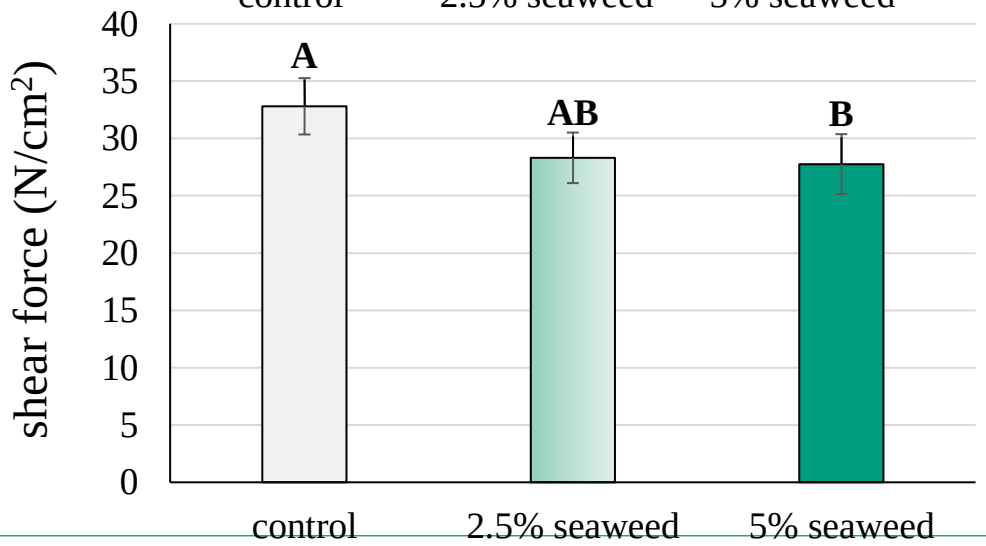
Results on growth performance and carcass quality

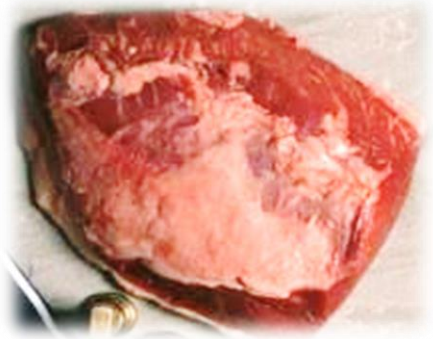
- ✓ No differences in feed intake or weigh gain
- ✓ No differences in carcass quality
  - carcass weight,
  - dressing%,
  - carcass meat and fat%

Effect of seaweed on cooking loss and tenderness in flatbeef 7 days chilled storage

Significance level (P<0.05)



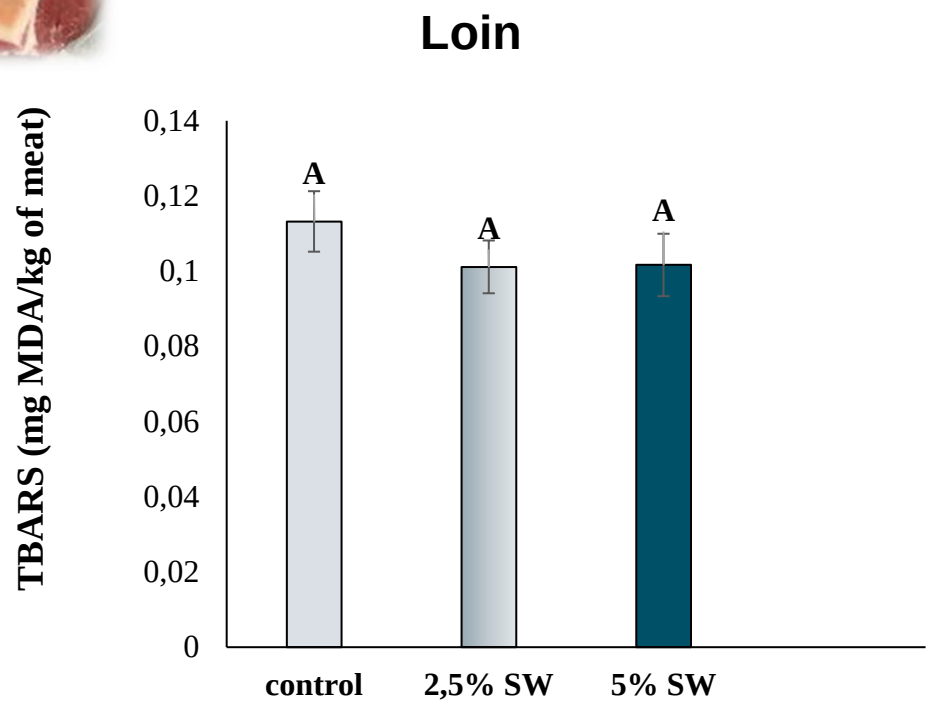


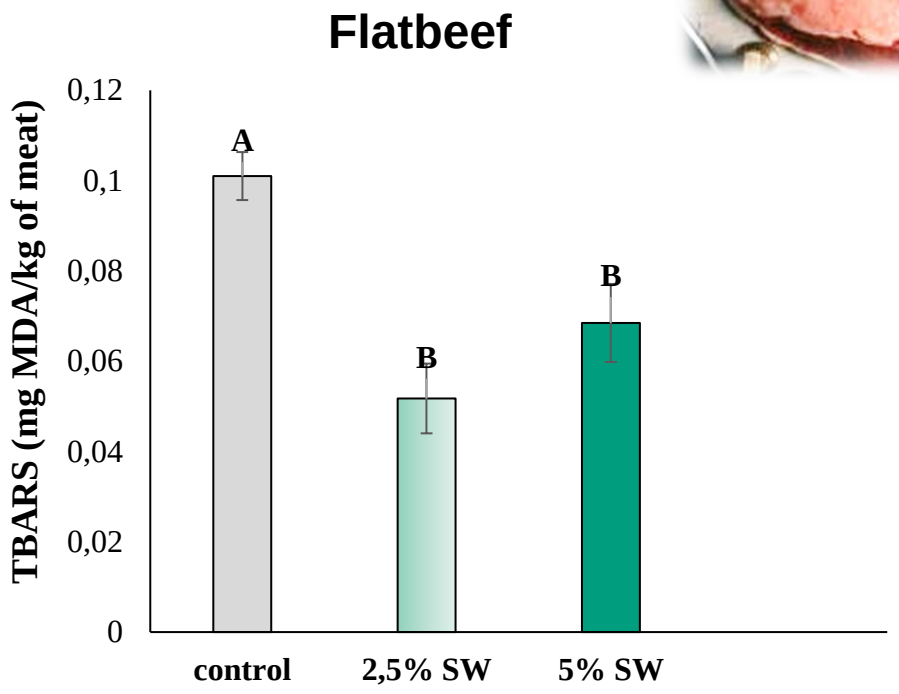


Grabež et al., 2022, paper in progress

Effect of seaweed on storage stability

TBARS, after 4 weeks storage

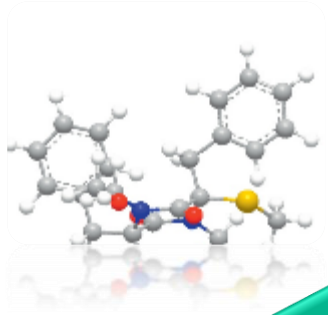




Consumer test

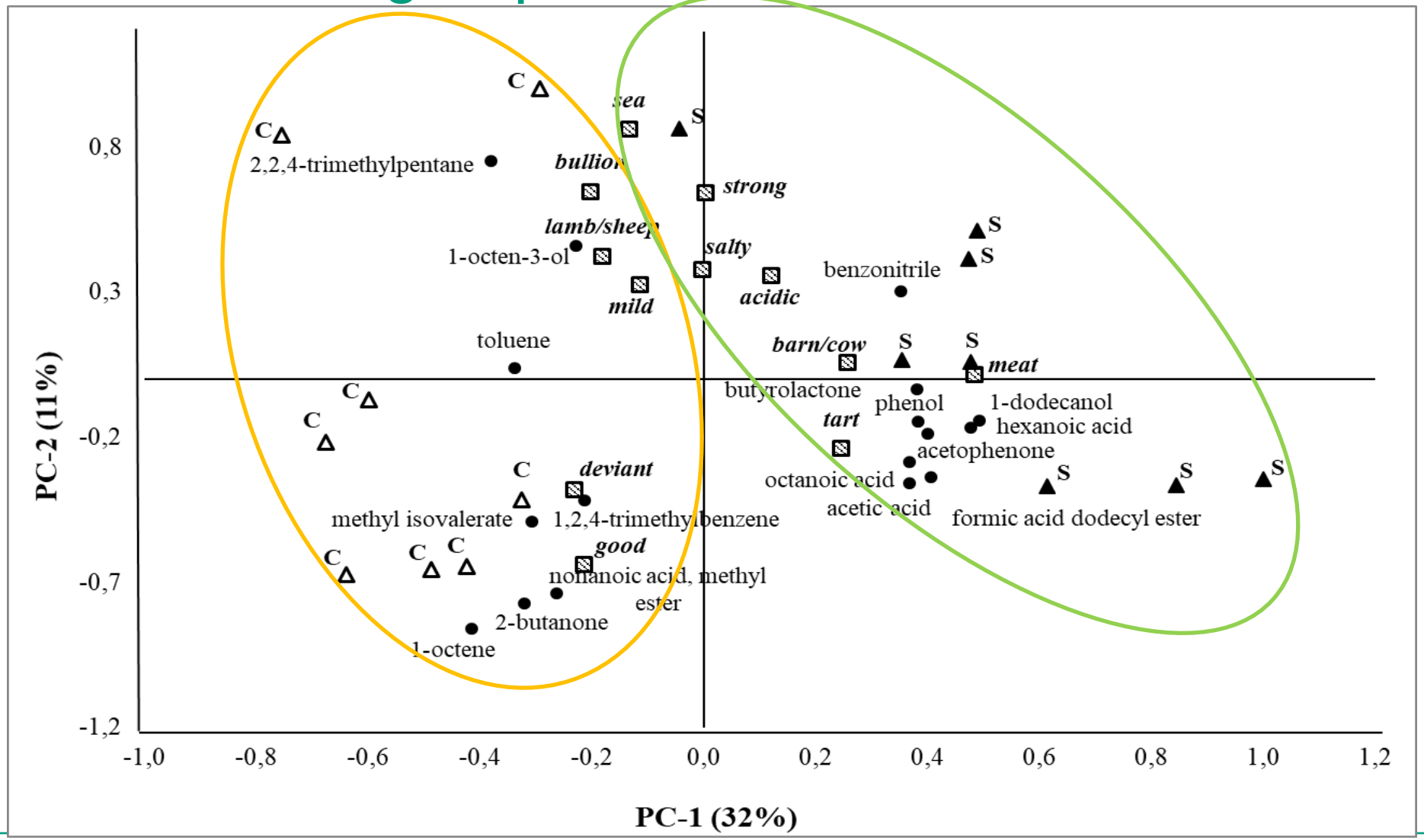
Volatiles and metabolite analysis of lamb

GC/MS-based method for (volatile) metabolite analysis	HPLC-QTOF method for metabolite analysis
	



To evaluate which molecular compounds are involved with the meat attributes

Consumer study and volatiles in the fat from control and 5% seaweed group

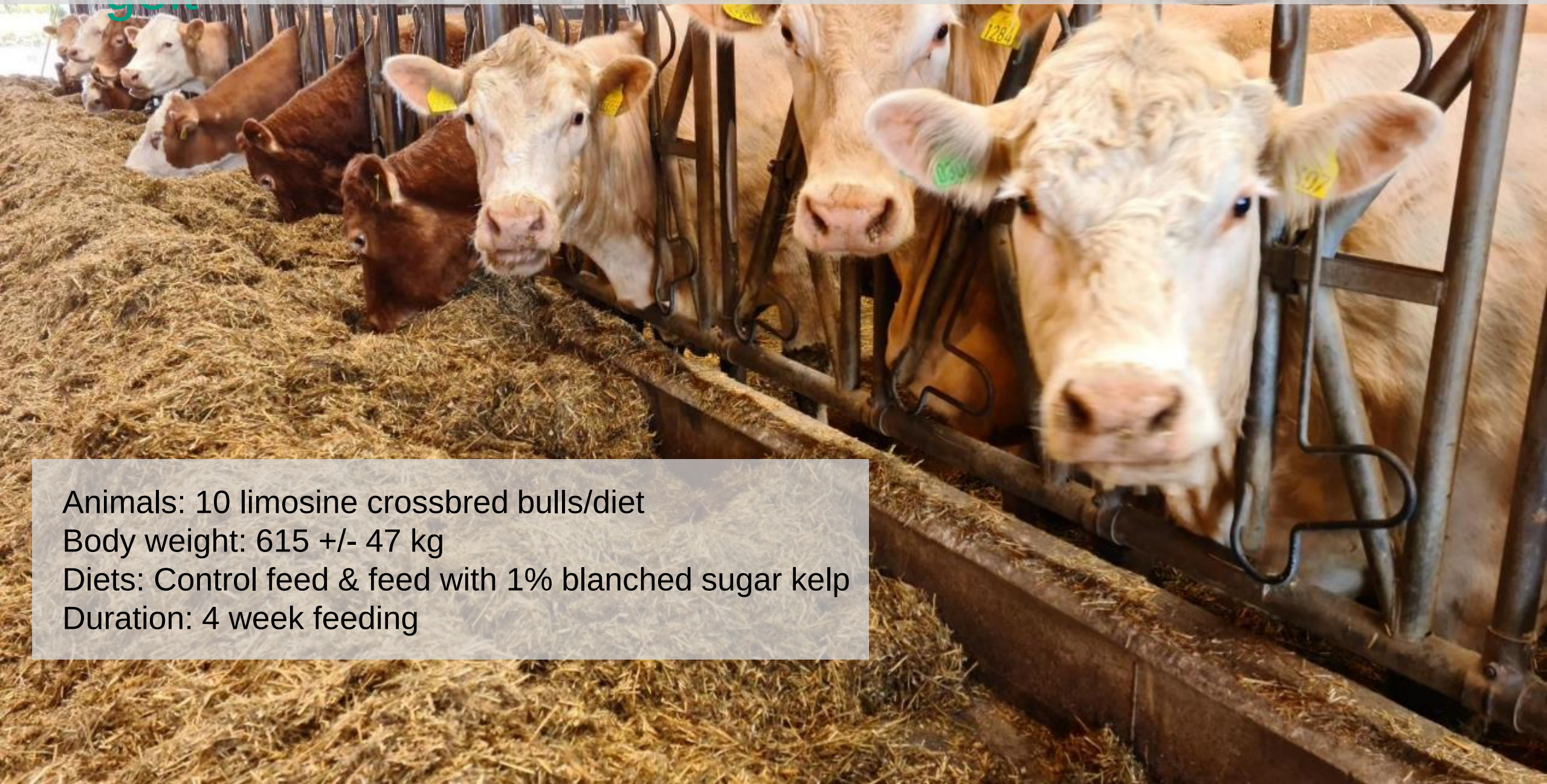


Seaweed in diets for lamb

- Juicier meat with increase tenderness
- Increased red color intensity
- Increased shelf life
- Unique herbal and salty taste
- Increased content of iodine (2.3-89 ug/100g) and selenium (13.9-15.6 ug/100g) and arsenic (0.23 – 1.54 – 3.09 ug/100g) in the meat

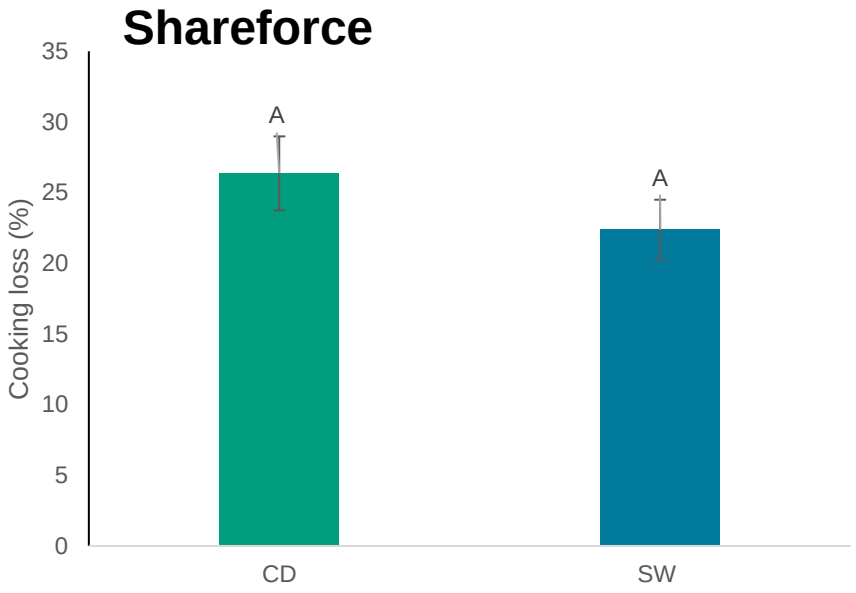
Source: Gabez´ et al., 2022

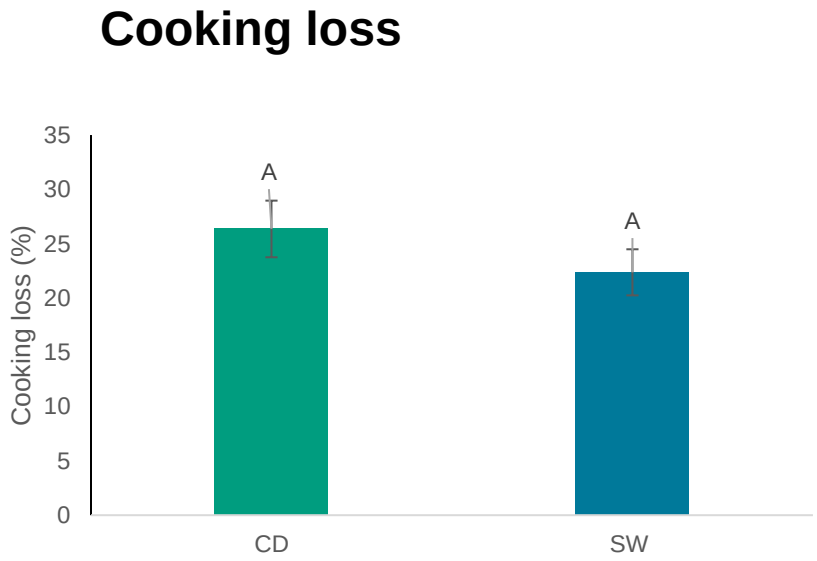
Seaweed *(Saccharina latissima)* in diets for beef cattle



Animals: 10 limosine crossbred bulls/diet
Body weight: 615 +/- 47 kg
Diets: Control feed & feed with 1% blanched sugar kelp
Duration: 4 week feeding

Effect of seaweed on tenderness and cooking loss,flatbiff





Se and iodine content in meat			
µg/100 g meat	Control	Seaweed	P-value
Selenium	17.8	18.87	< 0.001
Iodine	1.58	6.54	< 0.001

Source: Gabez´ et al., 2022

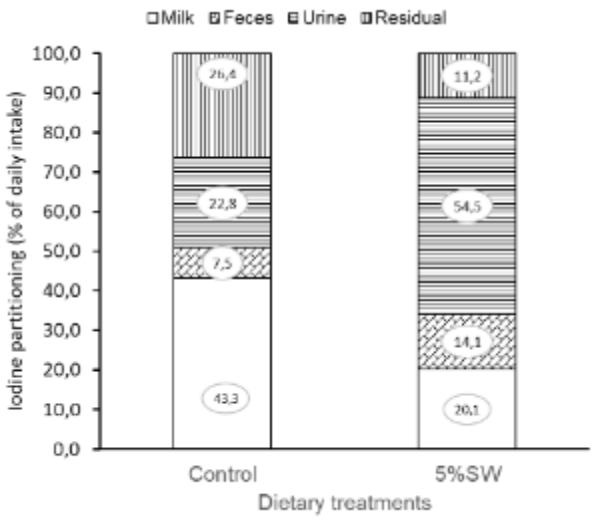
Seaweed *(Saccharina latissima)* in diets for dairy goats

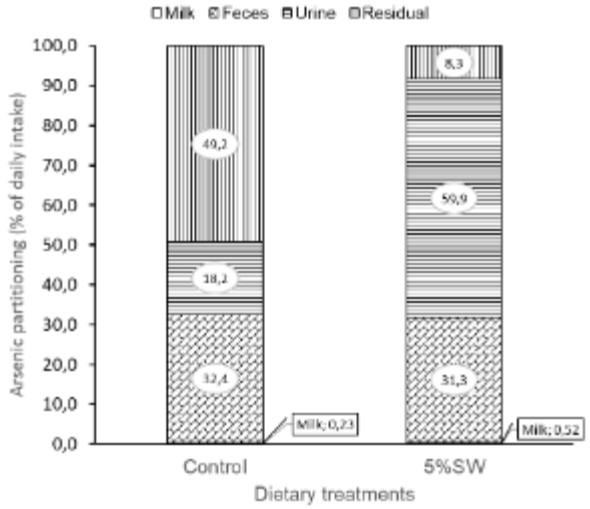
- ✓ Diets: Control, 5% sugar kelp
- ✓ Animals: 3 individually fed goats/diet
- ✓ Duration: Late lactation, ~3 weeks

Fremtidsfestivalen

Pilot study with 5% seaweed in diets for lactating goats

- Increased milk yield by 32% during late lactation
- Increased daily production of fat, protein and lactose (but reduced concentration in milk)
- Increased iodine content in milk from 40.4 to 73 mg/day
- < 1% of the arsenic intake was secreted in the milk





Source: Kidane et al. unpublished

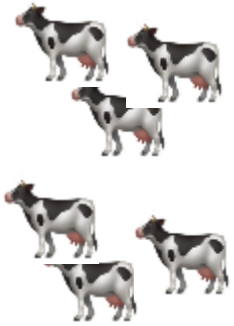
Seaweed *(Saccharina latissima)* in diets for dairy cows

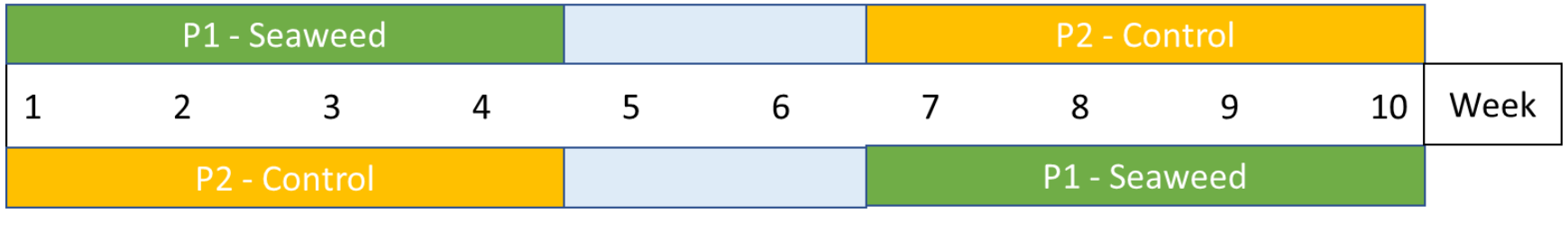
Seaweed in diets for high lactating dairy cows

Photos: Mary Ueland

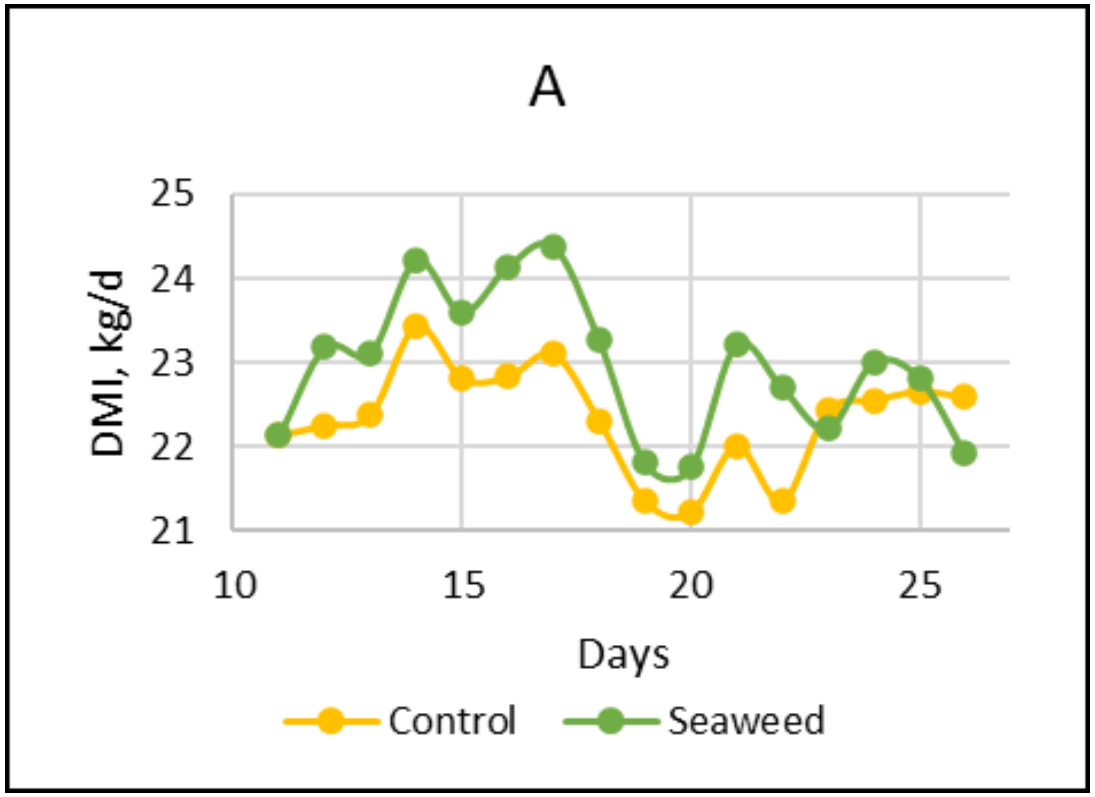
	Experimental diets[1]	
	CON	**SW**
Components, kg/ton TMR		
Grass silage	847	822
Concentrate	138	137
Sugar kelp	0	38
TMR-preservative[5]	3	3
Water[6]	12	0

Total mixed ration with 1% blanched sugar kelp
[6]Water added to reach the same DM content as the SW diet.





Feed intake, total mixed ration, g/kg DM



Feed intake			
Intake, kg/day	Control	Seaweed	P-value
Dry matter	22.3	23.0	< 0.01
Organic matter	20.6	21.1	< 0.01
Crude protein	3.4	3.6	< 0.001

Nutrient digestibility and rumen methane production:

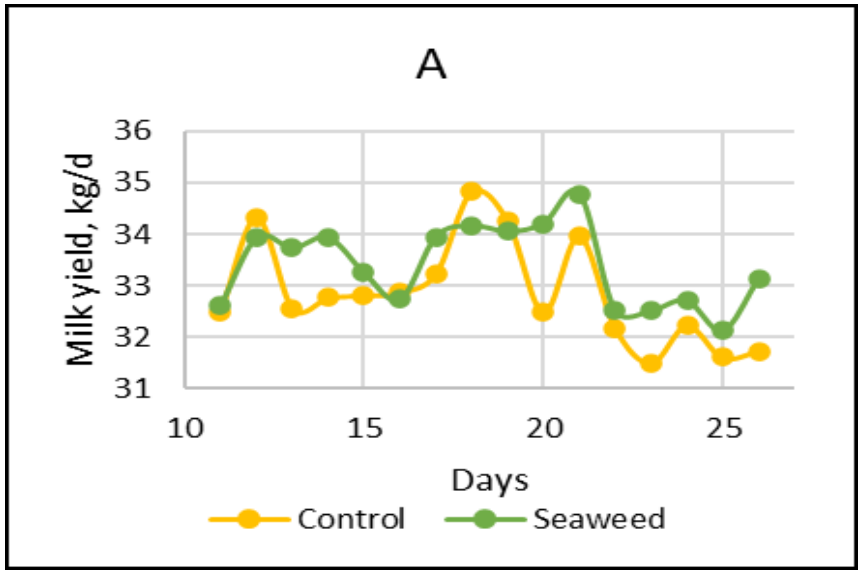
No differences in digestibility of dry matter, organic matter, fiber or protein

No differences in rumen fermentation parameters (pH, VFA, ammonium-N, methane)

Source: Ueland, MSc Thesis, 2022

Milk yield and composition

Milk yield and composition			
	Control	Seaweed	P-value
Production, kg/day			
Milk yield	32.9	33.4	< 0.05
Energy corrected milk yield	33.9	35.8	< 0.05
Composition			
Protein	3.47	3.48	NS
Fat	4.33	4.47	0.06
Lactose	4,80	4.78	NS



Sensory analysis of milk:

all samples were “normal with no adverse smell or taste.

Source: Ueland, MSc Thesis, 2022

Conclusions – seaweed hold promise as a feed resources

Seaweed extracts has a high potentials in functional aquafeeds
Low processed seaweed has high potential to improve meat quality and milk yield in dairy cows

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Seaweed Solution
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