FISH FEED INGREDIENTS AND FEED PRODUCTION

Aspects of future fish feed production in arctic area

Cross-border innovations in arctic aquaculture – ARCTAQUA

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Content

1. FOREWORD AND ACKNOWLEDGMENT

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2. INTRODUCTION

2.1. Global fish meal and oil industry

In 2050 the world population will be 34 percent higher than today, reaching 9.1 billion people (FAO, 2009). However, wild captured fish production will not be able meet the demand from an increased world population as the globe fish stocks are overfished or depleted (Olsen and Hasan, 2012; Waite et al., 2014). Globally, the expansion of the aquaculture sector has resulted in an increased demand for fishmeal. Declining catches in fisheries have resulted in increased prices on fish meal. Marine ingredients contributed to around 17 percent of the total animal protein supply (Waite et al., 2014).

The fish meal industry faces a complex situation where the demand from the aquaculture industry is increasing while the production is decreasing (Naylor et al., 2009). The world production of fish meal has reached its limit (Olsen and Hasan, 2012). Between 1998 and 2015 fish meal production has declined over 2 million tons representing one third of the global production. Moreover, the world annual catch is limited to around 90-92 million tons per year (Olsen and Hasan, 2012; Waite et al., 2014) shows that no increase in effort from the industry would increase the production of fishmeal.

2.2. Development of aquaculture in Nordic countries

Aquaculture activities need large sea and land area for fish production. Northern parts of Norway, Finland and Sweden are sparsely populated and have large sea, lake and land area available for fish farming and fish feed ingredient production. There is a strong and growing interest in developing aquaculture within the Kolarctic area.

According to the strategy of the Norwegian government (Røed and Henning, 2020), the aquaculture production in Norway will increase from 1,3 mill (2021) to 5 mill tons in 2050. Nordland county are among the largest producers in aquaculture, fisheries and fish industry in Norway. It also has the largest part (25%) of the Norwegian coastline admitting production of new species such as arctic char, halibut cod, haddock, and lumpsucker as well as increase the volume of salmon production the coming years. The feed cost in aquaculture is already relatively high. High prices and limited availability of high-quality fish feed, and 92%

of all fish feed ingredients were imported to Norway (Aas et al. 2022). A further reduction in feed ingredient availability and increased prices may hamper future development of aquaculture also in Nordic countries. In Norway, feed represent the highest part of the total production cost for cod (Heide, et al. 2022) and salmon https://www.fiskeridir.no/2021 around 41% of the total cost. The total production cost for cod was NOK 41,00 and for salmon NOK 40,15 (Heide, et al. 2022). Thus, high prices, less availability of local feed ingredients, issues of sustainability and environment may hamper future development of fish farming.

2.3. Alternative fish feed ingredients

The aquaculture industry is continuously on the search for new feed ingredients to maintain the flexibility in their formulations, and increase food and feed production. In the 1990s, herring and capelin were replaced by south American Anchovy and sand eel. Nevertheless, marine ingredients are being gradually replaced by other ingredients, mostly soy products. There are also many other alternative protein sources investigated for food and feed ingredients, such as insects seaweed, copepods, canola/rapeseed micro-algae and other microbes.

In Northern Europe/the Kolarctic area there are in particular large resources available, such as rest raw material from forest production, fisheries, fish farming and agriculture that, alone, in a mixture or via a vector e.g., insects could be used as an ingredient in fish feed. There is an increased interest in using insects not only as ingredient for fish feed, but also in feed for pets, pigs, and poultry. Many of these low-cost resources could be, directly or indirectly, used as insect feed in a circular economy model for further production of protein rich insect larvae for use in the fish feed industry.

Further growth of the Atlantic salmon production and diversification in new species for aquaculture will require a further increased inclusion rate of plant proteins and fats, and other alternative ingredients. Omega-3 HUFA is only available from marine resources and is potentially a limiting factor in further growth in aquaculture of new species such as arctic char, wolffish, trout, cod, halibut, and white fishes. Ingredients used as fish health promoters and growth enhancers will also be important in future feed production.

2.4. Demand of fish feed ingredients - future trends and challenges

There is a general trend that the large volumes of harvest of pelagic species used for fish meal and oil to the feed industry will be used for human consumption, i.e. products with potential for human consumption will not be used for fish feed. Accordingly, there will be an increased demand, competition and higher prices, especially on marine ingredients for fish feed from fisheries, which globally already has reached its maximum available volume.

Utilization of alternative ingredients will increase using insects, seaweed, rapeseed, barley, and high-quality proteins from blue mussel meal, microalgae, fungi, single cells and invertebrates. In some cases, waste organic material from horticulture, green houses, other agriculture products, rest raw materials of white fish from land and sea production, and aquaculture industry will be used as ingredients in new fish feed recipes. The present inclusion of non-marine fish feed ingredients, e.g. vegetal ingredients, may represent an upper limit, and future increase may reduce fish growth and make the fish more susceptible to diseases.

In Norway the salmon/trout producers used about 1.833450 tons (dry wt) fish feed, where 92% of the feed ingredients were imported (Aas et al. 2022).

The major challenges for the aquaculture industry are the low availability of national, high quality feed ingredients at a reasonable price. Fish meal and fish oil is a limited resource with limited possibilities for increased production in the future. One major task increase the national availability of high-quality fish feed ingredients, i.e., marine resources and land plants. Due to overfishing and low stocks of fish there will probably not be possible to increase the utilization of these resources.

Most of the feed ingredients, including fish and soy meal for feed production in aquaculture are available on the international market. However, in Nordic countries, large resources of hitherto unexploited ingredients from culture of low trophic organisms, and harvest of land and sea plants, may be available for processing into fish feed ingredients.

2.5. Tailor made feed

The profit in fish farming, especially in the stage of introducing new species in aquaculture, depends strongly on the availability of high-quality, cost-effective feed. I. e. the feed must be nutritious, provide healthy fish, good growth and development. Partial use of alternative fish feed ingredients, locally available, will increase the sustainability of aquaculture in Northern Europe. It may be possible to produce tailor made fish feed for new species and specialized feed for existing species and take a position in production of functional feed for delivery to customers in the region. High-tech products and tailor-made functional feed for fish have a huge potential in aquaculture.

Feed quality should maintain:

- good growth and feed conversion ratios, have a good digestibility and palatability, favorable levels of omega-3 fatty acids, and protein with a good amino acid profile.
- Low levels of anti-nutritional factors e.g. non-soluble carbohydrates, fibers, and heavy metals in feed, that may have an adverse effect on fish growth and development.

For new species in aquaculture volumes are often low during the first years. Low, or no availability of tailor made feed is may be an important challenge as many of the large fish feed factories do not produce low volumes of feed based on other recipes than those used for salmon. For the development of new marine species, as well as for the existing species on aquaculture, plants and animals collected lower in the feed chain may be very important as alternative feed ingredients.

A tailor made feed production may include specialized feed for:

1. New species at different stages, e.g. weaning feed.
2. Salmon, cod, wolffish, halibut and arctic char during juvenile stages and before stressful events.
3. Cleanerfish (lumpsucker, ballan wrasse and gold sinny wrasse).
4. Boosting PUFA content before slaughtering fish.
5. Brood stock of different species (Atlantic salmon, arctic char, Atlantic cod, Atlantic halibut, lumpsucker, gold sinny wrasse, and ballan wrasse).
6. feed to be used as carrier for treatment/medicines

2.6. National and local availability of feed ingredients

Side streams from fish processing may be used as novel ingredients in the development of tailor made feed as well as high priced functional feed for fish. This may increase utilization of by-products and waste of the fish processing in fisheries and aquaculture, add value to the industry production, and reduce dependency of import of plant raw materials such as soy. In general, fish products are low in calories and a very healthy food. New technology has made it possible to explore the therapeutic importance of fish-based diets on diseases, health and development. This is related to the fact that fish products, in addition to their high nutritional value, contain biochemical ingredients that may have bioactive properties.

Bioactive peptides have shown various biological activities including, antibacterial, anticoagulant, anti-inflammatory, and antioxidant activities, and may be a potential material for biomedical feed industries. Special products created from resources such as fish blood and testes may be high value ingredients for use in functional fish feed to strengthen fish stress resistance, reduce diseases, and improve growth and development. Marine protein and fat from by-products are favorable and may replace a significant volume of the existing feed products/ ingredients used for fish such as imported, and in many cases, not sustainable produced plant products.

Use of locally available raw materials as ingredients in aquaculture feed may contribute to a sustainable utilization of feed ingredient resources and as realizing the potential of a sustainable growth in aquaculture. Especially in northern parts of Norway there is a large potential of culture of plants and organisms. Further, for harvesting at low trophic levels amongst primary producers such as macroalgae, bacteria and phytoplankton, and further up in the food web, zooplankton e.g. krill and Calanus finmarchicus. Certain macroalgae has for a long time been used as an animal feed (Makkar et al. 2015; Broch et al. 2016). There is great interest in using macroalgae as a raw material to produce protein-rich feed (Øverland et al. 2014), and macro algae may also be a valuable source of antioxidants.

Alternative sources of protein and oil are necessary to reduce the dependency on meal and oil from soy and fish. Plant protein and oil has a dominant role as an alternative to fish oil and fish meal. During the last decades, plant sources such as soya and maize replaced much of the fish protein used in the feed. The marine ingredients is reduced, and about 60 % of the protein come from plants (Shepherd et al., 2017). Fish meal and soymeal are the two-main sources of protein in feed for salmon. The soybean has an important economic advantage as compared to fish meal and fish oil in fish feed production. When compared to fish oil and fish meal, soybean is very cheap.

2.7. Sustainability and footprint of aquaculture feed production

The present situation in fish feed production is characterized by environmental issues related to the large volumes of abroad production of feed ingredients, such as de-forestation, negative carbon and water footprints linked to soy production. The environmental footprints may be reduced if more of the feed ingredients were replaced by local and national feed ingredient resources**.**

The Northern part of Europe are known for its clean environment and high-quality food and feed products. Aquaculture businesses in this area may adopt the positive image of clean nature and low carbon and water footprint food products. Life cycle analysis (LCA) of salmonids through different production steps shows that the discharge of CO2 is much lower than production of meat from land animals (Philis, G. et al. 2019).

More than 90% of the footprint of aquaculture comes from feed issues. At farmgate the total green house gas (GHG) emissions related to feed production are close to 75% of all gas emissions in Norwegian salmon aquaculture. (Johansen, et al. 2022), indicating the necessity for changes in future.

Alternative feed should increase sustainability, i.e. reduce deforestation, give lower carbon and water footprint, increase use of other marine ingredient as an alternative to fish meal and oil. To improve sustainability, reduce carbon, water footprint and other negative environmental issues, feed should preferably be produced near location where it should be used.

Adopting the principles of circular economy and sustainability in feed and food production in aquaculture, will reduce environmental footprints and increase the market opportunities for cultured fish.

The present report on fish feed ingredients gives an overview on existing and alternatives to traditional fish meal and oil. The potential and availability of ingredients in the northern parts of the countries are emphasized, especially aiming at a reduction of imported ingredients, e.g., soy products. Increased access to alternative feed ingredients will open new possibilities for increased feed production in northern areas.

The aim of this report on feed ingredients and feed production is to address the status and potential of fish feed ingredients, and small-scale feed production. The focus is on innovative fish feed solutions for a competitive and sustainable aquaculture industry, especially focusing on available feed ingredients for use in the arctic area. As a major supplement and replacement of imported feed ingredients, increased availability of local feed ingredients, would strengthen the sustainability and image of aquaculture in Nordic countries. Many of these ingredients are not readily available as feed ingredients, but at are different levels of complexity as raw material. Several potential ingredients are under high focus for further development and will be available as feed/food ingredients the coming years.

3. POTENTIAL FISH FEED INGREDIENTS

Potential feed ingredients are presented in the following sections. I addition advantages and disadvantages of many alternative fish feed ingredients are listed in Table 1 (after Nagappan et al. (2021)). A more detailed description of selected ingredients are described after the table overviwew.

Table 1. Advantages and disadvantages of alternate fish feed ingredients (Nagappan et al.Kumar, et al. 2021). Full references are given in Nagappan et al., et al. 2021. Permission to use data are given by author prof. G. Kumar.

Guar meal

• Soy meal could be replaced with guar meal without affecting growth efficiency In some fishes.

• Anti-nutritional and anti-digestive compounds like Residual gum, saponin, phytate, and protease inhibitor tannin are present.

• Slow rate of gastrointestinal evacuation.

• Poor in amino acid digestibility.

• The supply of guar meal in the market is influenced by the oil industry's production and the amount of guar gum consumed. (Nidhina and Muthukumar, 2015; Ullah et al., 2016).

Macroalgae

• Apart from their nutritional value, macroalgae contain a variety of pigments, defensive compounds, and secondary metabolites that may benefit farmed fish.

• Complex polysaccharides leads to poor digestibility.

• Contains excess heavy metals.

• Presence of anti-nutritional factors like phlorotannins, lectins, and phytic acids, trypsin inhibitors and amylase inhibitors (Garcia-Vaquero and Hayes, 2016).

Soybean meal (SBM)

• High protein content ranging from 44% to 48%.

• Anti-nutritional factors like lectin and non– starch polysaccharides are present; reduced feed intake • Level of the amino acids like methionine, cystine lysine, and threonine and tyrosine are limited.

• Low in phosphorous (Goda et al., 2007; Zhou et al., 2018).

Canola meal

• High protein content • Low in phosphorous (Wickramasuriya et al., 2015).

Corn gluten meal

• Crude protein content ranging from 60% to 73%.

• Corn gluten meal is now commonly used in salmon and other aquatic fish such as gilthead seabream and European seabass and aquafeeds.

• highly digestible.

• Deficient in lysine (Liu et al., 2020; Wickramasuriya et al., 2015).

Cottonseed meal

• protein content of 40% can be used in aquaculture diets without causing growth inhibition.

• Presence of gossypol may be harmful (Delgado et al., 2021).

Peas/lupins

• High protein digestibility.

• Contain elevated amounts of non–starch polysaccharides lupins that are not metabolized.

• Anti–nutrient quinolizidine alkaloids are present.

• Lysine and methionine are scarce (Kokou and Fountoulaki, 2018)

Wheat

• Low in protein (70%).

• Lysine is a limiting amino acid. (Draganovic et al., 2013; Sørensen et al., 2011).

Barley

• Well digested • Low crude protein content (9–15%).

• High fibre content.

• Low available phosphorous.

• Lysine and arginine can be limiting; (Snow and Ghaly, 2007).

Hydrolysed feather meal

• protein content of hydrolyzed feather meal ranges from 74% to 91% crude protein, and it's high in cystine (4–5% crude protein).

• Less digestible.

• Low in lysine (2% of crude protein) and methionine (1% crude protein) (Grazziotin et al., 2008; Yu et al., 2020)

Poultry by-product meal

• High protein content • Deficient in methionine, lysine, and histidine (Laporte et al., 2009).

Blood meal

• High protein content.

• Rich in lysine • Deficient in methionine.

• Heat sensitivity and drying conditions have a significant impact on protein digestibility. (Aladetohun and Sogbesan, 2013; Hussain et al., 2011).

Fish by-products from fish processing plants

• High digestibility.

• Good palatability.

• Potential viruses and contaminants that are toxic to both fish may be present. (Hardy, 2000).

Insects

• Can be cultivated in food waste.

• Methionine and Cysteine were the most limiting amino acids for most insect meals.

• Chitin is present which is an anti nutritional factor (Bosch et al., 2014).

Bacteria

• Rapid growth rate.

• Least explored.

• Can be grown in variety of substrates.

• The bacterial meal diet has a lower digestibility than the fish meal diet and can contain unidentified antinutrients. (Skrede et al., 1998).

Yeast

• Can grow in lignocellulosic wastes.

• Except low methionine content, yeast protein has a favorable amino acid composition for fish.

• Rapid growth rate.

• Production cost is high.

• The sulfur-containing amino acids methionine and cysteine are usually low in yeast protein. (Blomqvist et al., 2018; Marques et al., 2004).

Microalgae and Algal oil

• Rapid growth rate.

• Diverse species availability with wide range of characteristics.

• Rich in Omega-3 fatty acids • High in antioxidants, colouring compounds and probiotic effect.

• High production cost in case of formulated feed.

• Selected microalgae have rigid cell wall leading to difficult in digestibility (Arun et al., 2020; Katiyar and Arora, 2020; Madeira et al., 2017).

4. BY-PRODUCTS FROM THE FISH INDUSTRY

Historically, by-products from the fish industry have a low value, or in many cases no value at all. During the last decades there has been a growing interest in utilization of these resources.

Raw materials of marine or land-based origin are combined with other ingredients in fish feed recipes.

In the fish industry, to a certain extent, rest raw materials such as liver, roe, stomachs, heads, backbones, cuts and rejected fish from processing are only partly used as raw materials for feed production. Additionally, large volumes of blood and nutritious process water from aquaculture slaughterhouses, as well as rest raw materials from on-board processing in fishing vessels are still dumped into the sea. A large share of by products in Norwegian fisheries and aquaculture has their origin in northern Norway (Myhre et al. 2020).

4.1. Side streams and rest raw materials from fish and aquaculture production

In white fish industry there are large volumes of fish rest raw material/side streams that may be available for further processing in fish feed. However, in many cases these resources may not be further used mostly because low cost technology and infrastructure to collect, and transform the raw material into fish feed ingredients are not developed.

The nutritional value from by-product meals differs from the traditional fish meal composed of whole small pelagic fish. Meal from side streams /rest raw material of white fish has a lower protein content and higher ash content than the traditional fish meal. Furthermore, meal of rest raw material from seafood processing may contain traces of PCBs and dioxins which can accumulate in farmed fish (Naylor et al., 2009).

62 638 tons of rest raw material can give rise to 1 503 tons of new fish feed in the two counties Troms og Nordland (Fiskeridirektoratet 2017). This shows that there are still large volumes of side streams that are not utilized.

By-products products of fish production may include blood, heads, eyes, tongues, livers, testes, roe, cut-offs, skin, bones, backs, guts, and swim bladder. Currently, some of the by-products that is being utilized are conserved by ensilage and processed for further use as gross animal feed ingredients where the value creation is relatively low. Nevertheless, the level of utilization of raw materials may be increased, and more advanced products developed, and contribute to value creation in the fisheries and aquaculture industry.

4.2. Categories of by-products

According to the Norwegian Seafood Research Fund – FHF (Fiskeri og havbruksnæringens forskningsfond) the specific definitions may be used for the different raw material basis and should apply to wild and farmed fish, shellfish, and mollusks harvested in Norwegian waters, or processed in Norway.

The by-products are divided into groups depending on origin and on further processing. By-products may be processed according to specific hygienic rules and regulations and may then be used for human consumption and/or feed for animals. Products according to the by-product regulations (e.g. ensilage, transport without refrigeration to fish meals factory etc.) is termed a by-product. By-products are divided into category II and category III. By-products shall not be used for human consumption.

4.3. Total raw material and by-products in Norway

In the present study, public available statistics are used to provide an overview of the fish industry and aquaculture in Norway, where the main sources are the Directorate of Fisheries – www.fiskeridir.no/statistikk/akvakultur, Statistisk Sentral Byrå (SSB), Analyse av marint restråstoff 2019 by Myhre et al. (2020). The Norwegian Sea food industry (2019) produces more than 964.400 tons of by-products, of this 812000 tons was utilized (Table 2).

By-products from aquaculture and fisheries constitute an important value-added resource in Norway. A large proportion of this material is utilized. In salmon production (93%) and in herring (100%) processing, most of the by-products is utilized, whereas in other fish industry (ex. herring) only 61% is utilized (see Table 2). According to Myhre et al. (2020), of the total by product volume, a rest of 152400 tons is potentially available for different applications, e.g., fish feed ingredient production.

Total raw material, rest raw material/by products and utilization in 2019 in different sectors in Norway is shown in Table 2 (Myhre et al. 2020). Landings of small volumes of other species are included.

4.4. Overview of Norwegian seafood industry

Table 2. Total raw material (fish and shellfish) and by-products/waste after processing, and percentages of utilization listed by species in 2019 in Norway. Numbers are given in tons x1000 (after Myhre et al. 2020).

	Aquaculture Salmon and trout	Pelagic, herring, capelin, mackerel	White fish, cod, saithe, haddock	Shellfish	Total
Total fish (tons)	1 543	1268	683	52	3066
By-products available (tons)	458	194	297	14,8	964
By-products in % of Total fish	30	15	44	28	27
By-products utilized (tons)	429	194	181	7,6	812
By-products utilized (%) by sector	93	100	61	51	84
Not used by-products	**29***	**0**	**116**	**7,2**	**152,5**

*Mostly fish blood at slaughter houses.

In excess of 116.000 tons of by products from the white fish sector is not utilized. This is partly related to lack of efforts in developing new methods and technological solutions on board the vessels for handling by-products/side streams. However, also low prices of by-products may explain the low interest amongst fishermen to bring this ashore. In the aquaculture sector, most of the by-products are utilized, except for the fish blood which are treated as part of the process water from the salmon slaughterhouses.

According to Myhre et al. (2020), by-products from the Norwegian white fish industry is around 296670 tons and distributed on different material such as heads (36%), guts (18%), liver (16%), roe and testes (12%), backs and cut-offs (18%). The potential for increasing the utilization rate and value creation on by-products is large. This is especially true for by-products that has a very low utilization, e.g. fish blood and testes. Different sources of material from fish production may be processed to high value feed ingredient products;

1. Salmon blood from slaughterhouses in aquaculture
2. Testes from fish industry (cod fishery and herring) in Norway.
3. Cut offs, backbones, heads, skin etc.

In 2019, 36719 tons of rest raw material was used in fur bearing animal production (Myhre et al. 2020). A large volum of this may be available for other feed production e.g., fish feed when production of fur bearing animals are terminated in many EU countries and in Norway (2025).

4.5. Fish blood

Like blood from warm-blooded animals, blood from fish may be a valuable product in future. If it is possible to separated plasma from red blood cells, the salmon blood may be used in different, more advanced fish products, whereas the red phase may be used as an iron enrichment in dietary supplements. In Norway, there are large slaughterhouses for farmed fish, mainly salmonids. In salmon and trout, blood is around 3.5 and 4.0% (of live weight) of the fish. This may be made available, and an interesting raw material for further processing and development. However, with the present slaughtering/bleeding technology, it is only possible collect up to 2 % of the fish's weight as blood.

With an annual production of farmed fish in Norway of 1411700 tons (2019), about 30200 tons (2%) of salmon blood may be available. Salmon blood contains approximately 10 - 12,5% protein and 0,8% fat with a high content of omega-3 fatty acids (Kjølås, F.H. and Storrø 2005). Blood plasma separated from salmon blood coagulate rather quickly after bleeding. Separated blood plasma of salmon blood gives weaker gels by heating compared with plasma from warm-blooded animals, however the red phase is forming strong gels.

Previous projects have reported large difficulties in collecting and drying fish blood as properties of fish blood was very different as compared to blood of warm blooded animals. Vital Marine, in collaboration with Marine Harvest and Core Competence, did not manage to separate blood plasma and hemoglobin in salmon blood and concluded that utilization of salmon blood must be based on gently dried whole blood (RUBIN-report 151, 188). Large scale separation of salmon blood in plasma and red phase have not been conducted, and methods for collection and separation of blood components are not developed. Thus, plasma and hemoglobin products of salmon, have not been tested by the feed/food industry.

4.5.1. Methods for collecting fish blood

There are two possible ways to approach the problem of collecting fish blood at slaughter houses, namely “dry bleeding” during bleeding and slaughtering of the fish, or by separating fish blood component from the process water after the bleeding. However, the latter may impose several problems related to different types of “pollution” of the process water, e.g. salt, fish faces and fish scales. When using a dry bleeding method at the slaughterhouses, it is possible to collect the blood of salmon during slaughtering. Blood of whitefish from fishery are also a potential raw material, but it would be a difficult task to find methods and equipment for this purpose. However, future prizes on this resource may be incentives to develop methods and equipment that will make it economically feasible to collect blood from wild caught fish.

The collection and processing of salmon blood is a complex task as the blood coagulates even at low temperatures. Addition of an anticoagulant solution to the blood immediately after bleeding may prevent this. The blood can then be fixated or separated in plasma and blood cells, for example by using membrane technology, centrifugation equipment, drying, or freezing the blood/plasma within coagulation starts. The coagulation time may be increased by lowering the temperature of the fish. This will extend the time allowed for bleeding and improve the efficacy of bleeding, especially in the summer months with higher seawater temperatures. Trials have shown that under temperature near 0ºC, the blood will coagulate within approximately 33 minutes, while at 10ºC the blood will coagulate within 10 minutes (Tobiassen et al. 2015). A somewhat longer time before coagulation of blood during slaughtering process was reported by Olsen et al. (2006), with up to ca 60 minutes at temperatures close to zero.

A Norwegian company, SeaSide AS, 6200 Stranda, has developed a salmon slaughter production line based on dry bleeding and individual handling of each salmon during the bleeding process. During the bleeding the fish is positioned head down, and the bled blood is pumped to a separate tank. Minimum bleeding-time is set to 4 minutes. This system may be a possibility for a profitable collection of fish blood from fish slaughterhouses.

Pre-treatment according to protocol, cooling and storing under controlled environment is very important. For fish blood, it is very important that coagulation is avoided after slaughtering. Chilling the fish before slaughtering and maintain very low temperature after the fish is bled will probably improve the fish fillet quality, increase the bleeding and postpone the coagulation time up to one hour (Olsen op sit. 2006). Future work have to focus on developing technology at traditional salmon/trout slaughter houses to facilitate collection of fish blood, avoid coagulation, and to separate plasma and blood cells.

4.6. Cod testes

Cod testes contains several interesting components, such as DNA/nucleotides, phospholipids and positive nuclear proteins. Proteins from cod testes may stimulate the immune system and may represent a large value as functional fish feed ingredient (Khora, 2013). Nucleotides are the building blocks in DNA and are used in the pharmaceutical industry and may be a valuable feed ingredient (Fehringer et al. 2014). Phospholipids in cod testes contain high amounts of the polyunsaturated fatty acids, DHA, and EPA.

Nuclear proteins are bound to DNA in the nucleus and have a particularly high percentage of positive amino acids. As there is an increase in use of land plant ingredients in fish feed the content of particularly two essential amino acids, taurine and arginine is very low. Rhus, this has made the amino acid profile of today's commercial diets less favorable compared to diets based on fish products. These amino acids are abundant in marine fish testes and make testes an even more valuable ingredient in new feed products. These amino acids should be included in fish feed to enhance fish health and growth.

4.7. Cut offs, backbones, heads, skin form the white fish industry

Meal from these ingredients is nutritious but contain relatively high levels of ash/calcium. Much of this are being used as feed ingredients in feed for furbearing animals.

4.8. Protein processing

Different methods for use in separation of functional feed/food ingredients should be further explored, for example membrane technology, hydrolysis and other extraction methods and processes for protein isolation. A method developed by Kristinsson and presented by Hultin et al. (2005) that have shown that fish proteins can be solved at very high or low pH values. The high or low pH value gives the protein a powerful charge and causes disintegration. Based on this, the fat content is less, and results in better oxidative stability and less odour in the end products. A further advantage is that unwanted items such as bones, microorganisms, cholesterol, and membrane lipids (phospholipids) are removed by the first centrifugation. This is a promising method for processing and isolating valuable materials and ingredients of both cold-and warm-water fishes (Geirsdottir 2005). Whether this method could be modified for use in utilization of testes and fish blood is not presently known but may be elucidated in a future project.

Ongoing developmental work aims to stabilize the proteins from changes in functional properties as well as to find economic/effective ways to stabilize the protein to avoid oxidation changes during processing and in the end product. However, protein isolates based on fish by products is a relatively new product and applications are under development.

The high content of phospholipids in many marine organisms has received great attention in the recent years. For example, BioSea Management AS, Tromsø has patented a technology to manufacture marine phospholipids from marine products. Eximo AS, Tromsø, is manufacturing marine phospholipids for own use in special feed products, PhosphoNorse and AgloNorse Extra.

4.9. Applications of fish rest raw materials

Development during early stages and weaning is a very critical period during the early life of many fish species. During this time the digestive and immune system is immature. Often a combination of environmental influences and inferior quality of the feed make the larvae more susceptible to diseases during early development and weaning. In many cases, the absorption of energy and nutrients tends to be low. This may increase the stress level, affect the immune system negatively, reduce growth, and have large impact on general development in juveniles. The feed for fish larvae and juveniles should contribute to normal development and increased growth in early life stages.

There are certain restrictions using ingredients of by-product from processing of fish where side streams from this species may not be used in feed for the same species. Further, heavy metals, dioxin and PCB may occur in raw material from raw material from the white fish production and aquaculture. Large volumes of the potential fish feed ingredients may be made available for small scale fish feed production in Northern Norway. However, it may be necessary to import some plant materials. The use of national and local resources in feed production will strongly reduce the dependency of imported soy meal and oil.

Determination of scores is different and stated on an estimation based on prices, quality of the raw materiel, necessity of prepossessing before use as feed ingredient, research necessary before start of production of the feed ingredient. Methods, equipment etc. price as is and price after processing. As a benchmark, we think that price of alternative feed ingredients should not be much higher than present prices on fish oil and protein.

5. MACROALGAE

5.1. Production

Globally, the annual growth of seaweed volume rate is about 10%, and it is expected that the total value would increase up to USD 26 million by 2025 (Ferdouse et al., 2018). Macroalgae is the largest group of species in aquaculture, with a global production of 2.94 × 107 tons wet weight per year (FAO, 2018). It has been suggested that by 2050, the value of the kelp industry may have a turnover of 4 × 109 Euro per year in Norway alone, with a production of 2 × 107 t per year (Brock et al. 2019, Olafsen et al., 2012).

The potential of value creation based on macroalgae in Northern Norway is large, e.g. Nordland county has approximately 25 % of the Norwegian coastline. Thus, there is a large potential of macroalgae cultivation inshore, and offshore, when technology is developed for offshore production. In 2030, the report estimates that in Norway around 160000 tons of wild kelp are being harvested yearly, for production of alginate and alginate-like products. Whether this production could be combined with other production processes, e.g., extraction of polyphenols, should be further elucidated. The present volume of macroalgae culture in Norway is still very small (116 tons 2019).

5.2. Protein

Protein content in brown algae (up to 15%) is generally less than in greenalgae (up to 30%) and redalgae (up to 50%) (Makkar et al. 2015; Przedrzymirska and Sapota 2016). The content of protein and fermentable carbohydrate varies throughout the year. The level of protein is highest in the spring and carbohydrates is highest in the autumn (Makkar et al. 2015; Øverland et al. 2014). Amino acid profile and content in macroalgae species along the Norwegian coast were mapped by Biancarosa et al. (2016). According to Angell et al. (2016), the content of essential amino acids are approximately the same as in fish meal and soy meal, but contain less of the important amino acids, methionine and lysine. There are different methods to remove other substances, and to extract protein. Due to the high cost related to extraction of protein other interesting high priced ingredients of macroalgae should be extracted at the same time (Angell et al. 2016). Thus, from an economic point of view such an ingredient could be polyphenols.

5.3. Feed ingredients - green and red macroalgae

Species of green algae sea lettuces (Ulva genus) is relatively rich in protein. For example, when mixed into feed it has a positive effect on percentage of breast meat, and a reduced level of abdominal fat in chicken (Nielsen et al. 2012). Processed green macroalga, Ulva prolifera, increased feed intake, weight, and conversion ratio when mixed into feed in diets for chickens (Wang et al. 2013). Marinho et al. (2013) found no negative effects on growth performance, protein utilization, or protein retention when fishmeal was replaced by Ulva spp. (50:50% mixture of U. rigida and U. lactuca) in feed for Nile tilapia juveniles. Feed containing 5 g kg−1 of air-dried and pulverized Ulva pertusa fed to juveniles of red sea bream (Pagrus major) increased body weight gain, feed efficiency, and muscle protein deposition (Ventura et al. 1994). Green macroalgae meals as feed ingredients has a large potential as substitutes for conventional feed protein sources. However, this species is not easy to culture, and the wild stocks are relatively small as compared to brown macroalgae.

Most red macroalgae are rich in protein and may be used in dried form as a protein source in feed. As with other macroalgae, protein digestibility may be low (Marion et al. 2005; Maehre et al. 2016). When Atlantic salmon (Salmo salar) was fed a mixture of red algae and fish meal, the growth rate and feed conversion ratio in alga feed and control diets was not different, and conclusion was that P. palmata may be a suitable component in feed for Atlantic salmon. Atlantic salmon fed a diet including P. palmata showed an increased yellow/orange through deposition of algae pigments, without any negative effects on texture, odor, or oxidation flavor (Moroney et al. 2015). In Atlantic cod (Gadus morhua),(Walker et al. 2009) fed up to 110 g kg−1 of Porphyra spp meal containing 321 g kg−1 of protein there were no differences in growth performance among treatments. In rainbow trout the flesh pigmentation increased the fish flesh from pinkish- orange to dark orange in the fish fed 150 g kg−1 of Porphyra spp (Soler-Vila et al. 2009). Thus, natural pigments from Porphyra spp. may enhance its potential for inclusion in feed for salmonids by reducing the need for artificial colours e.g., astaxanthin.

Overall, many studies show the great potential of several red macroalgae as feed ingredients for fish feed. However, high cost of many red algae as a protein source in diets for fish feed may limit the use of this ingredient. A general beneficial effect of low-level supplementation in fish diets may indicate a positive effect of unidentified bioactive compounds. Red algae has a rather complicated reproduction and lifecycle, thus, culture of this group is not extensive in Norway/North Europe. However, both green and red algae may be important ingredients in fish feed, but reproduction and growth technology at an industrial level has to be developed.

5.4. Feed ingredients - brown macroalgae

Brown algae (Phaeophyceae) such as sugar kelp (Saccharina latissima) has a variable content of protein during the growing season, but may be increased by cultivation near sources of protein e.g. effluents from fish farms (Øverland et al. 2014). The maximum content of protein in brown algae is in the range of 17-21% (Øverland et al. 2014). A maximum protein content in macroalgae of 40% of the dry weight may be obtained when harvesting in the spring as stated by Skjermo et al. (2014). Protein content in sugar kelp and winged kelp (Alaria esculenta) as measured when harvested in May-June was 15-18%. Olafsen et al. (2012) estimates that in 2050 it will be possible to harvest 20 million tons macroalgae in Norway. Thus, with a protein content of 20%, there may be potential of about 4 million tons of protein from macroalgae yearly.

Mohamed and Al-Gheeti (2017) give an overview of work on macroalgae cultivation using wastewater from fish slaughterhouse. Alger4laks (2019), University Nord obtained promising results when investigated algae growth using nutrient-rich waste as growth medium from fish slaughterhouse. Guedes et al. (2015)   give a summary of the use of protein from macroalgae in aqua feed,and Angell et al. (2016) provides an overview of the use of unprocessed macroalgae in feed for livestock.

The chemical composition of biomass of brown macroalgae is only suitable for low inclusion rates in fish diets. The low levels of protein and metabolizable energy, and the high mineral content of unprocessed brown macroalgae such as Laminaria spp. and A. nodosum, restrict the use as replacements for major protein sources like fishmeal and soybean meal in formulated feed. For example, the residue from A. nodosum after extraction of alginate was poorly digested and unsuitable as a protein and energy source for pigs (Whittemore CT and Percival JK, 1975). Costa et al. (2013) found no effects on feed conversion ratio and carcass yield when A. nodosum meal up to 20mg kg^{-1} on body weight was used in fish feed. Feed including extracts from brown seaweed (L. digitata) containing laminarin and fucoidan may improve the quality and shelf life of pork(Moroney et al. 2012). Trials demonstrated that supplement of low levels of seaweed boosted the growth and the immune system in fish. This may help in reducing the use of antibiotics to combat diseases in fish (Thépot et al.2021).

There is a potential for incorporation of macroalgae-derived antioxidant components into human food through the animal diet, suggesting that functional ingredients from macroalgae are likely to be utilized in future. Unprocessed brown macroalgae has a low value as ingredient in feed. A preferable application could be a separate use of bioactive substances used at low levels to potentially improve growth performance and health (Øverland et al. 2018).

5.5. **Bioactivity of macroalgae ingredients - health effects in animals**

In general, brown, red and reen marine macroalgae are rich in bioactive components with valuable pharmaceutical and biomedical potentials (Gupta S and Abu-Ghannam 2011; Eom et al. 2012). This may have a great potential as functional health-promoting ingredients in animal feeds. It has been suggested that bioactive components from macroalgae such as Laminaria-derived laminarin and fucoidan can serve as alternatives in-feed antibiotics (McDonnell et al. 2010; O'Shea et al. 2014; Lynch et al. 2010) or as environmentally friendly alternatives to therapeutic dosages of zinc oxide in pig diets (O'Shea et al. 2014).

For example, during weaning, pigs that were fed diets included Laminaria spp. or extracts containing laminarin and fucoidan, had better intestinal health (O'Doherty et al. 2010; Walsh et al. 2013; Heim et al. 2014), and reduced post-weaning diarrhea (McDonnell et al. 2010). I has been suggested that laminarin and fucoidan have a positive effect on gut health. Inclusion of laminarin may be more beneficial than fucoidan, or the combination of the two supplements in diets for weaned pigs (Øverland et al 2018). Alginate and mannitol may be growth inhibitors; thus these should be removed in diets. The extract from A. nodosum or L. digitate may improve growth performance by stimulating increased feed intake and by stimulating the immune function (Sweeney et al. 2016). Macroalgae or extracts of macroalgae have received increasing attention as safe alternatives to prophylactic and therapeutic agents in diets for fish. This may reduce large economic losses related to infectious diseases. Macroalgae may exhibit antimicrobial properties (Vatsos IN and Rebours C, 2015) and inhibitory effects against fish pathogens (Bansemir et al. 2006). Hence, there is an increasing interest in the use of macroalgae as a bioactive component in functional feeds for fish.

Red alga, brown Fucus spp., and green Ulva spp., had a positive effect on the innate immune response and antioxidant responses (Peixoto et al.,2016). In grouper (Epinephelus coioides), fed diets containing laminarin improved growth and feed conversion ratio was observed (Yin et al. 2014). P. palmata was mixed into diets of Atlantic salmon and had positive effects on health parameters, and may therefore have potential as ingredients of functional fish feed (Øverland et al. 2018).

Extracts of macroalgae may have beneficial health effects and a potential as sources of bioactive compounds in feed for fish. However, inhibitors in the intact macroalgae or in the extracts, may affect bioactivity of compounds like laminarin and fucoidan from macroalgae. Large scale methods for extraction, isolation, and characterization of bioactive components in macroalgae has still to be developed.

5.6. Applications of polyphenols in feed

There is an increased interest into food/feed additives and novel biologically active compounds (e.g., phlorotannins, sulfated polysaccharides, carotenoid pigments, phytosterols, dietary fiber, omega-3 fatty acids, and bioactive peptides) from algae with health benefits (Kadam et al., 2013, Magnusson et al., 2017, Yuan et al., 2018). Among these promising ingredients, the phlorotannins occurring in brown algae are probably the most interesting. Phlorotannins have been the focus of several studies in the last years because of their important biological activities (e.g., antimicrobial, antioxidant, anti-inflammatory, anti-allergic, and anti-diabetic). The biological activity of the polyphenols depends on their bioavailability on which there is limited information (Chiou et al., 2014). Phlorotannins are absent in terrestrial plants. Phlorotannins for industry applications will be the focus of many R&D and private companies the coming years. Bioactive ingredients represent a small, but valuable volume of the total algae biomass.

Lipid oxidation is one of the most important quality deteriorating processes in feed and food. The oxidative degradation of lipids in raw or processed feed is responsible for loss of nutritional value. Both synthetic and commercially available natural antioxidants such as ascorbic acid and tocopherols have been shown to be inefficient in some foods enriched with marine long chain omega-3 fatty acids, which are highly susceptible to lipid oxidation (Jacobsen, Let, Nielsen, and Meyer, 2008). For example, fish feed ingredients and products are sensitive to oxidation during prosessing and storage, and phlorotannins may be a valuable ingredient to extend shelf life, reduce oxidation, and increase the economics of the fish feed producer.

5.7. Antioxidants and use in functional food/feed

The antioxidant power of phlorotannins is 2 to 10 times more in seaweed as compared to Vitamin C and tocoferol (Vit E) (Freile-Pelegrín and Robledo 2013). The antioxidant potential, including their nutraceutical compounds for functional feed products, is valuable in the feed industry. The effect in improving health (as feed supplements), extend the shelf-life period when applied in processed functional food/feed are issues of great economic values for the industry.

The restrictions of use of synthetic ingredients in the food/feed industry argues for an increased exploitation of seaweed compounds such as phlorotannins as safe alternatives as antioxidants (Freile-Pelegrín and Robledo 2013). Their anti-microbial activities against major food spoilage and food pathogenic microorganisms (Gupta et al. 2011). Phenolic antioxidants may be used as enhancers of the oxidative stability, and to conserve and increase the intrinsic quality and nutritional value of foods.

Purified phenolic extracts may have powerful antimicrobial effect against bacteria, fungi (Lopes et al. 2012), and virus (Ahn et al. 2004), and may be used in pharmacotherapy. Phenols may modify and produce variations in the microflora community in the gut by exhibiting prebiotic effects and antimicrobial action against pathogenic intestinal microflora (Lin et al. 2018). Seaweed's polyphenolic compounds for feed and animal for health may be bioavailable to animals from the colon (Keyrouz et al. 2011) and be absorbed either directly in the upper digestive tract in untouched form or in the lower intestine after alteration by bacteria in the digestive tract. Galleano et al. 2010). In agreement, Nagayama et al. (2002) suggested that phlorotannins extracted from Ecklonia kurome could be used as an anti-bacterial drug.

5.8. Processing of macroalgae for feed, growth enhancers and health ingredients

Macroalgae biomass has to be stabilized as soon as possible after harvest. Pre- processing should include methods to maintain the essential nutrients and valuable bioactive components of macroalgae. Further, pre-processing may include treatments to increase digestibility and functionality, and remove potentially toxic substances. The harvesting of cultured macroalgae is usually in late spring, early summer. To ensure a continuous supply of macro-algae and year-round feed production, methods and sufficient capacity for preprocessing and stabilization of the biomass e.g. ensiling, freezing or drying, is necessary.

Drying and milling to a fine powder of macroalgae are performed for use as a compound of animal feed (Evans et al. 2014; McHugh, 2003). However, drying by using energy is demanding and costly, (Garcia-Vaquero and Hayes 2016). The addition of dilute hydrochloric acid will reduce the stickiness of the biomass and make it suitable for dewatering by screw-pressing (Calleger et. al. 2017). Most treatment after harvest, including drying (Gupta S and Abu-Ghannam, 2011; Chan et al. 1997), may affect the quality of the final product. After harvest, when rinsing in water at 60°C for 2-5 minutes the content of polyphenols and antioxidative properties was still very high (Nielsen et. al., 2020).

A cascading biorefinery model (Fig.) has been suggested as a way to deliver protein, and increase digestibility of amino acids, or to extractm bioactive compounds for high-value applications as feed ingredients (Øverland et al. 2018).

The extraction of protein from macroalgae is challenging due to the complex polysaccharide cell wall and extracellular matrix. Protein concentration in macroalgae products can be increased e.g. by processing technologies such as enzyme-assisted, microwave-assisted extraction, pressurized liquid extraction, supercritical fluid extraction, and pulsed electric field (Garcia-Vaquero and Hayes 2016; Bleakley and Hayes 2017). Enzymes may be too expensive because of the high enzyme:substrate ratio required (Harnedy and FitzGerald, 2011). The polysaccharide composition varies among macroalgae species and enzymes may be selected for each algae species. The proteins of macroalgae are protected in the cellular matrix and bioavailability Is very low (MacAartain et al. 2007), and the presence of xylan and carrageenan may also reduce protein bioavailability (Tibbetts et al. 2016, Marrion et al., 2003).

Fermentation may increase protein digestibility by degradation of insoluble fiber (Marrion et al., 2003). Protein production from macroalgae may be increased by conversion of organic constituents like carbohydrates and non-protein nitrogen into proteins by fermentation. Pretreatment by milling and enzymatic saccharification with cellulases, lamarinases, and alginate lyases releases fermentable sugars from brown macroalgae like Laminaria digitata and Saccharina latissimi. However, high costs of using enzymes may hamper further development in this direction.

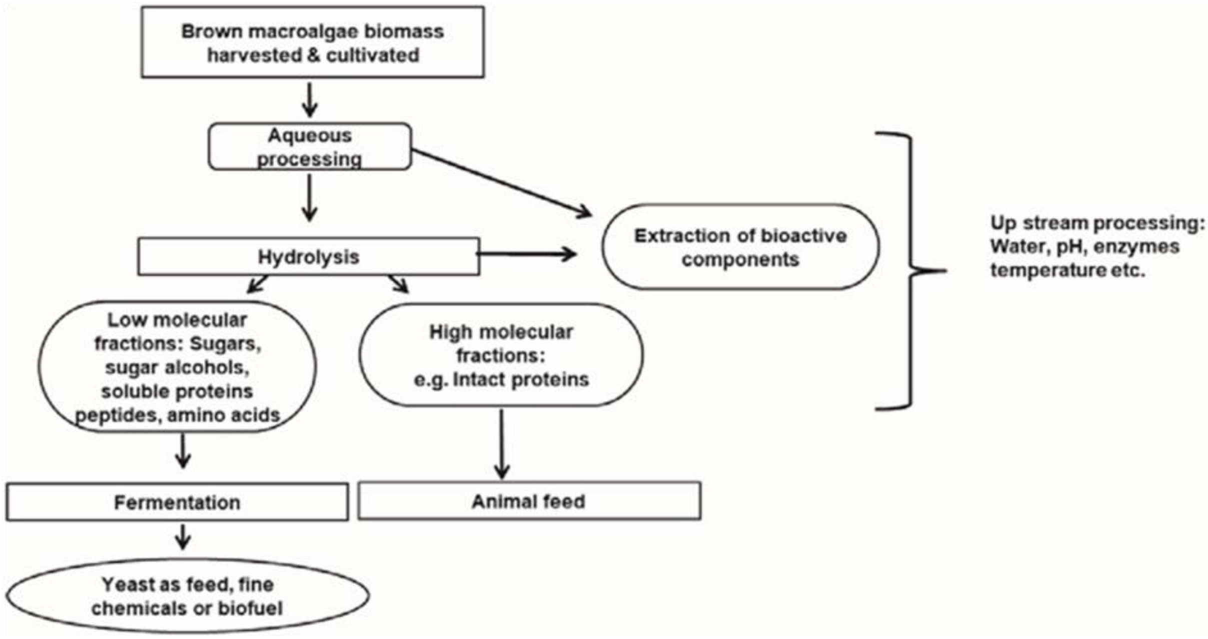

Figure 1. Flow chart of brown macroalgae processing (modified after Bikker et al.) involving: pre-treatment of the biomass to remove salt and soluble components; hydrolysis by acids or enzymes to convert macroalgal biomass to soluble and insoluble fractions; fermentation of sugars, sugar alcohols, soluble protein and other nutrients to produce single-cell proteins such as yeast; extraction of bioactive compounds; and direct extraction of proteins from the biomass (from Øverland et al. 2018).

The chemical composition of macroalgae biomass is complementary to lignocellulosic biomass. According to Øverland et al. (2018) this may be a substrate for yeast production by co fermentation in a biorefinery approach. The macroalgae contain essential nutrients such as nitrogen and minerals that are lacking in lignocellulosic biomass. Concurrently, yeast production allows utilization of the indigestible polysaccharides as well as the nutritionally useless non-protein nitrogen and mineral components in macroalgae.

Processing by biorefinery approaches may allow feed production in a downstream production line. However, production in large-scale industry of nutritionally well-defined animal feed products require improved low-cost separation technologies or fermentation procedures to convert sugars from complex macroalgae polysaccharides and non-protein nitrogen into yeast protein (Øverland et al.2018).

Table 3. EU and Centre d'Etude et de Valorisation des Algues (CEVA). Limits for content of iodine and heavy metals in seaweeds (From NOFIMA report 35/2020).			
Agency	Iodine	Inorganic arsen	Cadmium
CEVA	2000	3	0.5
EU	-	-	3.0

5.9. Minerals in macroalgae

Marine macroalgae are rich in nutritionally important minerals such as iodine, potassium, calcium, magnesium, phosphorus, iron, and zinc and have traditionally been used as a mineral supplement for farm animals.

There is a risk that accumulation of high levels arsenic, lead, cadmium, and other heavy metals in some species of macroalgae and this may limit their use in feed (Øverland et al. 2014). NIFES has conducted a survey of the content of various heavy metals in macroalgae (Table 3) to explore the possibilities of using algae for feed and food (Duinker 2016). The uptake and availability of heavy metal is related to salt content, pH, temperature, varying with day and season. Duinker et al. (2016) shows an overview of the content of various heavy metals in different species of algae. In general, content of copper, selen and zinc are below limits in Norwegian macroalgae. The content of arsen in green and red algae is below limits, while in most brown algae it is above the limit value.

Cadmium and Arsen

The content of inorganic arsenic in finger kelp is often very high, while sugar kelp converts arsenic into organic compounds. The heavy metal cadmium may be transported to the environment through pollution from agriculture and industry. The time it takes to reach half-life to be excreted, is from 10 to 30 years. It may be accumulating in the body, primarily in the liver and kidneys. Cadmium has been shown to cause kidney damage, and it may have many harmful effects on other organs. Tolerable weekly amount of cadmium intake (TWI) is from 7µg/kg body weight/week (in 2009) to 2.5 µg/kg body weight/week. Immersing seaweed into water may reduce the levels of cadmium and arsen in seaweed. However, this may lead to leakage of other valuable substances, such as pigments and polyphenols.

Iodine

Studies have shown that it is possible to remove significant parts of the iodine content from seaweed. Methods, such as high pressure, ultrasound, and enzyme treatments, may have the potential to reduce iodine and heavy metals. Further, treatment may reduce the Iodine content of macro algae more than 65%, with, fermentation, boiling, blanching, and soaking (see Nofima report 35/2020 and references therein).

Sugar kelp grown in Norway can contain very much iodine, and levels from 1700 to almost 6000 mg/kg of dry weight have been documented (Nofima report 35/2020 and references therein). There is great variation on level of iodine in harvested seaweed and how much is removed during the processing process. There is a need, both among producers of food and feed and consumers, to get more clarity on how much seaweed is safe to use as ingredients in food and feed. The content also varies depending on species, location, and conditions such as available iodine in the ocean where the seaweed grows, growth phase, season, and age of the seaweed. High levels of iodine and the heavy metals cadmium and arsenic are undesirable in feed and food.

Populations in many countries are iodine deficient. If iodine requirements in food are not met, the thyroid may not be able to synthesize sufficient amounts of thyroid hormone. This may result in series of functional and developmental abnormalities. For example, Iodine deficiency is the greatest cause of preventable brain damage in childhood. Thus, ingredients from seaweed with a controlled levels of Iodine may have a positive effect on health.

When immersion in water for 60°C for 2-5 minutes, iodine content was reduced by over 90% (Nielsen *et. al.,* 2020). Other methods have also been shown to reduce the content of iodine, but not to the same extent as boiling. Drying has a certain effect on the reduction of iodine. Approximately 25% reduction has been reported for drying at 70°C, However, with the use of lower temperatures, less loss of iodine is found. EDTA, an approved additive in the EU, selectively binds to metal ions, and it can be used for the removal of metals from seaweed.

However, macroalgae may be a potential ingredient for fish feed. As shown in several studies the iodine levels may be reduced to acceptable levels through different steps under processing. Iodine levels will be reduced if the seaweed are being processed during feed production. Blanching, i.e. heat treatment in water for a short time and at a temperature lower than 100 °C , was investigated by Nielsen et. al. (2020). The results show an iodine reduction in sugar kelp of 94% at temperatures between 45-80°C and heat treatment over 2 minutes. When the exposure time were more than 2 minutes, and the temperature above 45 °C the reduction of iodine was not affected.

Recommendations and limits for iodine and heavy metals intake in humans are shown in Table 2. and described in the report "Norway Risk of Iodine Deficiency" published by the National Council for Nutrition (2016). In Norway a maximum of 600 µg per day is recommended if the population lacks iodine. Ingestion of around 600 µg per day is considered safe even for people with iodine deficiency. Furthermore, bioavailability of iodine from raw kelp is relatively low, and if it is processed as described above it may be below maximum limit of 600 micrograms of iodine per day, depending on iodine content in the seaweed. There are still some uncertainties on how iodine contents respond to different treatment during and after harvest and the level of processing before being ingested.

Removal of unwanted ingredients will most likely increase the production cost of feed containing macroalgae.

5.10. Macroalgae - future perspectives

There are no difficult barriers to overcome for increasing production of macroalgae, other than the fact that the economy of culturing seaweed is positively related to the size of the farm (Emblemsvåg et al 2020), and that unprocessed algae are low priced in the market. Thus, the high prize and market demand for processed and extracted ingredients, including protein, is an important prerequisite for making biomass cultivation profitable. Side streams from food/feed ingredient production creates opportunities to use waste fractions in applications to manufacture low-cost products such as various types of bioenergy and fertilizers (Olafsen et al. 2012).

In the processing of macroalgae it will be important to use all the raw material and the side streams of ingredient production following the principles of circular business economy.

6. SOY PRODUCTS

The world production of Soy meal was estimated to 226.45 million metric tons (2017) and is increasing with 4.5% per year (USDA, 2018). The price of soy meal was 384.25 dollars per metric ton while the one metric ton of fish meal was estimated at 1567.50 dollars (Index Mundi, 2018a, 2018b). Soy meal and oil are available on the world market. The world's two largest producers of soybean products are the US and Brazil. The contribution of soy to carbon emissions can be traced to multiple activities, including deforestation in south America, industrial processing and transportation. However, importing only sustainable and organic produced soy could be an option to reduce some of the environmental and health hazard. Further, the transport of the soy from South America to Norway is not sustainable and should be reduced. By using other resources available in Norway, or preferably in northern Norway for production in this part of the country.

Imports of soybean meal to Norway were 500 865 tons in 2018. Of this, 177 185 tons of soybean meal with 45-50% protein content were imported for use in agriculture and 323 680 tons of soybean meal with 61-62% protein content imported for use in fish feed. All soy imported into Norwegian livestock feed and fish feed is certified. In aquaculture soybean meal have replaced some of the fish meal in feed (Naylor et al., 2009). Most plants have a lower protein content, and anti-nutritional factors that reduce nutrient availability and may also counteract with vitamins (Olsen and Hasan 2012). These disadvantages may be reduced or removed by chemical and mechanical processing.

The industry is still looking for new sources of protein (Shepherd et al., 2017). Soybean reserves under pressure (Carvalho and Lacerda, 2006). However, importing only sustainable and organic produced soy could be an option to reduce some of the environmental and health hazard. Nevertheless, the transport of production represents some environmental challenges, and may have a major impact on the destruction of forest, savanna and prairies (Scharlemann and Laurance, 2008). The production of soya use much water, and may place the water the soy from South America to Norway is not sustainable and should be reduced.

Soy beans contain around 35% protein, 17% oil and 31% carbohydrates (Liu, 1997) and it is available in large quantities (Shepherd et al., 2017). Because of the inferior quality of protein and oil (as compared to fish oil), the soybean cannot replace fish meal/fish oil. For example, soy meal and other plant sources have a less favorable amino acids profile and may contain fibers and antinutrient elements making it difficult to digest and absorb by fish (Glencross, Booth, and Allan, 2007; Lock et al., 2016). Plant derived meal has more indigestible organic matter, such as insoluble carbohydrates and fibers, leading to higher levels of fish excretion and waste (Naylor et al. (2009).

Previous studies (Mundheim, Aksnes, and Hope, 2004) demonstrated that inclusion of high quantity soy in salmon diet decreased the growth performance of salmon, probably related to antintinutritional elements in soy products (Mundheim et al., 2004).

Studies have shown that Arctic char seems to have limited ability to utilize soybean meal, suggesting a corn gluten maximum of 15% in the diet, similar as for Atlantic salmon diets whereas in start feed the limit is around 18%. High levels of soy and other land plant products in fish feed give higher FCR, resulting in less efficient digestion. This means that more nutrients are released to the environment.

7. RAPE SEED

Rapeseed. Rapeseed (Brassica napus subsp. napus), also known as rape, or oilseed rape, is a bright-yellow flowering member of the family Brassicaceae (mustard or cabbage family), cultivated mainly for its oil-rich seed, which naturally contains appreciable amounts of erucic acid. Canola is a group of rapeseed cultivars which were bred to have very low levels of erucic acid and are especially prized for use for human and animal feed.

Rapeseed oil is one of the oldest known vegetable oils, but historically was used in limited quantities due to high levels of erucic acid, which is damaging to cardiac muscle of animals, and glucosinolates, which is it less nutritious in animal feed.

Rapeseed is grown for the production of animal feed and edible vegetable oils. Rapeseed was the third-leading source of vegetable oil in the world in 2000, after soybean and palm oil. It is the world's second-leading source of protein meal after soybean (Heuze et al. 2020). Rapeseed is Europe's most important oil growth (see rapeseed oil), and is the world's third most important vegetable oil after soy and palm oil.

Rapeseed oil can contain up to 54% erucic acid (Sahasrabudhe, 1977). Food -grade canola oil derived from rapeseed cultivars, also known as rapeseed 00 oil, low erucic acid rapeseed oil, LEAR oil, and rapeseed canola-equivalent oil, has been generally recognized as safe by the United States Food and Drug Administration (USFDA 1 April 2010). Canola oil in feed/food is limited by government regulation to a maximum of 2% erucic acid by weight in the US (USFDA 1 April 2010) and 2% in the EU (Regulation (EC) No 1881/2006) with special regulations for infant food.

The seeds contain up to 50 percent fat used for cooking oil and biofuels. The oilcake is protein-rich and is used for power feed.

Processing of rapeseed for oil production produces rapeseed meal as a byproduct. The byproduct is a high-protein animal feed, competitive with soybean. The feed is employed mostly for cattlefeeding but is also used for pigs and poultry (Heuze et al. 2020). However, natural rapeseed oil contains 50% erucic acid and high levels of glucosinolates that significantly lowers the nutritional value of rapeseed press cakes for animal feed (Potts el al. 1999).

Nuseed ltd. Claims to have Omega-3 and being the FIRST LAND-BASED SOURCE OF DHA ESSENTIAL NUTRIENTS, extracted from Bioengineered canola. Nuseed's omega-3 program will help relieve the pressure on our oceans to supply this essential nutrient for eye, brain, heart, and cardiovascular health, by providing a land-based source. Estimates indicate over 80% of people worldwide are not getting enough omega-3 through the food they eat. Wild fish stocks, the current major source, are already under intense pressure to supply the rapidly growing global demand. Nuseed Omega-3 Canola was developed to provide aquafeed and human nutrition markets with a land-based source. Nuseed Omega-3 Canola is processed into our proprietary oil ingredients, Aquaterra® for aquafeed and Nutriterra® for human nutrition markets. Both products are more than just alternative sources of omega-3; they are uniquely rich in DHA, a vital building block of good nutrition (https://nuseed.com/omega-3-canola-program/).

Canola, soy flax, and palm oils are used to partly replace fish oil because of limited availability and high prices on fish oil (Naylor et al., 2009). Because of the lack of long chain omega-3 fatty acids (Shepherd et al., 2017), salmon farmers use feeds containing "blends of plant and fish oils during the first part of the grow out, and increase omega-3 oil levels (fish oil) in the feed some weeks before harvest (Naylor et al., 2009). Rapeseed meal used at 30% in the diet for arctic char did not have negative effect on growth. It is also possible to use different sources of lipid, but this may change both the fatty acids composition and sensory traits in the farmed Arctic char.

The availability of rapeseed in Norway is very low, and can not meet the demand. In Sweden, institutes and farmers are doing research to evaluate and do trials on turnips in northern part of the country. This may be a possible resource for protein and oil for feed/food in future, especially in northern parts of Scandinavia. Land plants represent an important group of fish feed ingredients. However, the inclusion of land plants in fish feed may have reached its limits and other novel feed ingredients have to play an more important role in fish feed production.

8. KRILL AND CALANUS

The biomass of Antarctic krill is estimated to be between 100 and 800 million tons. In the Norwegian sea and the Barents Sea the yearly production of krill is calculated to be ca. 287 million tons (Wikipedia). There are also large volumes, around 33 million tons, of "Rauåte" (Calanus finmarchicus), in the Norwgian sea.

Krill and calanus spp are important in marine ecosystems. This may, with a sustainable and careful harvesting, be a good resource for use as feed ingredients. However, harvesting of krill and calanus at large scale may have serious effects on ecosystems, and effect nutrient availability at different trophic levels and effect reproduction of important fish stocks. The total global harvest of krill amounts to 150,000–200,000 tons annually, most of this from the Scotia Sea. Krill are already used as an ingredient in fish feed. Small volumes of rauåte are being harvested for use in processing into human food.

Krill is a potential source of high quality nutrients for fish feed, rich in protein and lipids, especially high levels of omega-3. Krill stocks are underfished, less than 15% of the global quota (6 mmt) are being harvested (Naylor et al., 2009). The fatty acid profile of krill is depending of the season and the location of the harvest (Phleger et al. 2002). Fish feed trials to using side streams from this processing as feed ingredients have shown good results.

Expensive infrastructures are necessary in order to catch, process and store krill. The most important issue is to avoid degradation and maintain high quality, especially oxidative changes of the lipids (Naylor et al., 2009).

In a recently released review article from Aker BioMarine, researchers conclude that Antarctic krill products have a positive impact on the feed intake, growth performance, fillet quality and organ health in salmonids, based on more than a decade of well-documented scientific studies and experimentation (https: //www.akerbiomarine. com/news/krill-meal-improves-health-and-performance-of-salmonids-according-to-new-review-article-from-aker-biomarine).

As stated by Standal (2021), the zooplankton Calanus finmarchicus is a natural resource widely available in Norwegian waters, and has a beneficial chemical composition for use in salmon feed: the lipid fraction is astaxanthin rich and with high n-3 PUFA content, the proteins have well balanced amino acids composition, and free amino acids are known to induce strong feeding responses. However, there are still challenges, e.g., environmentally, and ecological to overcome to fully exploit this resource. The project will develop handling and processing technologies for production of nutritional feed ingredients and evaluate their effect in feeding trials. The potential of commercial production of feed ingredients from C. finmarchicus, evaluation of social, economic and environmental sustainability of harvesting this species are being elucidated by the project Cala Feed (Standal et al. 2021). Here, research experts on raw material processing, nutrition and sustainability are participating to provide an overview of Calanus' potential as a feed ingredient for salmon, and a sustainability assessment of C. finmarchicus- based feed production.

There is an ongoing debate on what approach and level that has to be adopted for harvesting as there are insufficient data on krill and calanus to fully understand the effect of fisheries on the krill and calanus populations in the ecosystem, especially of Calanus harvesting on early life stages of marine species, e.g Atlantic cod.

The price on this resource will most likely be too high for use in the feed industry. However, in some cases when this are processed for human consumption, there may be side streams available for feed ingdredients.

9. TUNICATES

Tunicates (Ciona intestinalis), are animals that have a wide distribution, including areas of northerns hemisphere. They have good growth in sea water of the fjords and coast of Norway. As filter feeders they feeds on microalgae and bacteria.

Research at The University of Bergen (UiB) has shown that tunicates has a large potential as a protein source. Dried tunicates may consist of more that 60% protein (Andersen et al. 2014). UiB and UniResearch, Bergen are studying the cultivation and growth of tunicates. They estimate a production of 100-200 kg per square meter of sea farm (Amundsen B. and Lie, E. 2013). The wet weight of tunicates consists of 95% seawater (Andersen et al.

2014). Thus, it can be expected 3 kg of protein per square meter of sea farm. Initial works are in progress to develop methods for culture harvest and processing tunicates in Norway.

10. FOREST AS RAW MATERIEL

Forests are currently mainly being used for timber, paper, and as energy supply (fuel/bioenergy). Research and development of methods to transform the rest raw materiel from the forest industry into protein-rich foods and feeds are being conducted in many Nordic countries. Methods such as heat treatment, enzyme technology and microorganisms are able to convert forest raw material to protein-rich foods (Øverland et al. 2014; Jóhannson 2016). Wood contains cellulose (approximately 45%), hemicellulose (approximately 25%) and lignin (approximately 30%). Lignin can be used as energy/heating and electricity), whereas cellulose and hemicellulose can be reduced to various sugars, fermented and used in production of protein.

Trials using technology based on cultivation of fungi using rest raw materials from the paper pulp industry and in the forest industry is going on in many northern countries. The fungus is using the sugars in several end product from other steps in production for growth. The fungal biomass produced is rich in protein, fat, amino sugars, and vitamins which makes it very suitable as a fish feed ingredient particularly as the amino acid composition is close to that of fish meal. Fungus have been studied for protein content and growth, e.g. Saccharomyces cerevisae, Candida utilis, Kluyveromyces marxianus. They grow well on sugars derived from cellulose and hemicellulose. Comparisons show that these are not much different from fish meal and soymeal in content of amino acids. Øverland et al. (2013) shows that yeast can replace 30% of salmon feed, i.e. 40% of the protein. Øverland and Skrede (2016) have summarized the production, amino acid content and effect of yeast on fish health. The annual increase of forest in Norway is approximately 25 million m3 while yearly harvest are approximately 10 million m3 (Øverland et al. 2014). Thus, annual harvest is around 40% of the annual biomasse increase. A potential withdrawal of an additional 15 million m3 per year for feed production is possible. Extraction from forest of 800 000 m3 of timber can give about 220 000 tons of sugar that can be used to produce 100 000 tons of yeast (Øverland et al. 2014).

11. REST RAW MATERIAL FROM LAND ANIMAL PRODUCTION

The volume of animal residues from meat production in Norway is 264 000 tons per year (Lindberg et al. 2016). Much of this are being destroyed, mainly because of ovine spongiform encephalopathy (BSE) – mad cow disease. The average protein content is estimated to be around 20%, based on an overview of protein content in various foods (Granum 2006). Some land animal by-products are sources of animal protein and lipids, e.g. bone meal, feather meal, blood meal and poultry by-products. The amino acid profile of land animals is more optimal as feed ingredient for fish than land plant proteins (Naylor et al., 2009).

Technology for utilization of blood from warm-blooded animals as food and feed ingredients are developed. The blood is separated in red haemoglobin and a colourless plasma and sold separately to various food/feed applications. Dried blood from warm blooded animals is well known in the feed/food market. It has a good protein composition with favourable amino acids. As with warm-blooded animals, plasma of fish blood may be used in the food industry as water binders and as an gelating ingredient in the feed/food. Haemoglobin meal is the red part of the separated blood. It may be used as iron enrichment in feed like bread, blood sausages, black pudding etc. Traditional blood products from warm blooded animals has to be dried at high temperature. The proteins denaturize and often get a bitter taste. In Scandinavia, approximately 15 000 tons of plasma of blood of warm-blooded animals are produced per year (2008). The price is around 10 GBP/kg for frozen plasma with a dry weight content of 10%. The red phase, hemoglobin meal, of food quality are sold (2008) for around 10 GBP/kg, but then with a dry weight content of 90% (Rubin report 167). For example, it has been suggested that the pet food industry might be willing to pay a significantly higher price for dried fish blood as compared to traditional dried blood products (RUBIN report 167).

12. Conclusions

Macroalgae products has increased attention as potential ingredient in fish feed. Previous work indicate that protein from macroalgae preparations can be increased by suitable extraction methods. However, cost-effective and environmental friendly extraction and processing methods to separate protein, and biologically active ingredients e.g. polyphenols, laminarin and fucoidan from macroalge, remains to be developed.

13. MICROALGAE

13.1. Background

Microalgae accounts for about 40% of all photosynthesis and oxygen production globally (http://www.norskalgeforening.no/mikroalgae/). Heterotrophic microalgae can grow without light, but need oxygen, a growth medium and a carbon source. According to Nofima (2014) heterotrophic algae can produce 160-180 g of dry weight per liter of growth medium, while phototrophic algae can produce 1-4 g of dry weight per liter of growth medium.

Many species of microalgae are rich in protein and have good amino acid profiles which make them valuable protein alternatives for fish feed (Shepherd et al., 2017; Tocher, 2015). The content of protein may vary (Guedes et al. 2015), but is at the same level or higher than soymeal. The content of the amino acid lysine is lower and can limit use for pigs, but will not prevent the growth of poultry, fish and shrimp (Lindberg 2016). Experiments at Nofima suggest that Schizochytrium have the potential to replace fishmeal in salmon feed (Nofima 2014). Content in several relevant species is shown in the report 'Nordic alternative protein potentials mapping of regional bioeconomy opportunities' In Andersen and Tybrig (eds. 2016)

The photosynthetic microalgae, commonly used in northern fish hatcheries, is a source of long chained omega-3 fatty acids for live feeds, such as rotifers and Artemia nauplii (Tocher, 2015). Micro algae oil is a good alternative to fish oil and may be a sustainable solution to meet the demand for long chained omega-3 fatty acids (Tocher, 2015). Heterotrophic microalgal are used for large scale production of fatty acids and is a good alternative for replacing fish oil (Naylor et al., 2009). High production costs and limited production are linked and these two obstacles must be overcome in future production.

Land plant-based feed support fish growth, but lacks essential amino acids such as methionine, tryptophan, lysine, and threonine. The lack of essential amino acids may influence the quality of the digestion and quality of the fish. However, some algae such as Chlorella, Chlamydomonas, Porphyridium, Isochrysis, and Nannochloropsis have high content of methionine and may be a potential feed ingredients. The structure and quality of the microalgae cell wall in many microalgae may be a barrier for using this in fish feed as It may reduce the digestibility of microalgae (Niccolai et al., 2019), especially in higher concentrations, without certain pre-processing steps. Many microalgae remain to be tested as feed ingredient in both new emerging species and existing species in arctic area in Nordic countries.

13.2. Digestibility, trace metals, unwanted elements and antinutrients

Microalgae may accumulate trace elements that must be removed, and may contain harmful toxins (Caruana and Amzil, 2018). Components of microalgae may impact fish health and reduce nutrient absorption (Mohebbi et al., 2016). For example, some microalgae may have low level of protein and high contents of carbohydrates that may reduce the growth in fish (Skrede et al., 2011).

Many microalgae have low digestibility due to the presence of non-starch substances and rigid cell walls (Skrede et al., 2011). Thus, preprocessing is necessary when microalgae shall be used as fish feed. The content of starch in microalgal species varies between 7% to 45% (Dragone et al., 2011). Tetraselmis ormis, Chlamydomonas rheinhardtii and Chlorella vulgaris have a very high starch content, varying between 30–49%. The low palatability and digestibility of feed with microalgae as an ingredient may also be improved by breaking the cell walls and by adding attractants.

Pre-treatment to break the cell wall will lead to extra costs for the fish feed production. This will improve microalgae digestibility by fish (Batista et al., 2020b). The microalgal cell walls may consist of high levels of cellulose (Table 1xc). The digestibility of the cellulose in Chlorella sp., Desmodesmus sp., Nannochloropsis sp., and Tetraselmis sp. may prove difficult. Different steps in processing of feed may break algae cell walls and increase the availability of the algae cell nutrients (Maehre et al., 2016). For example, extrusion of feed including Nannochloropsis to Atlantic salmon, S. salar, the feed was more digestible than non-extruded processed feed (Gong et al., 2018). However, microalgae fiber lack lignin and contain low hemicellulose suggesting better digestibility (Niccolai et al., 2019). When compared to fish meal, the microalgae feed may result in lower feed intake. Adding taurine to the feed may increase the growth in fish (Takagi et al., 2008).

13.3. Antioxidants and bioactive ingredients

Some microalgae have positive antioxidant properties, such as pigments e.g., carotenoids, that may provide functional properties (Chen et al., 2017). Different processing such as drying, cold pelletization can prevent degradation of the ingredients, but may increase the production cost of the feed.

13.4. **Inclusion in fish feed, live feed and green water**

The positive effect of microalgae used in low or moderate inclusion in the diet is shown by many studies. Normally, a maximum of 15% microalgae will result in normal growth in fish: When higher than 25% it may result in starvation and reduced growth as shown in Atlantic cod (Gadus morhua) (Walker and Berlinsky, 2011). This was also shown in rainbow trout when fish meal was replaced with a mixture of green microalgae and cyanobacteria above 15–20% in feed (Dallaire et al., 2007). However, the inclusion of microalgae in feed may be increased when cost effective methods to break the cell wall makes it possible.

Gaping, fillet firmness and soft fillets are considered as an inferior product quality. Microalgae have been shown to reduce gaping in the fillet When Schizochytrium sp. (5%) diet was included in feed for Atlantic salmon the gaping was reduced (Kousoulaki et al., 2016). Furthermore, fish pigmentation may be influenced by microalgae, e.g. Haematococcus pluvialis that contain high levels of astaxanthin, and are used as feed additives (1.5% in range) in the feed industry (Chen et al., 2017).

Pre-treated microalgae are available in commercial products such as microalgal paste in dry, flocculated, microencapsulated, or cryopreserved products, as alternatives to a fresh or live feed (Raja et al., 2018). Use of green water, and algae paste during start feeding of marine species such as halibut, cod, and ballan wrasse is a favorable method to increase growth and survival. There are several issues to handle, including harvesting, which is expensive, using off-the-shelf feeds (Wan et al., 2019). Algae paste may be used as a protein substitute in feed for marine fish larvae, and as feed and enrichment for rotifers and artemia before being fed fish larvae.

Nannochloropsis oculata is used in the culture of early-stage larval marine fish using the “Greenwater formula” (Reed Mariculture Ltd commercial product) is designed to create diffuse light conditions for the first feeding of larval marine fish. This also help to initiate first-feeding and promote schooling activity. It has a good fatty acid profile which means that high quality feed are available to rotifers in the tank. Cell densities are approximately 30 billion cells per ml. of paste (Reed Ltd). Use of microalgae paste replace work demanding cultures of microalgae and expensive infrastructure for microalgae production at hatcheries.

13.5. Storage and shelf life

Shelf life of microalgae paste may be increased by low-temperature preservation, freezing, vacuum packaging, and lyophilization of biomass, as well as maintaining antioxidants, food acids, and vitamins (Amouzad Khalili et al., 2019). The algal paste sensitivity means that sufficient time has to be calculated to manufacture, transport, and use the products. Commercial concentrates, e.g. Reed Mariculture's Nanno 3600, have a shelf life of 12–14 weeks in the refrigerator. Nauplii (Brazil) offers another concentrate – LiveNanno that includes live Nannochloropsis sp. cells and has a three-month shelf life.

Comparing paste to live microalgal diets, nutrients in Skeletonema costatum and Chaetoceros calcitrans algae pastes was not different after operations such as concentration, transportation, and preservation (McCausland et al., 1999).

Shrimp grown in "green water" costs US$ 1–3 per kg, while shrimp grown in a conventional feed supplemented system costs US$ 4–8 per kg (Neori, 2011). Pathogen inhibition is higher in green water ponds than in clear water ponds (Palmer et al., 2007). Species growth was higher in green water than clear water (fed with fish meal), as seen in Asian tiger shrimp (Glencross et al., 2014). Ammonia excreted by fish could act as a nitrogen source for microalgae; thus, green water/poly-aquaculture techniques reduce eutrophication potential

Microalgae feed is also recommended because it improves the gut health and survival of fishes. However, many studies have suggested that a pro/prebiotic effect are based on a mixture of algae, bacteria, and other organisms rather than just microalgae (Shah et al., 2018; Tacon, 2020). Depending of species, microalgae contain high levels of omega-3 fatty acids, and may function as an immunostimulant and prebiotics.

13.6. Rules and regulations

According to US-FDA (US Food drug administration) and the European Food Safety Authority (EFSA), many microalgae are safe. US-FDA have approved Haematococcus pluvialis for use as a colour ingredient in salmonids and shrimp feed (Han et al., 2013). FDA-USA has classified oil extracts from Crypthecodinium cohnii, Schizochytrium sp., Ulkenia sp., dried Spirulina platensis, Chlorella protothecoides, and Dunaliella bardawil as "generally recognized as safe" (GRAS) (Jha et al., 2017). The European Union approved algal oil and meals as salmon feed for commercial purposes in 2017. EFSA approved carotenoids from

Dunaliella salina and DHA from C. cohnii (Enzing et al., 2014). EFSA authorized Aphanizomenon flos-aquae, Chlorella luteoviridis, Chlorella pyrenoidosa, Chlorella vulgaris, Odontella aurita, and Tetraselmis chuii as foods or food ingredients (Lähteenmäki-Uutela et al., 2021). Chaetoceros gracilis, Isochrysis sp., Tetraselmis suecica, Skeletonema costatum, Pavlova lutheri, Dunaliella tertiolecta, Phaeodactylum tricornutum, Nannochloropsis sp., and Chlorella sp. have not been reported to contain toxins (Enzing et al., 2014), and are marketed as supplements. Toxicological studies have shown that various microalgae are safe to use as feed supplements (Dineshbabu et al., 2019).

13.7. Environmental issues

Microalgae could have a much higher global warming potential and water footprint than other alter native feeds and fish meal (Nagappan et al. 2021). Improvements in biomass yield, use of renewable energy e.g. flue gas, and wastes as carbon sources may help to reduce global warming potential/carbon footprint (Jeno et al., 2021, Taelman et al., 2013). Another possibility is large-scale cultivation as microalgae-based fish feed produced on a large scale (2.5 ha) had 20 times lower carbon footprint than fish feed produced on a pilot scale (0.024 ha) (Taelman et al., 2013). Further, when the growth media is recycled, the water footprint of microalgae can be reduced by 90% (Pugazhendhi et al., 2020). Nagappan et al. (2021) states that water footprint of microalgae production is lower than that of plant and insect production. In open cultivation system, the water loss due to evaporation is a major contributor to the water footprint of microalgal biomass production. Nevertheless, most likely indoor closed systems will be the best option for microalgae production in arctic area.

13.8. Availability and production

One obstacle for using microalgae as fish feed is the high cost of production (Fasaei et al., 2018). i.e cost mainly related to break the rigid cell wall. There are several approaches to lower production costs, but most of them has not been implemented in commercial large-scale production of microalgae. Biorefinery techniques, renewable energy, use of waste flue gas from industry, e.g. AlgaeScaleUp in northern Norway using flue gas at Finnfjord smelteverk to produce microalgae (for fish feed), and heterotrophic cultivation methods based primarily on organic carbon sources are some possibilities being explored. Some companies may select their location for production of microalgae and in area with stable, surplus and cheap energy, e.g. in northern Norway. Many of the feed companies in Norway have microalgae as a feed ingredient in planning of future large scale feed production. According to the feed company

BioMar, microalgae is no longer considered a niche ingredient. At their facility in Brande, Denmark, they are scaling up the inclusion of microalgae into their raw material portfolio. The use of microalgae in the flagship product line produced in Brande enables BioMar to reach the sustainability criteria as this ingredient contributes to a reduced dependency on wild fish stocks. (https://www.biomar.com/en/global/articles/press-releases/microalgae-no-longer-considered-a-niche-ingredient-in-biomar/). The feed company Skretting is also using algae oil in their feed. This is delivered by the microalgae producer Veramis in Netherland.

13.9. Conclusion

Fish feed made from microalgae has a large potential to partly replace fish meal and soybean meal. Microalgae is a valuable source of protein with a favorable amino acids, lipids, and carbohydrates, and a number of functional compounds. Microalgae have many advantages and may be used in aquaculture in various ways, such as algal paste and extruded pellets. The high cost of production is one of the most significant problems of most microalgae. A selection of strains with optimal cell composition, and lower production cost as feed may meet the demand and partly replace soybean and fish meal and oil in future feed production.

14. INSECTS

14.1. Background

Small scale farming of insects for use as food and feed started decades ago. In some tropical countries eating insects was based on harvesting from nature. Sometimes this occurred at a large scale, such as the harvesting, processing and marketing of the mopane caterpillar in southern Africa. There are examples of semi-domestication by indigenous people e.g. as providing egg laying sites for aquatic Hemiptera in lakes of Mexico, manipulating the habitat to increase edible caterpillars in Africa, and cutting palm trees deliberately to encourage palm weevils to lay their eggs. There are also examples that insects were used as feed, such as luring termites to devices which were fed to chicken.

Insects are an upcoming alternative protein source investigated for food and feed ingredients (Van Huis et al. 2013), also in northern parts of Norway, Sweden and Finland. There is an increased interest in using insects not only as an ingredient for fish feed. Many low-cost resources, e.g. side streams from other industry production, could be used as insect feed ingredient in a circular economy model for further production of protein rich low trophic organisms, such as insect larvae for use in the fish feed industry. Several companies for culturing insects, and insect derived products, are now being established in many countries in Europe. Many of these are small scale producers are using their own developed production lines.

The International Platform of Insects for Food and Feed (IPIFF) 2018 has provided an overview of the production and processing of insects and insect-derived ingredients (e.g., processed proteins or insect fat), applicable to the production of both animal feed/ food for human consumption. The present section shows some of the most relevant information. For more details and information please see the IPIFF (2019) documents including suggested downloads. Some options for down loading are also given at the end of this section, hopefully it will help interested parties to update on important information and on regulations on insect farming.

14.2. Insect species approved for culture

Along with EU, Norway authorizes the use of insect proteins originating from seven insect species – Black Soldier Fly (Hermetia illucens), Common Housefly (Musca domestica), Yellow Mealworm (Tenebrio molitor), Lesser Mealworm (Alphitobius diaperinus), House Cricket (Acheta domesticus), Banded Cricket (Gryllodes sigillatus) and Field Cricket (Gryllus assimilis) are approved for use in feed for aquaculture animals (EU Regulation No 2017/893/Matilsynet 2018). There has been a special focus on insect species such as the common housefly (Musca domestica), the yellow mealworm (Tenebrio molitor) and the black soldier fly (BSF) (Hermetia illucens) (Tran et al., 2015) for feed/food ingredient production. These species grow well on organic waste, producing high-quality protein and fat (Čičková et al., 2015; Nguyen et al., 2015).

14.3. Environmental issues

Insects are poikilothermic, and body temperatures depend on ambient temperatures, and growth is temperature dependent. Consequently, energy requirements are high due to the relatively high temperatures that has to be maintained during rearing. On the other hand, consumed feed by insects can be efficiently used for growth, and not for maintaining a constant body temperature. Nevertheless, energy use in insect production is low as compared to many other production systems on food and feed.

Some important environmental advantages of insect farming compared to livestock production are: (1) less land and water is required; (2) greenhouse gas emissions are lower; (3) insects have high feed conversion efficiencies; (4) insects can transform low-value organic by-products into high-quality fish feed. Many insect species accumulate protein very efficiently.

Replacing demand for livestock products with insects, may be a good mitigation option (Schösler et al. 2012; Hedenus et al. 2014; Davis et al. 2016; Herrero et al. 2016; Lamb et al. 2016). For example, ruminant meat where production of 1 kg of beef requires around 50 times more land than the production of 1 kg of vegetables, while greenhouse gas emissions are about 100 times higher, all depending on the production system used (Nijdam et al. 2012). Poultry fed optimized diets converts 33% of dietary protein to edible body mass. Yellow mealworms , black soldier fly larvae utilize about utilize 22–45%, and 43–55%, respectively.

14.4. Culture of insects and substrates

In general, insect larvae can grow and survive on different organic matter. In fish feed production optimal diets for insects would lead to more efficient utilization of the feed (see above), but certain ingredients could be too expensive. Utilization of organic side-streams from different industry sources should be explored further (Halloran et al. 2016). This approach may help in establishing a circular economy in food/feed production.

The black soldier fly is well known for effectively utilizing waste streams, such as rice straw (Manurung et al. 2016), coffee pulp (Larde 1990), fish offal (St-Hilaire et al. 2007), and catering waste (Surendra et al. 2016). It utilizes waste and can simultaneously kill pathogenic bacteria such as Escherichia coli or Salmonella enterica.

14.5. Insect meal, oil and minerals

Black soldier fly is an effective converter of biomass; 2 kg of rest raw material/waste can give 1 kg of insect protein per 1m2 (Makkar et al. 2014).

Insect meal has high levels of protein, between 50-82% of the dry weight (Rumpold and Schlüter, 2013). This is in line with good quality fish meal that may reach up to 73%. Soybean meal may contain up to 50 %of protein whereas the level of oil varies between 10 and 30% (Barroso et al., 2014). Insects are a good source of minerals such as potassium, calcium, iron, magnesium (Schabel, 2010), and selenium (Finke, 2002). The vitamin profile of insects will depend on the composition of the insect diet. Black soldier fly larvae is a high-value feed source, rich in protein, fat, calcium (Ca: 5-8%DM) and phosphor (P: 0.6-1.5DM), magnesium, iron, manganese, zinc and copper. Meal worm meal has a high protein content (up to 70%) and a well-balanced profile of essential amino-acids. The meal is highly digestible, and it does not contain antinutrients. The fat of larvae depends on the diet, and the level may reach 50% if the feed is rich in oil.

The fatty acids, including Omega-3, content of larvae depends on the fatty acid composition of substrate they are fed (Makkar, Tran, Heuzé, and Ankers, 2014). It has been reported that replacing fish meal by yellow mealworm or black soldier fly meal decreased the concentration of long-chained omega-3 fatty acids, which should be added to the fish diet (Makkar et al. 2014).

The fatty acid profile of the insect does not contain omega-3. However, the lipid content of black soldier larvae can be manipulated to include desirable fatty acids such as ALA, EPA, and DHA by feeding (St-Hilaire, 2007), e.g., close to harvest to ensure high levels of these fatty acids at harvest.

14.6. Application of insect meal and oil in fish feed

Insects are naturally present in salmon diet (Johansen, Elliott, and Klemetsen, 2005; Rumpold and Schlüter, 2013). In nature, fish, e.g. salmonids are feeding on a wide range of pray from zooplankton, shrimps, squid, worms and fish. When returning to the fresh water to spawn, Atlantic Salmon feed on aquatic insects and surface insects (Johansen et al., 2005). Thus, a feed formula that contains insect protein is close to a natural diet (Rumpold and Schlüter, 2013).

It has been shown that meal of yellow mealworm (Tenebrio molitor L.; Coleoptera: enebrionidae), could partially (35%) replace fish meal in the diet of European sea bass (Dicentrarchus labrax) without affecting mortality or growth (Gasco et al. 2016). However, depressed growth was seen when 70% of the fish meal was replaced. In rainbow trout (Oncorhynchus mykiss) weight gain was not affected at higher inclusion levels of mealworm meal. However, the protein content increased and lipid contents of fillets decreased, compared to the control (Belforti et al. 2015). The replacement of fish meal by yellow mealworm meal increased the fat but did not affect its growth in Pacific white shrimp. In common catfish (Ameiurus melas Raf.) fingerlings and African catfish, C. gariepinus, the growth was lower when high levels of insects meal were used in fish feed (Ng et al. 2001). Replacing fish meal by yellow mealworm or black soldier fly meal decreased the concentration of long-chained omega-3 fatty acids, which has to be added to the fish diet (Makkar et al. 2014).

The Black soldier fly protein meal seems to be a good source of amino acids and has high bioavailability in Atlantic salmon nutrition (Ikram op sit). Lock et al. (2016), has investigated the use of brown algae in culture of black soldier fly. The fly larvae accumulated algae nutrients, and when 70% of the diet was replaced by brown algae 100% survived. Optimal inclusion of soldier fly larvae in feed may be around 50%. Apparently, a partial replacement is possible, but may affect production quality and outcome. Thus, insects are demonstrating a very high protein efficiency. In fish feed production optimal diets for insects would lead to more efficient utilization of the feed, but certain ingredients could be too expensive. Utilization of organic side-streams should be explored further. The use of insect larvae as feed for fish and animals are summarized by Makkar et al. (2014). This indicates that macroalgae may be used as an ingredient in insect feed – see section on Macroalgae.

Ikram et al. (2018) demonstrated that BSF larvae fed seaweed (Ascophyllum nodosum), enriched the larvae with marine nutrients, such as eicosapentaenoic acid (EPA) and iodine (Liland et al., 2017). Thus, the insect larvae may carry essential nutrients from sources which are not directly suitable for animal nutrition, such as seaweed, which is not ideally used in high concentrations in feed for carnivore fish species due to its high content of complex carbohydrates (De Jesus Raposo et al., 2015), and iodine. Thus, it is possible to add 600 g kg^{-1} of insect meal in combination with insect oil in the diets of fresh-water Atlantic salmon without negative effects on growth performances, and feed utilization. The BSF protein meal seems to be a good source of amino acids and has high bioavailability in Atlantic salmon (Ikram op sit). Thus, depending on the fish species, a high partial replacement is possible but may negatively affect production quality and outcome.

In processing of seaweed for extraction of different bioactive compound, side streams may constitute more than 90 percent. This potential large resource may be utilized in feed for insects. A circular economy model may be established, increasing the sustainability of both insect and seaweed production.

14.7. Public perception of using insects in feed

Insects represent a new source of feed, therefore attitudinal barrier towards insects represents a main issue regarding the acception of insect fed salmon. In some Asian countries insects are widely consumed. In the Western societies, however, insects can generate fear and are perceived as disgusting or unsafe (FAO 2013).

A survey among Scottish consumers showed that the consumers were positive to eating salmon that were fed insects (Popoff et al. 2017). A third of the interviewed were in favor of consuming insect fed salmon only if the price, the taste, and the safety of the fish remains unchanged. Only 10% of the persons were unwilling to eat salmon fed insects. A survey indicated a positive attitude to the use of insect in fish feed amongst consumers in Belgia. There was no difference between genders in terms of acceptance of insect in feed (Verbeke, et al. 2015).

14.8. Insect culture – conditions and environment

The EU ‘feed ban’ rules hinder use of insect derived proteins to certain animal species, such as cows, pigs and poultry animals. This is due to possible infection by the Bovine Spongiform Encephalopathy (BSE). The feed ban, see; Regulation No 999/2001 (see article 7 and Annex IV), ‘TSE Regulation’.

The European Safety Authority (EFSA) emphasized the influence of the substrate used to feed insects. Biological hazards (such as bacteria, viruses, fungus contamination) and chemical hazards depend on the substrate. There are some uncertainties concerning insect farming that need to be addressed such as chemical accumulation from substrates; the occurrence of human animal bacterial pathogens in insects processed for feed (EFSA Scientific Committe, 2015). Consumption of insects may cause allergic reactions, and this made the industry to put warnings on the product label. Nevertheless, the use of processed animal protein, other than ruminant in aquaculture feed, are allowed (IPIFF, 2017; Lähteenmäki-Uutela and Grmelová, 2016).

Insects offer nutritional flexibility as the nutritional profile depends on the species and on the substrate. Potentially, insects can be produced in large quantities and at a low and stable price. Insect farming does should not require intensive labor force and should be highly automated production lines and inexpensive feed ingredients, e.g. marine and agriculture by-products/side streams. However, the products of insects are still very expensive, because production cost is high, the supply of cheap feed ingredients is very limited, and the production is still very small. Apparently there is a positive opinion on the development of the price of insect meal in the future. However, the price of insect meal is still higher than fish meal, estimated (2022) to be more than 2 euros for one kilogram of black soldier larvae meal.

The organic waste is often rich in carbohydrate but has less protein content. The larvae themselves are protein-rich and can convert carbohydrate-rich organic rest raw material into protein-rich feed. Many companies have chosen black soldier (Hermetia illucens) fly as the main focus in their production of fly larvae.

14.9. Production facilities

The establishments and production facilities for insect protein and meal production must be approved. The potential biological risks associated with production should be dealt with by the business owner. see EU 'animal by products legislation' – i.e. in Regulation No 142/2011 (annex IV, chapter III). The animals have to be held in good health and prevented to spread diseases between groups within own production, and externally to other farms. Health and biosecurity in animal breeding are regulated by the 'EU Animal Health Law' Regulation (EU) No 2016/429 on transmissible animal diseases.

Insects are non-invertebrate animals, which means that insect producers are exempted from EU legal obligations on animal welfare, see Directive 98/58. Protection of animals kept for farming purposes (see article 1 d), in the area of animal welfare, normally valid for vertebrates.

- Temperature: insect growth rate is influenced by temperature levels. Temperatures between 25°C to 45°C are most beneficial in most cases.
- Humidity: temperatures must correlate with a specific level of relative humidity, depending on the phase of development (e.g. approx. 70% of humidity for Tenebrio Molitor, 50- 70 % for Black Soldier Fly and house fly, 90% for crickets and 50% after hatchings).
- Enclosed space: the insect colony must be enclosed and secured to facilitate pest control and prevent livestock escape. It is common to use multiple self-contained spaces, each with its own population, water supply and food sources.
- Ventilation: proper ventilation of the premises is required and must be suited to the species characteristics and projected temperature/humidity levels. This ensures clean rearing conditions and avoids cross-contamination through the air.

Black soldier flies are typically fed and grown on wet substrates, whereas mealworms (e.g. yellow mealworm and lesser mealworm), or crickets are grown on dry materials; Intense light and certain wavelengths may affect both feed intake and pupation of certain insect species: e.g. bright light inhibits the growth of black soldier fly species, and to some extent affects the growth of other allowed species; Production equipment used must be shaped and adapted to each species in order to prevent escape risks: e.g. mealworms can be safely raised in open containers, while Black Soldier Fly or Housefly must be stored in closed containers specifically designed to prevent any escapes. The responsibility lies with each producer to optimize and tailor the rearing conditions according to the specific insect species to ensure that escape risks are minimized.

The quality of the insect breeding flocks is an important parameter to take into consideration and a program for breeding, reproduction and selection of insects with specific growth and health parameters should be established.

14.10. Harvest of insect larvae

Harvesting operations consist of collecting larvae or adults at the end of the rearing cycle. Insects are removed from the rearing containers or chambers and then separated from the growing substrate and frass. For holometabolic insects (i.e., mealworms, black soldier fly, housefly) fully grown larvae are harvested, whereas in hemimetabolous insects (e.g., crickets and grasshoppers) animals are harvested at young nymphaea or adult stage. The harvesting method(s) may differ from one species to another:

- Usually, mealworm larvae remain in their growing substrate until they are mechanically separated (sieving).
- Black soldier fly larvae may naturally (at a mature level) migrate from the moist substrate to a dry environment, where they can be easily sieved manually or mechanically.
- Mealworm and black soldier fly larvae are often collected by a sieving procedure (manual or automated).
- Cricket adults are often collected by sieving from the growing substrate or by insect collecting nets. The responsibility lies with each insect producer to take account of the characteristics of each insect species reared and to design a harvesting process, which enables the effective separation of the larvae or adult insects from their frass, dead individuals and remaining substrates before killing.

- Most insect producers use sieving machines (for larvae) or ‘sorters’ (vertical devices like stackers, cardboard tubes or egg trays for crickets).
- Hand-selecting of insects is also sometimes practiced.

14.11. Imports of insect species.

If the insect species is not aboriginal, it would not be able to survive in nature if it escaped. Further, it should not be a danger to humans, animals, plants, or the biodiversity. Environmental risks of replacing the current livestock systems with insect farming systems should be considered, especially, danger for humans, plants, animals, and biodiversity. To prevent invasion of unwanted insect species to the environment in Europe, European insect producers must follow EU environmental laws, see “Regulation (EU) No 1143/2014. Prevention and management of the introduction and spread of invasive alien species”, restricting the number of eligible insect species that are allowed to produce in Europe.

14.12. The International Platform of Insects for Food and Feed (IPFF) 2019

The objective of the is to help insect producers achieve a high level of consumer protection and animal health through the production of safe products. The Guide covers the following activities:

1. The production of insects for human consumption.
2. The production of insects as feed for food producing animals.

Insects intended for animal feed use must be registered as ‘feed business operators’ by national authorities (Regulation (EC) 183/2005). Insects and their derived products, intended to be used in animal feed are considered as ‘animal by-products’ – i.e. animals and products from animals that are not intended for human consumption – under EU Law.

Producers of processed animal proteins derived from insects or insect derived fat intended for animal feed must be approved before national competent authorities. These activities of food and feed producers in the European Union (in most cases, also Norway) are regulated by EU through different documents defining general standards the ‘General Food Law’ in the area of food/feed safety (Regulation No 178/2002) and the ‘Hygiene Package’ (Regulation No 852/2004 on the hygiene of food and Regulation No 183/2005 – listing requirements for food/feed hygiene).

Farmed animals mean (see The European regulation No 1069/2009): any animal that is kept, fattened or bred by humans and used for the production of food, wool, fur, feathers, hides and skins or any other product obtained from animals or for other farming purposes. Insects are considered as a “farmed animal" by the European legislation and therefore is submitted to strict feed regulation.

Feed/substrate for insects – allowed and not allowed

Allowed

According to the EU Catalogue of Feed Materials (Regulation (EU) No 2017/1017) former foodstuffs are “foodstuffs, other than catering reflux, which were manufactured for human consumption in full compliance with the EU food law, and no longer intended for human consumption.

Insects may only be fed with eligible materials for farmed animals: i.e., materials of vegetal origin and/or animal origin such as:

- fishmeal.
- blood products from non-ruminants
- di and tricalcium phosphate of animal origin
- hydrolysed proteins from non-ruminants
- hydrolysed proteins from hides and skins of ruminants
- gelatine and collagen from non-ruminants
- eggs and egg products
- milk, milk based-products, milk-derived products and colostrum
- honey
- rendered fat

Substrates commonly used by EU insect producers includes:

- Cereal-based materials (e.g., wheat bran, chaff bran, bruised rye, oatmeal, grass, brewery/ distillery grains)

- Fruits and vegetables and their derived products

When using commercial compound feed, insect producers must comply with applicable restrictions and/or prohibitions - e.g., insect producers must ask guarantees to their suppliers as to the absence of feed additives that is prohibited in insect feed.

These have to be free from packaging residues, in accordance with EU legislation.

In most cases insects must be fed with feed ingredients of vegetal origin. Several exceptions apply (see above). Additionally, exceptions are admitted for materials of animal origin: Blood products from non-ruminant animals, exception will also include slaughterhouse rest raw materials from aquaculture and fish farming, e.g. blood and rest raw material from fish production.

Not allowed

The European regulations on animal by-products (1069/2009), prohibits use of animal by-products or derived products as this may negatively influence public or animal health, e.g. foot-and-mouth disease, mad cow disease, and dioxin (Lähteenmäki-Uutela and Grmelová, 2016).

Animal by-products (see European regulation No 1069/2009) means entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption.

According to the European regulation No 1069/2009, "derived products" means products obtained from one or more treatments, transformations or steps of processing of animal by-products; problems of manufacturing or packaging defects or other defects and which do not present any health risks when used as feed. Further, former foodstuffs not containing meat or fish can be used as feed (Lähteenmäki-Uutela and Grmelová, 2016).

Annex III of Regulation (EC) No 1069/2009 prohibits the use of certain materials that could be used to feed insects, including:

1. "Feces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract, irrespective of any form of treatment or admixture"

2. "Seeds and other plant-propagating materials which, after harvest, have undergone specific treatment with plant protection products for their intended use (propagation), and any by-products derived therefrom".

3. “Solid urban waste, such as household waste”.

4. “Packaging from the use of products from the agri-food industry, and parts thereof”. Therefore this regulation prohibits the use of some animal protein sources that might be suitable as feed for insects, like manure and gut content, dead-shell poultry, and fallen stock (van der Fels-Klerx, 2013).

The feeding of catering waste (i.e. Regulation 1069/2009 - article 11 (b)), ‘former foodstuffs’ containing meat and fish is not allowed.

Insect producers

There are several insect producers in Norway, Sweden and Finland. Startups will depend on competence and knowledge on biological, technological and EU regulatory aspects of culturing insects as described above.

In the Kolarctic area there are only one insect producer (Nordland), and a contact is established. To get a better insight into the potential and status of insect production, a visit and meeting was conducted at their production site. According to this producer, insects have a large potential as fish feed ingredient. Several of the side streams from different processing steps may also be considered as feed for insects, and several of side streams described in the present report may be considered valuable ingredient in feed for insects. Companies will have the possibilities of being updated on the development and status of alternative fish feed ingredients.

Further details on insect feed quality based on seaweed will be clarified after the trials have been conducted in future. Seaweed side streams, and surplus macroalgae from culture, from production of polyphenols will be further processed as necessary, dried, grinded, and sieved to particles less than 150 micrometer to be suitable feed particles in feed to black soldier larvae.

14.13. Conclusions

Per 2022, insects are not produced in sufficient volumes to be used in commercial fish feed production. However, insects show a great promise as sustainable ingredients for future aquafeed production.The possibility of using insects as feed ingredient for fish is a very promising option in the future. However, the realization of this strongly depends on the availability of cheap feed ingredients for insects. Some of these possibilities are listed in the present section (see above). However, ingredients for insects should be low priced products. Many of the listed possible of raw material etc. for have some drawbacks both as availability in Nordic countries and in in general legal status and permission to use the material for feed. At an economic point of view, the costs of production is very important. During processing of seaweed for extraction of valuable compounds, often more than 90% of the total raw material are considered waste. In general, seaweed is a highly nutrient rich foodstuff with favorable content of minerals, vitamins, fiber, and protein. Side streams from processing this material may be used as feed for insects in a loop of circular economy**.** However, many of the already tested sources of rest raw materials/sidestreams may not be readily available for feed to insects, or allowed in the Nordic/EU countries. To reduce cost of transport and ensure sustainability in production, insect feed should be collected locally/regionally. Insect oil may not represent a realistic alternative to fish oil as it does not naturally contain omega-3.

Potentially, insects can be produced in large quantities and at a low and stable price. Insect farming does not require intensive labour force (as it may be highly automated). Insect production as part of a circular economic production may become a reality in the future. This depends on the availability of cheap ingredients for feeding insects are available.

The products of insects are still very expensive, because production cost is high and the production is still very small.Economic viability of insect production and development of large scale highly automated production will largely depend on future availability of turn key production lines. In near future, insect meal may constitute a good alternative to fishmeal from an economic point of view. The availability of insect meal will increase, and are expected to develop into a stable priced source of protein.

Download *Animal Welfare in Insect Production*

Download *Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption.*

Download *Regulation (EU) No 142/2011 implementing Regulation (EC) No 1069/2009.*

Download *Regulation (EC) No 999/2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (TSE Regulation).*

15. TECHNOLOGY FOR FEED PRODUCTION

15.1. Equipment, techniques and machines for feed production

Dry feed will cover around 36% of the total aquafeed demand in 2019 (Allaboutfeed, 2021).The dry feed can be produced by either cold pelleting or an extruder. Extrusion involves high pressure (20–30 bar), high temperature (120–130 ◦C), and shear forces (Dalbhagat et al., 2019). The microalgae can affect the extrusion process (Gong et al., 2020). E.g., lipids may act as a lubricant in the extruder barrel and reduce the viscous heat dissipation and lowering pellet quality (Samuelsen et al., 2018). The recommended maximum lipid level for making fish feed pellets by using an extruder, 120 g/kg (Rokey, 1994). When a high lipid feed (>30%) is needed, oil has to be coated on the dried pellet using a vacuum coating process, similar to salmon feed (Samuelsen et al., 2018). Extrusion may have a positive effect on nutrient availability and digestibility (Gong et al., 2018) as this may break the cells of macroalge, as well as the cell walls of microalgae However, the extrusion process may degrade the functional compounds of both macro and micro algae. Thus, to avoid this cold pelletization techniques may be an option.

During Artaqua meeting in Netherland 2022 with representatives of three companies involved in /owners of turn key fish feed factories, feed/technology at different locations was visited. Information given in the present section originates mostly from these meetings, their information folders, web pages and public available information.

Dry feed will cover around 36% of the total aquafeed demand in 2019 (Allaboutfeed, 2021). The dry feed can be produced by either cold pelleting in a feed mill or an extruder.

15.2. Pelletization in mills

Pellet mills can be used for making sinking feeds and when fat requirements are below ca. 10 percent. The pelletization is conducted in a pellet mill by compression of raw material. Moisture, temperature, and pressure are important parameters to control. Pelletized feeds are dense and heavy and used as sinking feed.

15.3. Extrusion

The extrusion process can make feeds that are both sinking and floating. Extrusion is dominated as method in the production of fish feed. The ability to control the buoyancy of feeds, makes extrusion a superior choice in most cases. This process allows better control of the buoyancy of the feeds and is more easily controlled as compared to pelletizing. Optimal buoyancy is obtained by control of temperature and moisture, the extruder screw profile and screw speed. During extrusion the feed is compressed, cooked, with higher levels of moisture, temperature, and pressure. Extrusion involves high pressure (20–30 bar), high temperature (120–130 ◦C), and shear forces. Lipids may act as a lubricant in the extruder barrel that may reduce heat and improve pellet quality (Samuelsen et al., 2018).

The recommended maximum lipid level for making fish feed pellets by using an extruder is 120 g/kg. When a high lipid feed (>30%) is needed, oil has to be coated on the dried pellet using a vacuum coating process, similar to salmon feed. Extrusion may have a positive effect on nutrient availability and digestibility (Gong et al., 2018). E.g. by breaking the cells/cell walls of macroalgae and microalgae, providing better availability of the nutrients from these ingredients. However, the extrusion process may degrade the functional compounds of both macro and micro algae. Thus, to avoid this cold pelletization techniques may be an option.

The gelatinized starch, along with protein and fiber, acts as a glue and increases the integrity of feeds. The floatability of the feed is merely determined by the starch level, where around 10% starch gives a sinking feed and around 20% starch a floating feed. The expansion of cooked and melted starch is the most important cause to make the feeds float. In a single screw extruder both types of feeds may be produced. Moreover, in the single screw extruder, the mixing capability is limited, and any flow restrictions lead to reduced throughput of the extruder.

There is a wide diversity of specialized screw designs. This allows mixing and shearing to be precisely adjusted, providing better control of mixing degree and quality. When considering investment in feed production, a comparison between pellet mills, twin screw and single screw extrusion is an important task to do before investing in feed production technology.

15.4. Twin screw extruder

Twin-screw extrusion is widely used in the feed industry. The process includes several operations that includes mixing, cooking, kneading, shearing, shaping, and forming. Selecting the best extrusion system is very important, as single screw extruders gives lower capital cost and simplicity, but twin screw extruders provide higher quality and a wider range of products.

With a twin screw, high process flexibility, throughput, and screw speed independence, handling many processing functions in series is possible. In a single screw extruder, throughput and screw speed are dependent, and screw designs provides fewer processing functions.

Twin screw extruders offer higher business potential and economic opportunities than single screw extruders. Owing to its higher productivity and process flexibility, twin screw extrusion offers a wider range of end products and handle product quality more consistently.

15.5. Economy, performance, and retention of nutrients in feed

The economics of feed production is related to important factors such as: manufacturing cost, cost savings due to formulation, and feed performance. The production cost is higher for extruded pellets because the cost of the equipment is higher than for a pellet mill. Also, the production capacity of the extruder for the same motor capacity is lower than for a pellet mill.

The quality of the feed is linked to the nutrient content, including micronutrients, in the feeds. In the extrusion process factors like moisture, shear and oxidation may have negative effect on vitamin stability. During extrusion a higher temperature (>90°C) is used than under pelletization in mills, in which temperature are seldom above 90°C. Fat soluble and water soluble are all effected by the different production parameters, such as temperature, moisture, and shear. Vitamin A and D are more susceptible to oxidation during extrusion and the presence of heat and moisture in the process increases the oxidation. The water-soluble B vitamins, B1 and B6 are unstable. Most of lso, L-ascorbic acid are destroyed during extrusion. Thus, more stable and heat resistant forms are used. The losses of vitamins, especially fat-soluble vitamins are lower in pelleted feeds than in extruded feeds. This may be caused by lower shear, heat and pressure during pelletization in mills.

Selection of ingredients depends on the type of process used for making feeds. Pellet mills use compressive force to bind the pellet together. Use of higher quality raw material and additional binders is important. E.g. higher starch amounts in pelleted feeds is often used as compared to extruded feeds. As lower volume of starch is needed in extruded feeds, additional protein ingredients may be added to meet the protein requirements in the feed. This may balance the costs in comparison with pellet feed as the formulation cost would be lower in extruded feeds.

The feed impact and performance is based on the feed conversion ratio (FCR). FCR is calculated as the volume of feed fed divided by the increase in weight of the fish. The lower the FCR, better is the feed performance. Pelleted feed are conditioned by the use of steam, however the starches and proteins are not fully cooked. In contrast to the production in an extruder where the high heat and pressure cook these nutrients making them more digestible. Thus, extruded feed is more easily digested, and ingredients are utilized more efficiently, giving lower FCR for extruded feeds as compared to pelleted feeds. Additionally, FCR of pelleted feeds increases as they produce more fines/dust that are lost during feeding. Lower FCR would means lower cost to produce every kilogram of fish produced, thus increasing the income for the fish farmer.

Meetings with companies fish feed technology – turn key feed factories

15.6. Feed Design Lab (FDL)

Feed Design Lab has three primary activities: renting out their plant, providing training and developing projects. Feed Design Lab do research, training and trial feed production within the same institute. Feed Design Lab is the leading practical research and education center for innovation and sustainability in the animal feed sector. E.g., students can do their practical studies at this lab. It is also possible to arranges short stays for students and others to participate in feed production as an introduction to feed production.

The FDL facilities are established as a vertical construction with different activities at different floors. According to the representatives of FDL this organization saves work and may be a very practical way of organizing feed production in a commercial fish feed production.

15.7. Almex

Almex is an independent company that specializes in single screw extrusion equipment, from the extrusion unit to complete installations. Almex extruders and Contivar Expanders are in use worldwide at fishfeed-, oil extraction-, petfood- animal feed plants, the food industry and the processing and chemical industries.

Almex was the first company using DC drives on single screw extruders in order to select the extrusion shaft speed to match the product and selected die specifications.

15.8. Ottevanger Milling Engineers & Aqua Feed Manufacturing

Aquatic feeds have very high requirements in terms of both nutritional and physical characteristics of feed. These nutritional and physical feed requirements are driven by the life stage of a specific species under consideration. Physical characteristics include issues such as pellet size and shape; pellet density allowing us to produce floating, slow sinking and sinking feeds; water stability and pellet durability. The challenge is to achieve all of these while having a negligible effect on the environment. Ottevanger Milling Engineers keep these and other project specific issues in mind when designing an aquatic feed processing plant.

The choice of equipment, technologies, processes, and equipment is, therefore, the key to success. The company consults their customers to fully understand their requirements and the specific market the customer is serving.

During the meetings in Holland, several opportunities were discussed for establishing feed production plants. The companies had the possibilities to be consultants, producers and liaison between other companies for establishing turn key feed plants. and is a very solid constellation for further collaboration. These three companies expressed their interest in collaboration in future activities on feed production.

16. Final conclusions

In the present report, the focus is on innovative fish feed solutions for a competitive and sustainable aquaculture industry in Nordic countries, especially focusing on available feed ingredients and feed production in the arctic area.

There is a rapid growth of the global aquaculture industry leading to increased demand for fish feed ingredients. In turn, this will lead to increased national and international competition and increased market prices for feed ingredients such as fish meal, soy products, and rapeseed. This may significantly impact the operating costs of markedly small-scale fish farmers and small-scale fish feed producers in northern, remote locations that may suffer from increased prices, and difficulties in supplies of feed ingredients.

Lack of sufficient essential feed ingredients and high levels of plant ingredients in feed may result in imbalanced fish feed that may affect fish health, welfare, and growth.

Production of fish feed using local available feed ingredients such as micro and macro algae, side steams from aquaculture and fishery production, new hitherto unexploited natural marine resources such as meso-pelagic fish, benthic organisms and zooplankton should be further elucidated in fish feed production in Northen countries. Use of local/regional resources may increase the profitability of the fish feed producers and increase the sustainability of the aquaculture industry.

Many of the fore mentioned potential fish feed ingredients are not readily available, but at are different levels of complexity as raw material. Several potential ingredients are under focus for further development and may be available as feed ingredients the coming years.

As a major supplement and replacement of imported feed ingredients, use of local feed ingredients, following principles of circular economy, would strengthen the sustainability and the "green" image of aquaculture in the arctic area.

17. Abbreviations

EFSA European Food Safety Authority (Den europeiske myndighet for næringsmiddeltrygghet)

TWI Tolerable Weeky Intake (tolererbar ukentlig mengde)

CEVA Centre d'Etude et de Valorisation des Algues (senter for studie og promotering av alger)

WHO World health organization (Verdens helseorganisasjonHO World health organization (Verdens helseorganisasjon

European Commission, Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, Scientific opinion on food from the oceans, 2021, https://data.europa.eu/doi/10.2777/436052

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