A Nordic approach to food safety risk management of seaweed for use as food

Nordic Council of Ministers

Contents

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Terms and abbreviations

The following definitions and abbreviations are used in this report:

ALARA	As Low As Reasonably Achievable
ANSES	French Agency for Food, Environmental and Occupational Health & Safety
BfR	The German Federal Institute for Risk Assessment
CEVA	Algae Technology & Information Centre
CFU	Colony forming unit
DVFA	Danish Veterinary and Food Administration
EC	European Commission
EEA	European Economic Area
EFSA	European Food Safety Authority
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Heavy metals	In this report heavy metals refer to cadmium, lead, mercury, and inorganic arsenic
IMTA	Integrated multitrophic aquaculture
LOD	Limit of Detection
ML	Maximum Level
MRL	Maximum Residue Level
NFSA	The Norwegian Food Safety Authority
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
PFAS	Perfluoroalkyl substances
RASFF	Rapid Alert System for Food and Feed – the European reporting system where information about food hazardous to health is exchanged between the EU Commission, EU Member States, EFTA, ESA, Norway, Liechtenstein, Iceland, and Switzerland
SCF	Scientific Committee for Food (now EFSA)
TWI	Tolerable Weekly Intake
WHO	World Health Organization

Executive summary

Background

Interest in using seaweed as food is growing in Nordic countries and in other countries in Europe.

Seaweed is the biggest aquaculture product in the world, yet there are still no international standards on food safety, such as Codex standards or guidelines. The EU is also lacking specific legislation on food safety for seaweed.

In Europe there is limited experience of using seaweed, and little is known about potential risks and benefits to human health when it is consumed. Risk management of foodstuffs based on seaweed is therefore a challenge. Guidance is needed for both producers and public agencies to ensure food safety, to facilitate uniform control and trade, and to support innovation and growth in this sector.

A common Nordic approach is called for, in view of the differences, both globally and within Europe, in tradition, food culture, production methods, seawater quality, and types of seaweed species used. Nordic species and production conditions should be considered in future development of legislation in EU and also of global standards.

The scope of this report covers food safety aspects of seaweed used as food, with the main focus on currently identified chemical and microbiological food hazards. Aspects outside the scope of this study are refined industry products such as alginate and carrageen, potential health benefits of eating seaweed, legislation on organic production, and self-picking of seaweed by consumers.

Status in the Nordic countries and identified food hazards

Existing production and risk management of seaweed used as food in Denmark, the Faroe Islands, Iceland, Norway, and Sweden, are described. Nordic seaweed species currently relevant for food are listed, including their respective novel food status, as well as ranges of their heavy metals and iodine content.

Based on current knowledge, the most crucial food hazards relevant for seaweed harvested in the Nordic countries are iodine, cadmium, and inorganic arsenic. Iodine is an essential micronutrient, but both insufficient and excessive intake may pose health problems. Some food products based on seaweed contain very high levels of iodine, which is why iodine is classified as a hazard in this context.

Other important food hazards to be considered are lead and mercury, *Bacillus* spp in heat-treated products, kainic acid in dulse, and allergens. Several other possible hazards are also discussed in this report.

There is currently a shortage of data on food hazards in seaweed, and this should be kept in mind. Knowledge concerning food safety in seaweed is increasing, but more data is needed to ensure proper risk assessments. The type, level and ranking of food hazards in seaweed in Nordic countries may change in the future as research produces new data, and conditions may be altered by climate change, such as increased sea temperature. New seaweed species may also be introduced into Nordic waters.

Variations in levels of heavy metals and iodine within and between seaweed species

The levels of heavy metals and iodine vary greatly between and within species, and can be affected by age, growing conditions, and processing methods.

The data on iodine, cadmium, inorganic arsenic, lead, and mercury in seaweed from Denmark, the Faroe Islands, Iceland, Norway, and Sweden confirm great variabilities both between and within species. Differences between species seem to be quite similar in the Nordic countries.

Despite the shortage of data available for this report, there is enough to at least give an indication of which species present the greatest challenges in terms of heavy metals and iodine in Nordic seaweed production.

In general, the brown algae have the highest iodine content, with the highest levels found in the species sugar kelp, winged kelp, oarweed, and tangle. Red and green algae species have lower levels of iodine than the brown algae, except for the red algae wrack siphon weed. Oarweed can have exceptionally high levels of inorganic arsenic, while cadmium levels are highest in several brown and red algae.

Legislation and future considerations

The current status of EU legislation regarding food safety aspects is discussed. Legislation on foodstuffs other than seaweed is presented to illustrate existing legislation on food safety hazards. It is also emphasised that legislation applying to a specific foodstuff is not directly applicable for other types of foodstuffs.

Regardless of the current limitations of legislation specific to seaweed, the general requirements in EU food legislation apply for all types of foodstuffs, including seaweed.

Food business operators are responsible for ensuring that foodstuffs placed on the market must be safe to consume.

Compared to other organisms used as food, such as terrestrial plants like vegetables, fruits and mushrooms, seaweeds have different properties and growth environment and might also differ in terms of bioavailability of the food hazards. In addition, seaweed may be consumed in different amounts and patterns than other foodstuffs. The great differences between seaweed species and the effect of age, growing conditions, and processing methods on the levels of food hazards should also be considered in future legislation.

The authors of this report strongly recommend development of a harmonised legislation on food safety in seaweed. In such legislation, seaweed should be classified as a specific group of foodstuffs, with subgroups for different seaweed species.

In the near future, the EU Commission is expected to evaluate risk management options for heavy metals and iodine in seaweed. This work will be welcomed by the food authorities in Denmark, the Faroe Islands, Iceland, Norway, and Sweden.

1 Introduction

1.1 Background

The Nordic countries have a long history of using seaweed in various ways, but in modern times it has not been a tradition to use seaweed extensively as food, apart from in industrial production of polysaccharides such as alginate.

However, interest is now growing in using seaweed in Nordic and other European countries, mainly because of the focus on a greener and more sustainable economy and consumers' search for healthy and sustainable food.

Seaweed is considered to be a valuable food resource in the world, and production has many sustainable characteristics (FAO, 2022). The European Commission has launched an initiative that will focus on how to increase sustainable algae production, ensure safe consumption, and boost the innovative use of algae and algae-based products in Europe (EC, 2021).

Despite seaweed being the biggest aquaculture product in the world, with significant global trade (FAO, 2020), there are still no international standards on food safety, such as Codex standards or guidelines. Some of the significant gaps in regulations for food safety in seaweed, along with an overview of food safety concerns in seaweeds, are identified in a FAO-WHO report (FAO and WHO, 2022).

The EU also lacks specific legislation on food safety in seaweed. The European Food Safety Authority (EFSA) has identified consumption of seaweed as an emerging risk, and the EU Commission has recommended monitoring of heavy metals and iodine in seaweed as a background for future risk management of seaweed as food and feed (EC, 2018).

There is limited experience of using seaweed as food, and knowledge is lacking about potential risks and benefits for human health relating to its consumption in Europe. Risk management of seaweed-based foodstuffs is a challenge, due to lack of knowledge and specific legislation and the many new business operators in the sector. Guidance for both producers and public agencies is required to ensure food safety, to facilitate uniform control and trade, and to support innovation and growth in this sector.

Regional differences, both globally and in Europe, in tradition, food culture, production methods, seawater quality, and types of seaweed species in use, favour a joint Nordic approach to the issue. This would support appropriate guidance for producers and food agencies in the Nordic region and ensure that Nordic species and production conditions are considered when legislation is developed in the EU.

1.2 Objectives

The purpose of this report is to help develop a common Nordic approach to risk management of food safety in seaweed. The main goal is to identify food safety issues in seaweed in general, with a specific focus on conditions relevant for the Nordic countries involved in the project, i.e. Denmark, the Faroe Islands, Iceland, Norway, and Sweden.

The report can be used as a basis for developing guidance for food agencies and businesses, and for harmonising the risk management of seaweed used as food in the Nordic countries. The report may also contribute to future development of risk management of seaweed in the EU, as well as in Codex Alimentarius.

1.3 Scope

The report covers food safety aspects of seaweed used as foodstuff, with a main focus on chemical and microbiological food hazards.

Some aspects of seaweed are not included in the scope, i.e. refined industrial products such as alginate and carrageen, potential health benefits of eating seaweed, legislation on organic production, and self-picking of seaweed by consumers.

1.4 What is seaweed?

In order to understand food safety aspects in seaweed and to develop regulatory frameworks, it is important to have some familiarity with the properties and growing conditions of these organisms.

Seaweed, also named macroalgae, is a large and diverse group of multicellular photosynthesising algae, living predominantly in salt and brackish waters. Seaweed can be sub-divided into three groups:

- Red algae (Rhodophyta)
- Green algae (Chlorophyta)
- Brown algae (Phaeophyta)

Only the green algae are classified together with terrestrial plants in the phylum Plantae, but all three groups of macroalgae are often named as plants. One group of seaweed is referred to as kelp, which are large brown algae seaweeds making up the order Laminariales.

The distribution of seaweed species varies according to water depth. Typically, green algae live in the top and middle depth layers, and brown algae are found in the middle layer. Red algae can be found at all depths but dominate at deep and middle sea depths. Some seaweeds are perennial, living for many years, while others are annuals. Annual seaweeds generally begin to grow in the spring and continue throughout the summer.

Seaweeds do not have roots but are attached with a basal structure (holdfast), allowing them to attach to solid substrates like stones. Unlike roots, holdfasts do not take up nutrients. Seaweed does not grow stems like terrestrial plants. A leaflike, often flattened structure (lamina or blade) emerges from a structure called a stipe. The youngest part of the blade is situated in the proximal end and may have different composition to the older parts. The blades of the kelp age, wear, and fall off over time, and thereby comprise annual parts of the kelp, whereas the stipe is perennial. The same applies to, for example, the red algae dulce, while the green algae sea lettuce is predominately annual.

The chemical composition of seaweed differs from other types of seafood and also from terrestrial plants, in the high content of specific polysaccharides in the structural components of the algae. The types of polysaccharides vary in the brown, red and green algae. The polysaccharides have metal-binding characteristics that may affect both the levels of metals and other components in the algae and the availability of these components through the human digestion processes (Duinker *et al.*, 2016).

Both nutrients and contaminants are taken up and adsorbed directly through the blades. Seaweeds are not filter-feeders like mussels, so seaweed should not be treated in the same way as filter-feeders in legislation.

As seaweed also have quite different properties and growth environments to terrestrial plants, such as vegetables, fruits and mushrooms, seaweed should be classified in a specific group in respect to food legislation.

1.5 Primary production of seaweed

Seaweed can be produced by aquaculture or harvested from wild stocks in the sea. Aquaculture takes place mainly in the sea but can also be land-based. Seaweed can be grown as a monoculture or with other organisms in integrated multitrophic aquaculture (IMTA). Wild stocks are harvested through trawling, using smaller harvest equipment, or picked by hand.

Diseases and pests in seaweed aquaculture in Asia are described by Ward *et al.* (2019). In Nordic production, diseases, use of fertilisers, algicides, or pesticides are not yet reported, but agrochemicals can enter the marine environment through runoff from agricultural fields.

In land-based production the water quality can be manipulated for optimum conditions, giving the best yield and reducing levels of contaminants. For example, there is ongoing research on the effect of land-based production in different kinds of nutrient-rich food process waters (Stedt *et al*., 2022a and b).

There are some national regulations on wild harvesting and aquaculture of seaweed in the Nordic countries, such as requirements regarding where and how to harvest, but this is outside the scope of this report.

1.6 Use of seaweed

Seaweed is traditionally used for food, feed, soil fertilisers, and plant biostimulants in many countries, but is also used in cosmetics, medicine, biofuel, and packaging. There is an extensive production of several industrially produced hydrocolloids from seaweed for use as food additives, such as alginate, carrageen, and agar, used as thickeners, gelling agents, stabilisers, and emulsifying agents in a variety of food and other products. The amount of seaweed used for direct human consumption as food in Europe is still limited compared to Asian countries.

FAO (2022) reports on several properties of seaweed that are relevant for food and potential health aspects, such as mineral and vitamin content and high levels of soluble dietary fibres, and some species can be good sources of protein. Certain bioactive components from various seaweed species have been suggested to confer properties beneficial to health.

1.7 Legislation on food safety in seaweed

There is little specific legislation on food safety of seaweed, such as maximum levels (MLs) for actual food hazards. This is the status globally, including the EU. Discussions are ongoing regarding the need for more regulation on food safety in seaweed, both in the EU and in Codex Alimentarius.

However, general legislation on food applies for all types of food, including seaweed. Regulation (EC) No 178/2002 lays down the basic principles to protect human health and consumer interests. Article 14 in this regulation refers to general food safety requirements and stipulates that food must not be placed on the market if it is not safe to consume. More details about the EU legislation are given below for each hazard.

EU legislation concerning food safety also applies to Norway and Iceland through the EEA agreement.

2 Production and use of seaweed in the Nordic countries

2.1 Seaweed species used as food and their novel food status

Several seaweed species can be found in Nordic waters. Those that may be used as food are shown in Table 1, with English, Latin and Nordic names.

Seaweed species are classified as novel foods if they have not been consumed to a significant degree by humans in the EU before 15 May 1997, according to the Novel Food Regulation (Regulation (EC) 2015/2283). Novel food must be approved according to a specific procedure before marketing in the EU/EEA. It is the responsibility of the food business operator to document consumption of the foodstuff in the EU prior to May 15, 1997. Seaweed that is not novel food may be marketed as foodstuffs, provided that the product is safe according to Article 14 in Regulation (EC) No 178/2002.

Some Nordic species are not novel food, while for others the novel status has not yet been determined. Some of the most used species, like sugar kelp, winged kelp, dulse, and sea lettuce, are classified as not novel food.

Table 1. Nordic seaweed species used as food, and their novel food status in EU

Category	English name	Latin name	Nordic names	Novel food status (JRC, 2021)
Brown algae	Rock weed, egg wrack	*Ascophyllum nodosum*	NO: Grisetang DK: Buletang SE: Knöltång IS: Klóþang FO: Bólatari	Not novel
	Bladderwrack	*Fucus vesiculosus*	NO: Blæretang DK: Blæretang SE: Blåstång IS: Bóluþang FO: Bløðrutur skúvtari	Not novel
	Toothed wrack or serrated wrack	*Fucus serratus*	NO: Sagtang DK: Savtang SE: Sågtång IS: Sagþang	Not novel
	Spiral wrack or flat wrack	*Fucus spiralis*	NO: Kaurtang, spiraltang DK: Lav klørtang SE: Spiraltång IS: Klapparþang FO: Snúgvin skúvtari	Not novel
	Channelled wrack	*Pelvetia canaliculata*	NO: Sauetang DK: Furetang IS: Dvergþang FO: Vanligur Seyðatari	Novel food status not determined
	Sea lace	*Chorda filum*	NO: Martaum, åletang DK: Strengetang SE: Sudare IS: Skollaþvengur FO: Klænur marbendil	Novel food status not determined
	Sea spaghetti	*Himanthalia elongata*	NO: Remmetang, knapptang DK: Remmetang SE: Remtång Is: Reimaþang Fø: Langvaksin Reipatari	Not novel food
	Sea oak	*Halidrys siliquosa*	NO: Skolmetang DK: Skulpetang SE: Ektång	Novel food status not determined
	Wireweed	*Sargassum fusiforme*	NO: Japansk drivtang DK: Hijikitang SE: Hijiki	Novel food status not determined

	Sugar kelp	*Saccharina latissima*	NO: Sukkertare DK: Sukkertang SE: Sockertång IS: Beltisþari FO: Breiðbløðkutur sukurtari	Not novel food
	Oarweed	*Laminaria digitata*	NO: Fingertare DK: Fingertang SE: Fingertång IS: Hrossaþari FO: Tarablað	Not novel food
	Winged kelp	*Alaria esculenta*	NO: Butare DK: Vingetang (wakame) SE: Havskål IS: Marínkjarni FO: Tang	Not novel food
	Tangle	*Laminaria hyperborea*	NO: Stortare DK: Palmetang SE: Stortare IS: Stórþari FO: Tonglatarablað	Novel food status not determined
Green algae	Sea lettuce	*Ulva fenestrata* (synonym: *Ulva lactuca*)	NO: Havsalat DK: Søsalat SE: Havssallat IS: Maríusvunta FO: Blaðslýggj	Not novel food
	Gut weed, mermaid's hair	*Ulva intestinalis* (synonym: *Enteromorpha intestinalis*)	NO: Tarmgrønske DK: Tarmrørhinde SE: Tarmalg IS: Slafak FO: Leggslýggj	Novel food status not determined
	Sponge seaweed	*Codium fragile*	NO: Pollpryd DK: Plysalge SE: Klykalg IS: Hafkyrja	Novel food status not determined
Red algae	Dulse, dillisk	*Palmaria palmata*	NO: Søl DK: Søl SE: Söl IS: Söl FO: Søl	Not novel food
	Purple laver	*Porphyra purpurea*	NO: Purpurfjærehinne DK: Rød purpurhinde SE: Purpursloke FO: Reyð purpurhinna	Novel food status not determined

Laver, laverbread, tough laver	*Porphyra umbilicalis*	NO: Vanlig fjærehinne DK: Noritang SE: Navelsloke IS: Purpurahimna FO: Nalva purpurhinna	Novel food status not determined
Wrack siphon weed	*Vertebrata lanosa*	NO: Trøffeltang, Grisetangdokke DK: Uldtottet ledtang SE: Tryffeltång IS: Þangskegg FO: Loðin skeggtari	Novel food status not determined
Irish moss, carragenan moss	*Chondrus crispus*	NO: Krusflik DK: Carrageen tang SE: Karragenalg IS: Fjörugrös FO: Ývin brósktari	Not novel food
Gracilaria seaweeds	*Gracilaria gracilis*	NO: Pollris DK: Gracilariatang SE: Späd agaralg	Novel food status not determined
Gracilaria seaweeds	*Gracilaria vermiculophylla*	DK: Brunlig gracilariatang SE: Grov agaralg	Novel food status not determined

2.2 Food products

Seaweed is sold fresh or after processing, such as drying, blanching, freezing and fermentation. Nordic species are sold and used as ingredients in foodstuffs such as spices, bread, pesto, fish cakes, beverages, and food supplements, but also as a main ingredient in snacks/crisps, soups, salads, pasta, and smoothies. The imported species nori, kombu, and wakame are possibly the most used species in the Nordic countries, commonly used in sushi and other Asian dishes.

2.3 Status in the Nordic countries

Production of seaweed for human consumption is increasingly in focus in the Nordic countries. The food agencies have published some guidance for consumers and producers.

Denmark

Cultivation and production of seaweed in Denmark is increasing. Seaweed is generally considered a sustainable product for food and feed, and research and development of new products is ongoing. There is great interest in starting various kinds of businesses involving seaweed. Some business operators harvest fresh seaweed to be sold to restaurants, as well as directly to consumers. Others harvest seaweed in larger amounts and sell it as dried seaweed to industry and directly to consumers.

The Danish Veterinary and Food Administration (DVFA) has provided advice and guidance for consumers (DVFA, 2021; DVFA, 2022), and for food business operators (DVFA 2022a) on production, harvest, and consumption of seaweed.

The Faroe Islands

Seaweed cultivation in the Faroe Islands is a growing industry but, as yet, only two companies produce seaweed. The products are dried and frozen seaweed and also fermented seaweed for the feed industry. The main species are sugar kelp, winged kelp, oarweed, dulse and laver.

Iceland

There is a long tradition of using seaweed in Iceland, in particular dulse, probably since the first Nordic settlers arrived. Seaweed has been harvested on an industrial scale on the west coast of Iceland since 1974. The harvested species are rockweed and oarweed, which are dried and processed as algal meal. The dried product is used mainly as raw material for alginate production but also to a lesser extent as feed. There is also small-scale harvesting of dulse and other species for human consumption. There is currently no cultivation of seaweed in Iceland, but interest is growing.

Norway

There is a long history of seaweed use in Norway, dating back to the Norse era (Indergaard, 2010), but the degree of use directly as food has been very limited in modern times. However, for decades Norway has a history of wild harvesting of kelp for industrial production of refined polysaccharides for use in food and other products. Harvest for use in commercial fertilisers and feedstuff also has a long history.

Today, production of seaweed in aquaculture is a growing industry, with food products as the main objective, but also for use as feed. The dominating species are sugar kelp and winged kelp. Some producers are testing the use of IMTA and land-based production. Norway is the third largest seaweed producer for wild harvest and aquaculture in the world (FAO and WHO, 2022), mainly tangle for producing alginate. An increasing number of small business operators do hand-harvest of wild stocks.

The Norwegian Food Safety Authority (NFSA) has provided dietary advice on seaweed to consumers (NFSA, 2016) and advice on food safety to businesses (NFSA, 2019). Norwegian seaweed producers have published a guideline on cultivation, harvesting and handling of sugar kelp and winged kelp (Norwegian Seaweed Association, 2021).

Sweden

Interest is growing in the use of seaweed as food and food ingredients in Sweden, as shown by the activities of researchers, trading companies, and primary producers. Currently, seaweed such as sugar kelp and oarweed are farmed. Other species farmed at sea are sea lettuce and dulse, and there is some minor harvesting of wild seaweed. Land-based production involves gutweed and dulse.

The Swedish Food Agency has issued general guidelines on possible high iodine levels in seaweed and seaweed products (Swedish Food Agency, 2022).

3 Food safety hazards

All types of environmental contaminants can end up in marine organisms, including seaweed. Environmental contaminants caused or increased by human activities include pathogenic microorganisms, pharmaceutical residues, micro- and nano-plastics, radionucleotides, and other waste products from industry, agriculture, and sewage. Hazards can also originate from growing, harvesting, transporting, and processing. Other hazards are natural constituents from the sea water or from the seaweed itself, like heavy metals, excessive iodine, and biotoxins. Pesticides and fertilisers intended for use in seaweed production may also be actual hazards, but these are not yet reported to be in use in Nordic countries.

3.1 Identification and ranking of food hazards

Available occurrence data show that seaweed may contain significant amounts of arsenic, cadmium, iodine, lead, and mercury. The European Commission has therefore recommended member states to monitor these components (EC, 2018). Norway and Denmark have reported such data to EFSA.

Reported alerts on hazards from seaweed in The Rapid Alert System for Food and Feed (RASFF) mostly concern iodine, but there are also some notifications of heavy metals and microbiological hazards.

There are some reports on hazard identification in Nordic seaweed.

The Norwegian Institute of Marine Research has evaluated several risk factors in seaweed used as food and feed, including inorganic arsenic, cadmium, mercury, lead, iodine, kainic acid, microbiological risks, marine biotoxins, anti-nutrients, persistent organic pollutants, microplastic, and radionuclides (Duinker *et al* ., 2016, Duinker *et al.,* 2020). It was concluded that cadmium, inorganic arsenic, and iodine are the most predominant risks in species grown in Norwegian waters. Levels of lead and mercury in the various seaweeds were reported as generally low. No concerning levels of radioactivity were found with respect to food safety. Regarding microbiological hazards, data on winged kelp and sugar kelp showed low microbial numbers for total aerobic count as well as low incidence of cold-adapted bacteria and spore-forming bacteria. No indicators of faecal contamination, such as enterococci and coliforms, were detected, nor pathogenic vibrios or *Listeria monocytogenes* . However, in several of the examined samples, spore-forming *Bacillus* spp. were isolated, and these seem able to pose a challenge if processing and storage conditions do not consider their possible presence. Continuous chilling is needed to prevent revival and growth of *Bacillus* spores in heat-treated products. *Bacillus* spores comprise a low risk for dried products and other products that are not heated.

A study of occurrence of iodine, cadmium, lead, mercury, and total arsenic in Danish seaweed samples concluded that seaweed consumption by the general population would entail a low health risk regarding mercury, cadmium, and lead (Monteiro *et al.*, 2019). The authors recommend that the levels of these elements should be monitored, and potentially in the future, MLs should be set up for seaweed used for food in Europe. For iodine, in addition to establishing MLs, the authors suggest that specification of the species on the label of the commercial products could be a way to reduce exposure to high levels of iodine. There was no conclusion on arsenic due to lack of data.

In addition to studies focusing on Nordic seaweed, other studies have examined food hazard identification in seaweed. An Irish report concluded that current hazards associated with seaweed for use as food posing the greatest risk to consumer safety are iodine and certain metals (FSAI, 2020).

Banach *et al.* (2020) ranked 22 food hazards in seaweed, based on current knowledge from the literature, data from the RASFF, and results from a stakeholder survey. They identified arsenic, cadmium, iodine and *Salmonella* as major hazards, and lead, mercury, aluminium, *Bacillus* spp. and norovirus as moderate hazards. For hazards identified as minor risks, there were gaps in the data for most of them. These were other pathogenic bacteria, hepatitis E virus, dioxins and polychlorinated biphenyl, brominated flame retardants, polycyclic aromatic hydrocarbons, fluorine, pesticide residues, pharmaceuticals, marine biotoxins, allergens, micro-and nanoplastics, and radionuclides.

In theory, there may be even more contaminants relevant for seaweed products, although not yet found in the literature. The type, level and ranking of food hazards in seaweed may also change in the future, due to conditions affected by climate change, such as increased sea temperature. New seaweed species may also be introduced into Nordic waters.

Based on the literature and the recommendation from the EU Commission to monitor certain components, this report primarily focuses on heavy metals and iodine. Microbiological hazards will also be considered to some extent. Most of the Nordic data and studies concern heavy metals and iodine.

3.2 Consumption data

The amount of seaweed used for direct human consumption in Europe and the Nordic countries is still limited compared to Asian countries, but little consumption data are available. It is important to compile accurate consumption data in order to perform a proper risk assessment. EFSA is requested to provide a scientific report on dietary exposure to heavy metals and iodine from seaweed in the European population (EFSA, 2022).

3.3 Legislation regarding heavy metals and iodine in seaweed

Maximum levels (MLs) of inorganic arsenic, cadmium, and lead in various foodstuffs are set in the EC Regulation on contaminants in foodstuffs (Regulation (EC) No 1881/2006). However, no MLs currently apply to these substances in seaweed, except for some MLs in food supplements. For mercury, a maximum residue level (MRL) for algae and prokaryotic organisms is set in the EC Regulation on MRLs of pesticides (Regulation (EC) No 396/2005).

Regardless of the current limited legislation specified for seaweed, the general principle in Regulation (EC) No 178/2002 applies, stating that the food business operators are responsible for ensuring that their food products are safe to consume.

In France some national recommendations on MLs are in place for inorganic arsenic, cadmium, lead, mercury, and iodine in edible seaweeds (CEVA, 2019, ANSES 2018, ANSES 2020) and in Germany for iodine (BfR, 2007). The Nordic countries have no national legislation or recommendations on acceptable levels of heavy metals and iodine in seaweed.

Although this report has its main focus on food, it is worth mentioning that for seaweed used in feed, there are some MLs in the Directive (EC) No 2002/32 on undesirable substances in animal feed.

Drying factors for seaweed

Occurrence data on heavy metals and iodine in seaweed, and MLs in legislation, are given on both a wet weight and dry weight basis. For example, MLs for heavy metals regulated in the contaminant regulation (Regulation (EC) No 1881/2006) and for mercury in the pesticide regulation (Regulation (EC) No 396/2005) are based on wet weight.

For comparison and evaluation of data, information on drying factors is necessary. Dry weight percentages are given in a Norwegian report (Duinker *et al.*, 2020), and are summarised in Table 2. There are differences between the species, but for an approximate and quick calculation for comparing data on dry and wet weight, a drying factor of five can be used.

Table 2. Dry weight percentages in samples of some fresh seaweed species. (Adapted from Duinker *et al.*, 2020)

Group	English name	Range of dry weight percentages (25–75 percentiles)
Brown algae	Sugar kelp	10–15
	Winged kelp	12–18
	Bladderwrack	25–30
	Oarweed	15–21
	Rock weed, egg wrack	15–21
	Toothed (serrated) wrack	28–34
	Sea spaghetti	21–24
	Tangle	14–16
Red algae	Dulse, Dillisc	15–16
	Wrack siphon weed	13–18
Green algae	Sea lettuce	11–18
	Gut weed, mermaid's hair	8–13
	Sponge seaweed	5

3.4 Ongoing process in the EU regarding heavy metals and iodine in seaweed

In view of the occurrence of high content of heavy metals and iodine in some seaweed products, and an increasing contribution from seaweed to the consumption patterns of certain EU consumers, the EU Commission recommended Member States to, during 2018, 2019 and 2020, analyse arsenic, cadmium, lead, mercury, and iodine in a wide range of seaweed species and products used as food, feed, and food additives (EC, 2018).

The collected data will be used to assess whether the contribution of these heavy metals and iodine from seaweed to the total exposure of these substances would necessitate setting or change MLs for seaweed. The MRL for mercury for algae and prokaryotic organisms may also need to be amended, and action may be taken relating to the exposure to iodine through these products.

The EU Commission has asked EFSA to deliver a scientific report by 2022, including a consumer exposure assessment for arsenic, cadmium, lead, mercury, and iodine in seaweed, and also an overview of the available occurrence data of these components (EFSA, 2022).

The occurrence data from the monitoring would enable such a consumer exposure assessment. In the mandate to EFSA, the EU Commission notes that in cases where the consumption data for seaweed is limited, an estimate should be made of the exposure when specific components of the diet are partly replaced by seaweed. As certain processing and food preparation steps, such as soaking or cooking, can result in a reduction of the exposure compared to direct consumption of the seaweed or, for example, when used in soups, the effects of processing/food preparation on the exposure should also be addressed.

The EU Commission is expected to evaluate risk management options for heavy metals and iodine in seaweed in the near future.

3.5 Nordic data on heavy metals and iodine

Data on heavy metals and iodine in seaweed are collected in Denmark, the Faroe Islands, Iceland, Norway, and Sweden. Results from analyses of Nordic and some imported species are given in Table 3. For most of the species several samples have been analysed, while for some there were very few samples.

Table 3. Nordic data on heavy metals and iodine in seaweed – mean (min-max) mg/kg dry weight.

Species	Lead	Cadmium	Total mercury	Inorganic arsenic	Iodine	Country
Sugar kelp (*Saccharina latissima*)	0.62 (0.11–2.3)	0,44 (0.12–1)	0,016 (0.007–0,027)	0.04 (0 –0.12)	1432 (361–1969)	DK
	0.33 (<0.22–5.7)	0.94 (0.16–3.1)	(<0,0098–0.081)	0.17 (0.03–0.67)	3700 (670–10000)	NO
	(0.011–0.158)	(0.939–1.929)	<0,06	0.193(0.125–0.237)	(1158–4656)	IS
	0.2 ± 0.15	2.3 ± 1.1	<0.03	0.2 ± 0.07	4000 ± 1700	FO
	0.147	0.360	0.021	0.119	2648	SE
Winged kelp (*Alaria esculenta*)	0.66 (<0.055–4.4)	1.5 (0.3–4.8)	(<0.004–0.05)	0.77 (0.03–2.7)	840 (70–2400)	NO
	(0.011–0.947)	(0.959–6.020)	<0,06	-	-	IS
	- 0.3 ± 0.2	3.6 ± 1.2	<0.03	0.3 ± 0.1	250 ± 140	FO
Bladderwrack (*Fucus vesiculosus*)	0.54 (0.15–1.1)	0.48 (0.32–0.65)	0,011 (0.005–0.018)	0.24 (0–0.73)	312 (133–443)	DK
	<0.07	(1.469–5.905)	(<0.05–0.074)	0.185 (0.116–0.296)	232 (126–347)	IS
	0.49 (<0.077–3.3)	1.4 (0.41–3.1)	0.028 (<0.007–0.022)	0.2 (0.02–1.64)	380 (140–830)	NO
Oarweed (*Laminaria digitata*)	0,19 (0.14–0.27)	0.08 (0.047–0.14)	0.01 (0.007–0.013)	0.67 (0.33–0.92)	2405 (925–5752)	DK
	0.15 (<0.021–0.64)	0.38 (0.033–1.9)	0.03 (<0.006–0.067)	24 (0.06–79)	5100 (1400–10000)	NO
	-	-	-	-	7461	IS
	0.2 ± 0.1	1.8 ± 0.8	<0.06	-	5400 ± 1400	FO

Rock weed (*Ascophyllum nodosum*)	0.34 (<0.052–1.9)	0.29 (0.16–0.47)	(<0,0078–0.033)	0.11 (<0.01–1.21)	710 (320–1500)	NO
	(<0.07–0.105)	(0.235–1.421)	(<0.05–0.274)	0.081 (0.041–0.120)	804 (674–1011)	IS
Toothed wrack (*Fucus serratus*)	0.36 (0.24–0.68)	0.81 (0.40–1.20)	0.01 (0.007–0.014)	0.10 (0.011–0.26)	401 (115–698)	DK
	0.44 (<0.13–1.7)	1.9 (0.88–3.3)	(<0.005–0.015)	0.14 (0.010–0.56)	650 (280–1000)	NO
Spiral wrack (*Fucus spiralis*)	0.48 (0.19–1.2)	0.45 (0.38–0.57)	0.01 (0.009–0.014)	0.52 (0.011–1.8)	293 (126–609)	DK
	0.33 (0.27–0.4)	0.67 (0.45–1.1)	0.02 (<0.046–0.005)	0.04 (0.03–0.05)	150 (140–150)	NO
	0.037 (0.027–2.566)	2.874 (2.566–3,182)	LOD	-	-	IS
Sea lace/dead man´s rope (*Chorda filum*)	1.31 (0.32–2.3)	0,07 (0.04–0.09)	0.015 (0.012–0.017)	0.22 (0.21–0.23)	911 (669–1153)	DK
	0.37 (<0.21–0.52)	0.27 (0.07–0.47)	(<0.045–<0.051)	0.15 (0.03–0.27)	850 (120–1600)	NO
Channelled wrack (*Pelvetia canaliculata*)	0.022	0.561	0.031	-	-	IS
	0.4 (<0.21–0.75)	0.3 (0.24–0.36)	(<0.033–0.042)	0.1 (0.090–0.12)	210 (200–220)	NO
Sea spaghetti /thongweed (*Himanthalia elongata*)	<0.2	0.78 (0.39–1.8)	(<0,049–<0.051)	0.04 (00.01–0.05)	90 (41–230)	NO
Tangle (*Laminaria hyperborea*)	0.017	0.138	LOD	-	-	IS
	<0.25	0.82		0.036 (0.03–0.041)	4200	NO
Wireweed (*Sargassum muticum*)	0.28	0.37 (0.09–0.65)	(<0,04–<0.05)	54 (48–68)	300 (120–480)	NO

Wakame * (*Undaria pinnatifida*)	0.76 (<0.22–1.1)	2.7 (0.72–4)	(<0.053–<0.054)	0.03 (<0.01–0.06)	150 (39–280)	NO
	0.089 (0.073–0.104)	0.239 (0.223–0.257)	0.012 (0.010–0.014)	0.016 (0.014–0.019)	132 (128–137)	SE
Hijiki * (*Sargassum fusiforme*)	1.6	2.3		59	490	NO
Arame * (*Eisenia bicyclis*)	<0.21	0.6		0.02	450	NO
Kombu * (*Saccharina spp*)	(0.012–0.033)	(0.22–0.8)	(0.005–0.009)	(0.019–21.5)	2467–5399	DK
	<0.21	0.46 (0.15–0.75)	(<0.0512–<0.053)	0.03 (0.02–0.05)	2800 (2100–4000)	NO
Dulse (*Palmaria palmata*)	0.011	0.61	0.002	0.003	55	DK
	0.33 (<0.039–1.1)	0.37 (0.05–1.6)	(<0.004–0.005)	0.22 (0.02–1.03)	300 (15–790)	NO
	(<0.04–0.662)	(0.172–2.457)	(<0.06–0.105)	-	(4–360)	IS
Purple laver (*Porphyra purpurea*)	<0.01	-	-	-	-	IS
	0.24 (0.055–0.44)	0.67 (0.17–1.5)	0.006 (<0.005–0.007)	0.09 (0.03–0.19)	67 (22–100)	NO
Wracked siphon weed (*Vertebrata lanosa*)	0.064	4.291	0.004	-	-	IS
	0.96 (0.24–3.3)	3.4 (2.1–5)	(<0.017–0.068)	0.27 (0.04–1.04)	2500 (710–6200)	NO
Irish moss (*Chondrus crispus*)	(0.44–0.65)	(0.11–0.17)	0.007	(0.11–0.21)	(269–285)	DK
	0.35 (0.3–0.41)	0.21 (0.14–0.28)	0.006 (0.005–0.007)	0.23 (0.21–0.25)	260 (200–330)	NO
Nori * (*Porphyra spp*)	0.28 (<0.21–0.8)	1.7 (0.41–3.4)	(<0.048–<0.055)	0.08 (0.01–0.3)	51 (8–100)	NO
	0,160	1,45	0,087	0,048	47,7	SE

Sea lettuce (*Ulva lactuca alt fenestrata*)	0,55 (0.32–1.5)	0,66 (0.074–0.84)	0,009 (0.005–0.016)	0,16 (0.094–0.49)	105 (81–182)	DK
	0.62 (<0.2–2.8)	0.17 (0.08–0.34)	(<0.004–0.009)	0.14 (0.03–0.45)	110 (37–290)	NO
	0.470 (0.064–1.30)	0.071 (0.028–0.172)	< 0.036	0.379 (0.018–1.21)		SE
Gut weed (*Ulva intestinalis*)	0.89 (0.21–3)	0.24 (0.08–0.55)	(<0.005–0.011)	0.18 (0.02–0.44)	130 (29–240)	NO
Sponge weed / Green sea fingers (*Codium fragile*) >	1.4 (0.4–2.3)	<0.06	(<0.042–<0.058)	0.14 (0.07–0.21)	23 (17–29)	NO

* Not Nordic species
DK: Data from Denmark (DVFA, 2014)
FO: Data from the Faroe Islands (Bak, 2019)
IS: Data from Iceland (Matis, 2021)
NO: Data from Norway (Duinker *et al.*, 2020)
SE: Data from Sweden (The Swedish Food Agency and Trigo *et al., 2022)*

The great variability shown, both within and between species, is in accordance with the literature. The differences between species seem to be quite similar in the Nordic countries. The table shows some possible differences in the levels between countries, but these data are too sparse and not suited for further scientific evaluation.

Table 3 may however be useful for business operators and food authorities, as an indication of expected levels of heavy metals and iodine in the different species in these four Nordic countries. The data in Table 3 will be further discussed in the sections on the individual hazards.

3.6 Bioavailability

The bioavailability of the different food hazards is an important factor for the food safety assessment. However, data on bioavailability in seaweed are limited, and vary greatly.

A Norwegian report (Duinker *et al* ., 2020) indicates a bioavailability of 73–78% of iodine from sugar kelp, found in a rat model study. A review article states that the bioavailability of iodine from brown algae is generally high, with in vivo bioavailability ranging from 31 to 90% (Blikra *et al.*, 2022).

In general, risk assessors assume a full bioavailability of contaminants from foodstuffs due to lack of data, as is the case for seaweed.

3.7 Effect of growing conditions on the content of food hazards

The content of food hazards in seaweed is affected by several variables. Both nutrients and contaminants are directly taken up through the blades. The levels are affected by parameters such as water quality, temperature, age of the seaweed, and the part of the seaweed analysed.

According to Duinker *et al.* (2016), several aspects of the seaweed biology may influence the contaminant level. The shape of the blades, with a large surface area in contact with the water, will facilitate uptake of contaminants. Since seaweeds accumulate certain constituents from the water due to the metal-binding characteristics of their polysaccharides, age at the time of harvest is also important, as are the parts of the seaweed used.

In a study of kelp from Norwegian waters, cadmium decreased with increasing size of the plants. According to the authors, this suggests that fast growing individuals have lower concentrations of cadmium than slow growing individuals. Cadmium concentrations also decreased from the stipes and growth zone towards the tip. Iodine showed an opposite trend, with increasing concentrations towards the tip (Duinker *et al.*, 2020).

Fouling was found to increase metal concentrations, with higher cadmium concentrations found in areas of sugar kelp covered with the bryozoan *Membranipora membranacea*. An unknown filamentous algae considerably increased concentrations of inorganic arsenic in wild winged kelp. Data on factors such as season, geography, and exposure are still limited, and more studies are needed. The variation even within the same locality for cultivated kelp was surprisingly high, and more knowledge of the factors causing such variation is needed to enable more predictable product quality (Duinker *et al.*, 2020).

Seaweed has generally low levels of lipids, so low quantities of organic, lipid-soluble contaminants like dioxin and polychlorinated biphenyl (PCB) are expected. However, these chemicals can concentrate in seaweeds if they are grown in areas with high chemical contamination (FAO 2022).

The great variability in the content of heavy metals and iodine within each species, and several influencing factors on food quality, are described by several other authors (Banach *et al.*, 2020; Blikra *et al*, 2022, Steinhagen *et al.*, 2022).

3.8 Effect of processing on the content of food hazards

Seaweed may be processed before consumption, either by the business operator before marketing, in restaurants, or by consumers handling commercial products.

Dried seaweed is more likely to have fewer microbial risks than fresh products and seaweed as ingredients in mixed products with high water activity. The water content in fresh seaweed varies from 5 to 34% dry weight percentage, as shown in Table 2. The level of some of the food hazards can be affected by processing methods, such as rinsing, drying, blanching, boiling, frying, and fermentation.

Several reports and ongoing research projects examine the effect of processing on the content of food hazards in seaweed. Nielsen *et al.* (2020) and Trigo *et al.* (2022) reported how water blanching can reduce iodine content, and Blikra *et al.* (2019) reported on food quality and microbial safety through different processing methods.

Stevant *et al.* (2017) report that simple soaking treatments in warm fresh water reduced the iodine in *S. latissima* and treatment of *A. esculenta* in hypersaline solution reduced the relative cadmium content. However, both treatments affected the nutrient content of the biomass, illustrated by considerable variations in dry weight and the content of bioactive compounds (e.g. minerals, polyphenols, fucoxanthin). Cheyns *et al.* (2017) also demonstrated how processing reduced inorganic arsenic levels, and Wang *et al.* (2021) reported that arsenic in *S. fusiforme* could be reduced considerably by sequential processing using hot water, citric acid, and fermentation.

A review study by Blikra *et al.* , (2022) showed that the effect of processing on iodine reduction varied between no substantial reduction to more than 90% reduction in brown algae, depending on the method of processing and type of seaweed species. Processing methods included in that study were washing, soaking, rehydration, blanching, boiling, fermentation, and different drying methods. Although processing strategies may reduce the iodine content of brown algae significantly, the content may still be high after processing and the reduction is not predictable. It is difficult to extrapolate any expected results based on the species and degree of processing alone. The authors therefore conclude that more studies are needed to find out why the effect of processing varies, and it is important to find methods that allow manufacturers to sell safe and predictable products. Until more information is confirmed regarding the factors that account for these differences and how much the different factors contribute to the loss of iodine, the authors conclude that batch-specific data for the iodine content after processing should be used for calculating tolerable amounts.

Processing methods that reduce iodine may also reduce other quality aspects in seaweed, like beneficial nutrients and the flavour umami (Stévant *et al.*, 2021, Wirenfeldt *et al.,* 2022). Processing of food can also add new hazards like acrylamide and PAH, but according to the literature, this aspect has not been reported for seaweed.

3.9 Chemical hazards and some basic principles for legislation

Current knowledge suggests that the most important chemical food hazards in seaweed from Nordic countries are heavy metals and iodine. Other chemical hazards are only discussed briefly, either due to limited knowledge or because the hazards are ranked as minor risks in the literature.

Iodine is a nutrient and not normally classified as a hazard, but in the case of seaweed, iodine is identified as a risk due to the very high levels in some products. There are generally no MLs for nutrients in food, and therefore none for iodine.

There is EU legislation on chemical hazards for many specific foodstuffs but not for all types of hazards and for all types of foodstuffs. Legislation on chemical hazards in seaweed used as food is very limited.

The EU is working continuously on updating existing maximum levels (MLs) for chemical hazards on the basis of available occurrence data and current knowledge. Work on setting MLs for new hazards is also ongoing, but this process often takes several years.

The MLs are based on risk for human health, occurrence data, consumption patterns, and global trade, in combination with the intention to keep MLs as low as reasonably achievable (ALARA principle). This means that a ML for a certain substance in a specific foodstuff is set as low as possible, considering the existing levels in that specific foodstuff, the global trade, the health risk, and the extent to which it is consumed. MLs are therefore not a safe level in themselves and are certainly not necessarily safe for all types of consumer groups.

Food that is consumed more seldom can be allowed to have higher levels of toxic substances than food that is eaten more regularly. Stricter regulations apply for food intended for infants and young children, since children are more vulnerable to toxic substances than adults.

For chemical contaminants like heavy metals, it is typically not possible to set MLs low enough to protect all consumer groups from an intake that can pose a risk to human health. In many cases it could result in excessively high rejection rates and could disrupt the supply chains of certain foods. Dietary advice is therefore often needed to complement MLs for contaminants in foodstuffs.

Each of the MLs is specific to specific types of foodstuffs consumed in a specific way, so MLs are not comparable between different types of foodstuffs. In view of the lack of MLs for seaweed, existing regulations for other foodstuffs can serve as a tool to indicate which substances and what levels may be relevant. However, it is important to note that seaweeds have quite different properties compared to other organisms which are used as food, as described in section 1.4., and should be managed and evaluated accordingly. The lack of consumption data and exposure assessment for seaweed is an additional challenge in terms of risk management and comparison with other foodstuffs.

3.9.1 Cadmium

Cadmium is a heavy metal originating from natural sources such as volcanic activity and weathering of bedrocks, and also from industrial and agricultural activity. Fertilisers may contain cadmium and thereby increase cadmium levels in soil.

Cadmium accumulates in the kidney and can cause kidney damage. Cadmium can also affect bone mineralisation, which can lead to osteoporosis and subsequent fractures. Cadmium is classified as a human carcinogen and data indicate an increased risk of cancer in lungs, endometrium, bladder, and breast. In 2012, EFSA reduced the tolerable weekly intake (TWI) for cadmium to 2.5 µg/kg body weight. Cadmium intake by the average consumer in Europe is close to the safety margin and exposure should be reduced (EFSA, 2012). According to the World Health Organization (WHO, 2022), cadmium is one of the top ten substances of major public health concern.

Occurrence in food

Foodstuffs that currently contribute the most to the dietary intake of cadmium are cereal products, potatoes, vegetables, nuts, and pulses (EFSA, 2012).

Levels of cadmium reported from the Nordic countries show substantial variation, both between and within species (Table 3). Some species of seaweed contain high levels of cadmium, especially some brown and red algae. The highest levels of cadmium, around 6 mg/kg dry matter, are reported in some samples of winged kelp and bladderwrack, while in the same species the lowest levels listed are 0.3 mg kg dry matter. The same pattern is seen for other species, although the magnitude of the variation is less. Generally, cadmium levels are lower in green seaweed species, with levels not exceeding 1 mg/kg dry matter.

Legislation

Maximum levels for cadmium in foodstuffs are set in Regulation (EC) No 1881/2006. There is a ML for cadmium in food supplements consisting exclusively or mainly of dried seaweed and products derived from seaweed as sold, 3.0 mg cadmium/kg, but as yet no MLs for seaweed consumed as food.

MLs for cadmium in different foodstuffs are given in mg/kg wet weight, and some examples are given in Table 4. For processed, cereal-based food intended for infants and young children the ML is 0.04 mg/kg. For feed materials of vegetable origin, the ML for cadmium is 1 mg/kg in feed with a moisture content of 12% (Directive 2002/32/EC).

Table 4. MLs for cadmium in some foodstuffs (Regulation (EC) No 1881/2006)

Examples of some foodstuffs	MLs for cadmium (mg/kg wet weight)
Seaweed	-
Root vegetables (wet weight)	0.02–0.1
Cereal products/rice products	0.04–0.20
Other vegetables, leafy vegetables	0.02–0.3
Meat of terrestrial animals (wet weight)	0.05–2.0
Offal of terrestrial animals	0.5–1.0
Fish (muscle meat)	0.05–0.25
Bivalve molluscs	1.0
Food supplements consisting exclusively or mainly of dried seaweed and products derived from seaweed	3.0*

* As sold

Conclusion on cadmium

Cadmium in certain seaweed species may constitute a health hazard when used as food. The species with higher levels generally belong to the brown and red algae groups. For products consumed frequently in large portions, levels of cadmium should be kept as low as possible, as the average European consumer already has high exposure to cadmium from the diet.

3.9.2 Inorganic arsenic

Arsenic is a metalloid but is often included in the heavy metals. Arsenic occurs widely, both naturally and as a result of human activity.

Arsenic occurs in both organic and inorganic form. The main adverse effects are related to inorganic arsenic, including cancers of the lung, skin, and bladder, as well as skin lesions (EFSA, 2014). EFSA concluded there is little or no margin of exposure and the possibility of risk to some consumers cannot be excluded. According to the World Health Organization (WHO, 2022), arsenic is one of the top ten substances of major public health concern.

Occurrence in food

Inorganic arsenic is found in many different foodstuffs, but rice and rice products are the most well studied, as well as drinking water. The Asian seaweed species hijiki is known for containing very high levels of inorganic arsenic.

Levels of inorganic arsenic reported from the Nordic countries show substantial variation, both between and within species (Table 3). The highest levels are found in some brown seaweeds. The range of inorganic arsenic in red and green seaweed seems to be much smaller, with levels varying between 0.003 and 1.2 mg/kg dry weight, but similar ranges (0.01–3 mg/kg dry weight) are also seen in some of the brown seaweeds.

Variation within species can be substantial, as observed, for example, in oarweed. The Norwegian data on oarweed has a mean value of 24 mg/kg dry weight, the minimum value is 0.06 and the maximum 79. Thirty-three samples were analysed, and 50% of them showed concentrations above 24 mg dry weight (Duinker *et al.*, 2020). The Norwegian data on oarweed shows values a hundred times higher than for most of the other Nordic species and is at a similar level to hijiki.

Legislation and risk management measures

There are no EU maximum levels established for inorganic arsenic in seaweed used as food. Only rice and rice products are currently regulated in Regulation (EC) 1881/2006, with MLs of 0.1–0.3 mg/kg wet weight. The lowest ML, 0.1 mg/kg wet weight, refers to rice destined for production of food for infants and young children.

The EU Commission has proposed some MLs for fishery products, but not for seaweed. Levels in foodstuff without specific MLs are however evaluated according to article 14 in the general food regulation (Regulation (EC) No 178/2002). The regulation stipulates that food business operators are responsible for ensuring that foodstuffs to be placed on the market must be safe to consume.

For feed based on seaweed the maximum level is 40 mg/kg for total arsenic in feed with a moisture content of 12%. When requested by the competent authorities, the responsible operator must perform an analysis to demonstrate that the content of inorganic arsenic is lower than 2 mg/kg. This analysis is of particular importance for the seaweed species *Hizikia fusiforme* (Directive 2002/32/EC).

Table 5. Established (Regulation (EC) 1881/2006) and proposed EU maximum levels for inorganic arsenic in food (communicated by the EU Commission to the EC working group on contaminants, February 2022).

Examples of some food products	Established MLs for inorganic arsenic (mg/kg wet weight)	Proposed MLs for inorganic arsenic (mg/kg wet weight)
Seaweed	-	-
Fish (fresh weight)	-	(0.02–0.08)*
Cereal products/rice products	0.1–0.3	0.1–0.3**

* Proposed maximum levels that may be included in future revisions of 1881/2006.

**Current ML is only for rice products. Proposed ML also covers other cereal products.

Several countries, including Denmark and Norway, give dietary advice that consumers should avoid consumption of hijiki. The Norwegian Food Safety Authority also advises consumers to avoid eating products from oarweed, due to high levels of inorganic arsenic (NFSA, 2020).

Conclusion on inorganic arsenic

Levels of inorganic arsenic reported from the Nordic countries show substantial variation, both between and within species, with the highest levels are found in some brown seaweeds. Inorganic arsenic in certain seaweed species may constitute a health hazard when the seaweed is used as food. Producers and consumers should be aware of the risk of high inorganic arsenic content in certain species such as oarweed.

3.9.3 Mercury

Mercury is a heavy metal that is released into the environment from natural sources like volcanic activity and other natural degassing from the earth's surface, and from anthropogenic sources.

Mercury can occur in both inorganic and organic forms. The exposure to mercury is mainly in the form of methylmercury, when fish and shellfish containing the compound are consumed (WHO, 2017).

Mercury affects the development of the nervous system and is most critical for the foetus and children below the age of 14. EFSA has evaluated mercury (EFSA, 2012) and set a tolerable weekly intake (TWI) for methyl mercury of 1.3 µg/kg body weight expressed as mercury.

The critical target for toxicity is neurodevelopmental outcomes. Other targets include the liver, nervous system, immune system, reproductive and developmental systems. Unborn children constitute the most vulnerable group for developmental effects of methylmercury exposure. Mercury intake is critical, not only on a long-term basis but also the intake from a single meal, especially for vulnerable groups. Many countries have dietary advice on intake of fish by pregnant and breastfeeding women, and children below the age of 14

It is important to limit the intake of mercury in general but also within a single meal for vulnerable groups of consumers, such as pregnant women, breastfeeding women, and children below the age of 14. According to the World Health Organization (WHO, 2022), mercury is one of the top ten substances of major public health concern.

Occurrence in food

Fish and other seafood are the most important contributors to the intake of mercury. The mercury levels vary widely among different fish species, with larger predatory fish having the highest levels.

Levels of mercury reported from the Nordic countries show substantial variation, both between and within species (Table 3). Levels are typically below 0.06 mg/kg dry weight, but there are also some remarkably high levels.

Legislation

Maximum levels for mercury in foodstuffs are set in the contaminant legislation (Regulation (EC) No 1881/2006). No MLs for mercury are set specifically for seaweed, but the ML for food supplements also applies for supplements based on seaweed. The ML of 0.1 mg/kg is set for food supplements as sold.

Seaweed is included in the legislation on maximum residue levels (MRLs) of pesticides in or on food and feed of plant and animal origin (Regulation (EC) No 396/2005). Mercury is categorised as a pesticide due to its historical use as such. The regulation sets MRLs for mercury regardless of the occurrence originates from environmental contamination or not. The MRL for algae and prokaryotic organisms is set at the default level of 0.01 mg/kg wet weight.

All EU legislation currently refers to total mercury. The MLs for mercury in fish vary between 0.3 and 1.0 mg/kg wet weight, due to the occurrence levels in different fish species. For feed in general, there is a ML of 0.1 mg/kg for mercury in feed with a moisture content of 12%.

Table 6. EU maximum levels for total mercury in some food products

Food product	MLs for mercury in Regulation (EC) No 1881/2006 (mg/kg wet weight)	MRLs for mercury in Regulation (EC) No 396/2005 (mg/kg wet weight)
Seaweed	-	0.01
Root vegetables	-	0.01
Cereal products/rice products	-	0.01
Other vegetables, leafy vegetables	-	0.01
Meat and offal of terrestrial animals	-	0.02
Fish (muscle meat)	0.3–1.0	-
Food supplements	0.1*	-

*As sold

Conclusion on mercury

The Nordic data show very variable total mercury content between and within species. Levels of mercury are typically below 0.06 mg/kg dry weight but there are also some remarkably high levels. As the source of mercury may be natural, and the EU maximum residue levels for mercury are very low (0.01 mg/kg wet weight), compliance with legislation can be a challenge. Mercury intake is critical, not only on a long-term basis but also the intake from a single meal, especially for pregnant and breastfeeding women, as well as young children.

3.9.4 Lead

Lead is a heavy metal that occurs naturally in the environment primarily as inorganic lead. The main source of lead in foodstuff is from anthropogenic activities.

Lead is a cumulative toxicant that affects multiple body systems, including the neurological, haematological, gastrointestinal, cardiovascular, and renal systems. The central nervous system is the main target organ for lead toxicity.

Intake of lead is especially critical for young children and pregnant women. The developing brain is more vulnerable to the neurotoxic effects than the mature brain.

EFSA (2010) concluded that setting a tolerable intake for lead is not appropriate, as there is no evidence of a threshold for critical lead-induced effects. According to the World Health Organization (WHO, 2022), lead is one of the top ten substances of major public health concern.

Occurrence in food

Cereal and vegetable products are the main sources of lead in the diet due to the large amount consumed. Drinking water and beverages also make a significant contribution.

Data on Nordic species (Table 3) show variable content between and within species. Most data show levels below 1.0 mg/kg dry weight, but some seaweed species like sugar kelp, winged kelp, bladderwrack, wracked siphos, sea lettuce, and gut weed show levels up to 3–6 mg/kg dry weight. These are considerable levels compared to levels in other foodstuffs, even when considering an approximate drying factor of five.

Legislation

EU maximum levels for lead in foodstuffs are set in Regulation (EC) No 1881/2006. No MLs are specified for lead in seaweed, but the ML for food supplements also apply for supplements based on seaweed. The ML of 3.0 mg/kg is set for food supplements as sold.

MLs for cereals, vegetables and fish vary from 0.10 to 0.30 mg/kg wet weight. MLs in food for infants and young children are much more restrictive. For example, ML is 0.020 mg/kg wet weight for processed cereal-based foods and baby food for infants and young children. For feed materials in general, there is a maximum level of 10 mg/kg wet weight for lead in feed with a moisture content of 12%, and for complete feed the maximum level is 5 mg/kg.

Table 7. EU maximum levels for lead for some foodstuffs (Regulation (EC) 1881/2006)

Food product	MLs for lead (mg/kg wet weight)
Seaweed	-
Root vegetables	0.1
Cereal products/rice products	0.02–0.2
Other vegetables, leafy vegetables	0.05–0.3
Meat of terrestrial animals	0.1
Offal of terrestrial animals	0.1–0.2
Fish (muscle meat)	0.3
Food supplements	3.0*

*As sold

Conclusion on lead

Lead in certain seaweed species may constitute a health hazard when used as food. There seems to be no pattern in the findings of high levels of lead in the Nordic data on with respect to type of seaweed.

Intake of lead is toxicologically most critical for infants and young children, as well as the developing foetus. Therefore, special care must always be taken regarding food intended for children and pregnant women.

3.9.5 Nickel

Nickel is a heavy metal with widespread occurrence in the upper layers of the soil. Nickel is present in foodstuffs and water due to natural occurrence and anthropogenic activity.

EFSA has set a tolerable daily intake (TDI) of 13 microgram/kg bodyweight for nickel. Nickel has negative effects on the liver, kidneys, bones, gut microbiome, and neurological and reproductive systems, and on the immune system. Nickel is genotoxic by indirect effect. Nickel is a human carcinogen through inhalation, but it has been evaluated as unlikely that current dietary exposure to nickel results in cancer in humans. However, nickel may be an upcoming hazard as, in a recent evaluation, EFSA concluded that there may be a health concern especially for young age groups and not only for nickel-sensitised individuals (EFSA, 2020).

Nickel is not included in the EU recommendation on monitoring of metals and iodine in seaweed (EC, 2018), is not discussed in the food hazard ranking in section 3.8. and is not included in Table 3 on Nordic data.

Legislation

There is no EU legislation on nickel in food. The EU Commission has recommended member states to collect data on nickel in foodstuffs, including seaweed (EC, 2016). According to communication from the EU Commission, the collected data reveal high levels of nickel in seaweed, where the levels for 95 percentiles were 4.7 mg/kg for nickel in fresh seaweed and 20.3 mg/kg in dried seaweed. Levels in fresh seaweed were highest in dulse (14.0 mg/kg), Irish moss (6.3 mg/kg), and sea lettuce (5.7 mg/kg). For dried seaweed, the highest levels were found in kombu (29.6 mg/kg) and laver (27.3 mg/kg).

Based on these data on seaweed and other foodstuffs, EU Commission has proposed MLs for nickel in foodstuffs, as shown in Table 8.

Table 8. EU proposed maximum residue levels for nickel. (Communicated by the EU Commission to the EC working group on contaminants, February 2022.)

Food product	Proposed MLs for nickel (mg/kg wet weight)
Root vegetables	0.7
Cereal products/rice products	0.5–3.0
Other vegetables, leafy vegetables	0.2–1.0
Pulses	4.0
Tree nuts	3.5–7.0
Dried seaweed other than wakame	30.0
Dried wakame	40.0

Conclusion on nickel

Nickel in seaweed is an upcoming issue that will probably receive more attention in the future. Nickel in certain seaweed species may constitute a health hazard when they are used as food. Levels in certain seaweeds can be considerable, and intake of seaweed may contribute significantly to the exposure to nickel.

3.9.6 Iodine

Iodine is an essential micronutrient required for the synthesis of thyroid hormones. Both insufficient and excessive intake may pose health problems. Some seaweed products can contain very high levels of iodine, putting consumers at risk of excessive levels, which may have a negative effect on health.

The iodine status of populations varies considerably in the world. In Europe, the iodine status is generally low, with mild to moderate iodine deficiency. This is also the case in the Nordic countries. Iodine deficiency is a risk factor, particularly for young women in fertile age groups. If they are also vegetarian or vegans, the risk can be even higher. Iodine deficiency can damage the foetus and cause other health problems.

It is less well known for consumers that excessive intake of iodine may also constitute a health risk. Like insufficient intake of iodine, excessive intake can also be harmful to health by affecting the function of the thyroid gland. Vulnerable groups in the population must be careful about large intakes, especially pregnant and lactating women, young children, and people with diseases in the thyroid gland. Those with mild to moderate iodine deficiency must also be aware that a sudden high intake of iodine may increase the incidence of thyroid disorders, since the thyroid gland takes time to adjust.

Occurrence in food

Seafood, such as white fish, is a well-known source of iodine in the diet. Iodine can also be found in drinking water and in some foods of terrestrial origin, primarily in countries where fodder is enriched with iodine, which is the case in the Nordic countries and the EU. Products such as milk, dairy products, and eggs then become good dietary sources of iodine.

In some countries, foodstuffs are enriched by iodine. In Denmark there are requirements on mandatory enrichment of iodine in household salt, and salt that is used in bread and ordinary baked goods. In Norway and Sweden iodine is added to certain types of salt and foodstuff, but on a voluntary basis.

Seaweeds can accumulate iodine from the seawater, which may lead to very high levels, sometimes several thousand times higher than in other foodstuffs. The level depends on several factors, such as growing conditions and processing, as discussed in sections 3.7 and 3.8. The type of species is particularly relevant for the level of iodine.

Nordic data on iodine (Table 3) show that levels vary greatly, both between and within species. Some brown algae have high levels of iodine, with the highest levels around 10,000 mg/kg dry weight. Among the Nordic species, sugar kelp, winged kelp, oarweed, and tangle have levels above 2000 mg/kg. The green and red species have, in general, considerably lower content than the brown species. One exception is the red algae wrack siphon weed, with iodine levels above 2000 mg/kg. This species has a particular method of growth, as a symbiont on the brown algae rockweed. None of the species of brown, red or green algae listed in the table have levels below 20 mg iodine/kg dry weight

Iodine intake

Risk assessment

EFSA has issued recommendations on daily intake of iodine (EFSA, 2014b). The recommended intake of iodine for children from age 10 and adults is 150 µg/day. For infants aged 7–11 months and for children, an adequate intake (AI) range is between 70 µg/day and 130 µg/day. For pregnant and lactating women, an AI of 200 µg/day is proposed. Intake above 600 µg/day is not recommended.

In 2006 the Scientific Committee for food indicated that the ingestion of iodine-rich algal products, particularly dried products, can lead to dangerously excessive iodine intakes, if such products contain more than 20 mg iodine/kg dry matter and the exposed population lives in an area of endemic iodine deficiency (EFSA, 2006).

Iodine intake from seaweed consumption
The way public agencies manage iodine deficiency, varies somewhat in the Nordic countries, and probably the consumption pattern in the population as well, but there is lack of data on this topic.

There are indications that Norwegian young women with low iodine status choose to eat seaweed to compensate, since they are recommended to take food supplements containing iodine. In a study of 205 young Norwegian women with a vegetarian or a vegan diet, 17% consumed seaweed (Groufh-Jacobsen *et al.*, 2020).

Aakre *et al.* (2020) described the iodine status and thyroid function in a group of Norwegian seaweed consumers. One-third of the participants used seaweeds daily. Sugar kelp, winged kelp, dulse, and laver were the most common species. The participants showed an excessive iodine status after their intake of seaweed. Since including seaweed in the diet may cause excessive iodine exposure, the authors recommend that consumers are informed of the risk associated with seaweed in their diet.

Aakre *et al.* (2021) assessed the iodine content of foods containing seaweed, and reported levels generally exceeding the tolerable upper intake level of iodine. The iodine varied greatly, and some products had inadequate or inaccurate labelling of the iodine content.

Legislation and risk management of iodine

There are generally no EU maximum levels for nutrients in food, and thereby none for iodine. However, in feed additives, MLs for iodine are set (Regulation (EU) 2015/861).

In France there are national recommendations, with a maximum level of 2000 mg iodine/kg dry matter for edible seaweed (ANSES, 2018). Germany allows a maximum content of 20 mg iodine/kg in dried seaweed for consumption (BfR, 2007).

The lack of harmonisation and differences in risk management result in many notifications about levels of iodine in the European rapid alert system for food and feed (RASFF). A search in the RASFF data base with the keywords "seaweed" and "algae" (search date April 11, 2021) resulted in 116 alerts on high iodine levels.

None of the Nordic countries have national maximum levels for iodine in seaweed used as food, but specific findings of high levels are evaluated according to the principle in article 14 in Regulation (EC) No 178/2002, which stipulates that foodstuffs must be safe.

As a risk management tool, some of the Nordic countries give dietary advice to consumers about iodine in seaweed.

Denmark

The Danish Veterinary and Food Administration informs consumers that the seaweed species arame, wakame, kombu, oarweed, and sugar kelp can contain very high levels of iodine compared to other species. The levels vary during the year and according to geography. By consuming one gram of dried seaweed of one of these species an adult can have more than 2.5 times the upper tolerable intake. One occasional meal is not a big problem, as the body can excrete excess iodine. Seaweed can be part of a varied diet but should not be eaten on a daily basis. Rinsing the seaweed can be beneficial, as it reduces the levels of iodine. Pregnant women and children below the age of ten should be cautious about eating seaweed (DVFA, 2021).

Iceland

The Directorate of Health in Iceland issues recommendations to consumers about iodine consumption. Pregnant women are advised not to use seaweed or seaweed tablets as an iodine source, as it may contain iodine in larger doses than is desirable to consume during pregnancy, and other substances that may be harmful to the foetus (DOH, 2021).

Norway

The Norwegian Food Safety Authority advises consumers not to eat too much seaweed, especially certain species and products, particularly because of high iodine levels. Some vulnerable groups of the population are advised to be extra cautious, such as pregnant and lactating women, young children, and people with thyroid diseases. In addition, persons with mild to moderate iodine deficiency must be aware that the thyroid gland takes time to adapt. A sudden high intake of iodine may therefore increase the incidence of thyroid disorders for this group (NFSA, 2016).

Norwegian seaweed producers have published a private guideline that includes labelling recommendation for products with high iodine content, to ensure that consumers can make an informed choice (Norwegian Seaweed Association, 2021). It is recommended to label the actual content of iodine and include the following text: "The seaweed/kelp species has a naturally high iodine content. The recommended daily intake of iodine is 0.15 mg. Excessive iodine intake over time can affect the thyroid gland".

Sweden

The Swedish Food Agency gives general advice on seaweed products, encouraging people to be aware of possible high iodine levels and to be cautious, especially pregnant and breastfeeding women (Swedish Food Agency, 2022).

Labelling legislation regarding iodine in seaweed

The general labelling requirements of foodstuffs in the EU are laid down in Regulation (EU) No. 1169/2011. The regulation does not include specific labelling of iodine in seaweed, but the general provisions in the regulation apply.

When used as feed materials, seaweed must be labelled when the level of iodine exceeds 100 mg/kg fresh weight (Regulation (EU) 2022/1104).

Discussion on risk management of iodine

High iodine levels in certain seaweed products may constitute a health hazard when used as food. Seaweed may be a good source of iodine, but that is conditional upon an accurate level of intake. This can be challenging, as it depends on the frequency of the intake of seaweed, amounts, levels of iodine in the seaweed, and also the consumers' general iodine status.

Iodine is probably the component in seaweed that poses the greatest risk in Nordic products. Management is a challenge, as the content varies greatly, both between and within species. The lack of consumption data and exposure assessment is also challenging when developing strategies for managing the risk of iodine from seaweed.

High levels of iodine in seaweed can be managed in various ways and it is the responsibility of the food business operator to ensure that their products are safe.

It should be noted that the assessment by EFSA in 2006, indicating that the ingestion of iodine-rich algal products can lead to dangerously excessive iodine intakes if such products contain more than 20 mg iodine/kg dry matter, is based on a risk assessment of toxicity. However, for risk management, other factors must be considered.

Nordic data in Table 3 show that most of the seaweed species have iodine levels significantly above 20 mg/kg dry weight, and sometimes a hundred times higher. Applying a maximum level of 20 mg iodine/kg dry weight would result in high rejection rates of the seaweed products currently in the global market and might disrupt existing supply chains.

Processing of seaweed to reduce iodine content is not always an optimal solution, since this can cause a loss of nutrients and flavours. The degree of reduction of iodine also varies and is sometimes insufficient.

Other important factors for risk management of products with high iodine levels include product type, portion size, frequency of consumption, and type of consumer group.

Dietary advice is often needed to complement MLs for contaminants in foodstuffs. However, depending on the product type and expected consumption pattern, a specific risk assessment should be made. As is the case for many other foodstuffs with high levels of unwanted substances, ensuring that seaweed products are safe for all different groups of consumers presents a challenge.

It will probably be necessary to have dietary advice on seaweed, with differentiated advice for different groups of the population. The advice should also be differentiated according to type of product and species. Specific voluntary and obligatory labelling is also a probable method for risk management, but this option will not be further discussed in this report.

The EU Commission is expected to evaluate appropriate risk management options for iodine in seaweed in the near future, as described in section 3.4. This risk management will be based on collected data from the member states and the upcoming consumer exposure assessment from the EFSA.

3.10 Microbiological hazards

Microbiological hazards may originate from the food product itself or from the environment. Environmental sources for seaweed can be the water or sediments in which it grows, transport after harvest, and further handling like processing, storage, and packaging. The question is, which hazards are the most severe and most likely to appear in food produced from seaweed?

It should be noted that seaweed has particular properties, different from other organisms which are used as food, as described in section 1.4. Some antimicrobial properties of seaweed are described in the literature. Duinker *et al.* (2016) describe that the surface of seaweed forms favourable habitats for microbes, where the load and diversity differ between the various algal species and may differ from the surrounding water communities, indicating algae-microbe interactions. Such interactions seem to be important for host health and infection defence.

Most studies concerning microbial communities associated with seaweed have an ecological focus, describing the numbers, diversity, and role of bacteria on the surfaces of the algae. Some of the bacteria found on seaweed are potentially human pathogens or could present challenges during processing and storage. Terrestrial plants like vegetables may be compared to seaweed in risk management, but there are great differences. For example, vegetables may be polluted with soil and soil bacteria from the growth location, which may be a possible health risk. This kind of challenge is not relevant to seaweed.

Many seaweeds are rich in bioactive compounds, which may have antioxidant properties and antimicrobial activities against food pathogenic microorganisms (Duinker *et al.*, 2016). Banach *et al.* (2020) also report about antimicrobial effects on for example *Salmonella*.

Identification and ranking of microbiological hazards

A review by Løvdal *et al.* (2021), based on global data, identified pathogenic *Bacillus* spp., *Vibrio* spp., and *Aeromonas* spp. as the main inherent bacteria of special concern for the food safety of seaweeds. *Bacillus* spp. form heat-resistant spores and can produce heat-stable toxins, whereas *Vibrio* and *Aeromonas* spp. can grow under chilled temperatures. Several bacterial species, including *E. coli*, *Salmonella* spp., *S. aureus*, and *L. monocytogenes*, and the viruses Norovirus and Hepatitis A virus, are considered to be potential food safety concerns, predominantly by virtue of recontamination during processing. Some other pathogenic bacteria, e.g., *Campylobacter* spp., *Clostridium* spp., *Shigella* spp., and yeast and moulds, are considered as seaweed associated, and can on rare occasions lead to food poisoning, but presumably because of gross violations of food safety protocol. According to the authors, further studies and risk analysis, and updated guidelines concerning food safety of both wild-harvested and cultivated seaweed, are necessary.

The ranking study of Banach *et al.* (2020) included the microbiological hazards *Salmonella*, *Bacillus*, *Escherichia coli*, *Listeria*, Norovirus, *Staphylococcus aureus*, *Vibrio*, and Hepatitis E virus. *Salmonella* was identified as a major hazard, *Bacillus* as a moderate risk. Norovirus was also identified as a moderate risk, but this result was more uncertain because of data gaps.

Since this report is intended for Nordic countries and products, studies of Nordic products are of particular relevance. A study by Blikra *et al.* (2019) describes the food quality and microbial safety of winged kelp and sugar kelp, harvested and processed in Norway. Samples included raw and frozen kelp. There were low total bacterial counts on the algae – between 1 and 3 log cfu/g for unprocessed algae and for the examined heat loads. No enterococci, coliforms, pathogenic vibrios, or *Listeria monocytogenes* were detected in any of the seaweed samples analysed. Due to the isolation of potentially toxin-producing spore-forming bacteria (*Bacillus pumilus* and *B. licheniformis*), the authors recommend that measures must be taken to control the growth of these species in the food during handling and storage.

Reported outbreaks

Few outbreaks are reported originating from seaweed, and quite few alerts on this in RASFF. One reported outbreak in Europe was caused by Norovirus in frozen wakame seaweed salad from China in 2019, where the salad was suspected of being the cause of more than 100 cases of gastroenteritis from at least 11 eateries in different areas of Norway (RASFF, 2019). The outbreak may have been caused by contaminated water or other ingredients in the salad, and not necessarily connected to the actual seaweed, but this was not investigated. Norovirus may also originate from poor water quality at the cultivation sites.

In Japan, outbreaks are reported caused by Norovirus in dried seaweed (Kusumi *et al.,* 2017). According to the authors, previously, this foodstuff has rarely been considered to cause food poisoning, but in 2017 there were unprecedented multiple norovirus outbreaks due to shredded, dried, laver seaweed packaged for long-term preservation.

Origin of microbiological hazards in seaweed

Microbiological contamination may arise when seaweed is harvested from water which is polluted by industrial or other human activities. Alternatively, the cause may be post-contamination related to factors such as lack of bathroom and handwashing facilities during handling of the seaweed after harvest. Processing of the seaweed into different food products may also entail risks if the hygiene is inadequate.

There are many categories of seaweed products on the market, with different processing levels and methods, such as fresh, dried, fermented, frozen, and heat-treated, and seaweed mixed with other ingredients. Products with low water activity, like dried seaweed, are assumed to have a general lower risk for microbiological contamination than fresh seaweed and seaweed mixed with other ingredients, such as in wet products like wakame salad. However, there are reports that toxigenic moulds could be associated with shelf-stable dried seaweed, but the hazards may be considered insignificant for raw seaweed intended for consumption in unprocessed form (Concepcion *et al.*, 2020).

Fermented seaweed may have a lower risk because of low pH. Temperature is also important, both during handling and storage.

As reported by Blikra *et al.* (2019), due to the isolation of potentially toxin-producing spore-forming bacteria (*Bacillus pumilus* and *B. licheniformis*) in seaweed, measures must be taken to control the growth of these species in the food during handling and storage.

Continuous chilling should be considered to prevent revival and growth of *Bacillus* spores in heat-treated products. *Bacillus* spores comprise a low risk for dried products and other products that are not heated.

Legislation and risk management

As seaweeds are organisms quite different to terrestrial plants and animals, direct comparisons are not possible. The EU has no specific microbiological criteria for seaweed. However, as in all food production, good hygienic practices and the general hygiene legislation must be followed.

Most relevant are the Regulation (EC) No 852/2004 on the hygiene of foodstuffs and the Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs. The last one includes the criteria for *Listeria monocytogenes* on ready-to-eat food. An example of a ready-to eat foodstuff is fresh seaweed intended to be used without further processing, for example in a salad.

Some countries have national regulations and recommendations, for example France, which has MLs for microbiological hazards in dried algae (CEVA, 2019)

Conclusion on microbiological hazards

Microbial contamination in seaweed may constitute a health hazard in seaweed used as food. Few outbreaks from seaweed-based food products are reported globally, and Nordic analyses and reports show very few and low levels of detections.

Many studies have been published on antimicrobial properties in seaweed. It is unknown whether such properties are the reason for the small number of reported outbreaks.

There is still little knowledge within this topic and no specific legislation for seaweed. However, the general principle applies, that the producers are responsible for ensuring that the food is safe to consume.

Some microbiological hazards may be more important than others, but no microbiological hazards should be excluded from risk analyses on production of seaweed.

As always in food production, the seaweed producer should implement the best management practices to control microbial growth during harvest, handling, storage, and processing. Critical steps in the production system in question should be identified.

Based on the rather limited data and studies on microbiological hazards in seaweed, possible hazard types and levels are listed in Table 9. These will vary according to regional differences and need to be updated in the future when more data is published.

Table 9. Examples of various product types and possible microbiological hazard level.

Product type	Possible hazard	Possible hazard level	Comment
Fresh or fresh-frozen seaweed with high water content and no heat treatment	Many types, such as Salmonella	High	If the water quality at sea is poor and/or the hygiene control is inadequate during handling, many types of hazards may occur, like Salmonella (Banach *et al.*, 2020).
Dried seaweed		Low - moderate	Hazard level depends largely on the degree of drying and the water content in the end product. Norovirus has been reported in dried Nori (Kasuma *et al.*, 2017). Reported toxigenic moulds that could be associated with shelf-stable dried seaweed (Concepcion *et al.*, 2020).
Heat-treated products with insufficient chilling	*Bacillus*	Moderate	Hazard: *Bacillus* (Blikra *et al.*, 2019), (Banach *et al.,*2020).
Products containing contaminated water and other ingredients (e.g. seaweed salad mixed with other ingredients such as wakame salad)	Norovirus	Moderate	Hazard: Norovirus - identified as a moderate risk, but this result is uncertain because of data gaps (Banach *et al.,*2020).
Fermented seaweed		Unknown	There is a knowledge gap on this processing method for seaweed, but the risk is assumed to be lower than for fresh seaweed and mixed products with high water content, caused by low pH.

In addition to the hazards included in Table 9, in theory many other microbiological hazards may be relevant, such as *Vibrio* spp., *Aeromonas* spp. *Escherichia coli*, *Staphylococcus aureus*, *Listeria monocytogenes*, Hepatitis A virus, Hepatitis E virus, *Campylobacter* spp., *Clostridium* spp., *Shigella* spp. and yeast.

3.11 Some other hazards

Biotoxins

Some species of seaweed produce toxins, and other toxins are produced by epiphytes attached to the algae.

A study showed occurrence of pinnatoxins in Norwegian *Saccharina latissima*, possibly linked to the presence of dinoflagellates attached to the surface of the seaweed. The level of the pinnatoxins identified was 10 to 100 times lower than that reported in shellfish, and consumption of this seaweed was considered not to pose a significant safety risk (de la Iglesia *et al.*, 2014).

According to Duinker *et al.* (2016), no poisonings due to consumption of seaweed have been reported in Europe, and levels of toxins reported in a few European studies have been low and without any concern for human health.

A Danish analysis found that some toxins are particularly related to a specific species, like kainic acid in dulse (DVFA, 2015). The levels were quite variable, up to 500 mg/kg in dried seaweed. Kainic acid is neurotoxic, but toxicological knowledge is limited, and the findings are difficult to access.

Physical hazards

Physical hazards on the seaweed may be present, in the form of impurities such as sand and small stones, and plastic and metal pieces from equipment and the environment. Growth of barnacles can also be a problem, as they can be difficult to remove by rinsing and need mechanical removal. This is especially relevant when harvesting older seaweed. A sufficient degree of rinsing reduces the risk of physical hazards.

Allergens

There is limited information about the allergenic potential of proteins present in seaweeds, but there may be traces of crustaceans, molluscs, and fish on the surface. Such traces may be a health risk for people allergic to these substances. The degree of such fouling will increase with the age of the seaweed and the water conditions, such as water temperature. Various processing methods in production before marketing, may reduce the presence of such traces.

PFAS

The EU Commission has recommended that the member states monitor perfluoroalkyl substances (PFAS) in food in the period 2022–2025 (EC, 2022). Seaweed is also included in this recommendation.

3.12 Sampling and analysis of metals and iodine

Sampling is a key issue in analytical checks of foodstuffs. In sampling, the heterogenicity of the analyte to be checked must be considered.

The great variability in the content of metals and iodine within each seaweed species is illustrated in Table 3 in the Nordic data. Cadmium, inorganic arsenic, and iodine are also reported to be heterogeneously distributed throughout the blades of seaweed (Kleppe, 2016). These aspects are important to consider when choosing sampling methods for seaweed.

In the EU recommendation on monitoring of metals and iodine in seaweed (EC, 2018), sampling procedures for these components should comply with Regulation (EC) No 333/2007. This regulation stipulates the methods of sampling and analysis for checking the levels of trace elements and processing contaminants in foodstuffs.

4 Labelling and marketing

The general legislation on the provision of food information to consumers, Regulation (EU) No 1169/2011, also apply to food based on seaweed. Among several demands in this regulation, information should be provided on the presence of substances or products that may cause allergy or intolerance. Certain seaweed products may contain traces of crustaceans, molluscs, and fish on the surface, and should be labelled to ensure that consumers with allergies to such substances are properly informed. Examples of such labelling are "May contain traces of crustaceans, molluscs or fish" and "May contain shellfish or fish".

Seaweed is often reported to have health benefits and is marketed accordingly. Business operators should only use permitted claims when marketing their products. According to Regulation (EC) No 1924/2006, only claims that are on the list of permitted nutrition claims or authorised health claims may be used. Such claims must be based on and substantiated by generally accepted scientific data and must not be false, ambiguous, or misleading. The European Commission decides which claims are permitted.

There is also legislation on common organisation of the markets in fishery and aquaculture products, which also include seaweed (Regulation (EU) No 1379/2013). However, this regulation is not implemented in all Nordic countries.

5 Conclusions and future considerations

This report summarises the current state of knowledge on food safety aspects and the status of legislation for seaweed used as foodstuff, with a special focus on Nordic conditions.

Food hazards

Based on the current knowledge, the most critical food hazards relevant for seaweed harvested in the Nordic countries are iodine, cadmium, and inorganic arsenic.

Iodine is an essential micronutrient, but both insufficient and excessive intake may pose health problems. Some seaweed products contain very high levels of iodine, so iodine is classified as a hazard in this context.

Other important food hazards to be considered, are lead and mercury, *Bacillus* spp in heat treated products, kainic acid in dulse, and allergens.

Available data and studies on microbiological hazards in seaweed are limited. Harvesting in clean water and general good hygienic practice is important, as in all food production, and the general hygiene legislation must be followed.

The levels of heavy metals and iodine vary greatly between and within species, and can be affected by age, growing conditions, and processing methods. The data presented on iodine, cadmium, inorganic arsenic, lead, and mercury in seaweed from Denmark, the Faroe Islands, Iceland, Norway, and Sweden, confirm these variations, both between and within species. The differences between the species seem to be quite similar.

For both food business operators and public agencies, it is important to differentiate between seaweed species, since the levels of contaminants can vary substantially from one species to another. Although the amount of data in this report is limited, it can be used as an indication as to which species are most challenging in terms of heavy metals and iodine in Nordic seaweed production.

The Nordic data shows that the brown algae generally have the highest levels of iodine, with the species sugar kelp, winged kelp, oarweed and tangle containing the highest levels. Species of red and green algae are considerably lower in iodine than the brown algae, except for the red algae wrack siphon weed. Oarweed can have exceptionally high levels of inorganic arsenic, whereas cadmium levels are highest in several brown and red algae.

Processing methods may alter the content of hazards; in particular, the iodine content can be reduced. However, some products may still contain excessively high levels of iodine after processing. Since a high intake of iodine may cause health concerns, consumers should be appropriately informed about the possible risk of such products, to enable them to make an informed choice. Dietary advice and labelling are possible tools to be used for this information.

Other hazards should also be considered. Examples of other possible hazards in seaweed discussed in the literature are Norovirus, *Vibrio, Clostridium* spp., *Aeromonas* spp., *E. coli*, *S. aureus*, Hepatitis A virus, Hepatitis E virus, *Campylobacter* spp., *Shigella* spp., yeast and moulds, various toxins, anti-nutrients, persistent organic pollutants, microplastic, radionuclides, nickel, aluminium, dioxins, polychlorinated biphenyls, brominated flame retardants, polycyclic aromatic hydrocarbons, fluorine, pesticide residues, pharmaceuticals, micro-and nanoplastics, and perfluoroalkyl substances.

It should be borne in mind that data on food hazards in seaweed are currently sparse. Knowledge about food safety in seaweed is increasing, but more data is needed to enable proper risk assessments. The type, level, and ranking of food hazards in seaweed in Nordic countries may change in the future, as more research produces new data, and conditions may be affected by climate change, such as increased sea temperature. New seaweed species may also be introduced into Nordic waters.

Risk assessment

The data on heavy metals and iodine in seaweed collected from the Nordic countries, is limited. For most seaweed species several samples have been analysed, but for some, only very few. The amount of data will increase considerably when the data collected from the EU monitoring becomes available.

The fast-developing seaweed market in the Nordic countries is in an innovative phase, and the level of consumption of seaweed products is not yet known but is probably increasing. The lack of data on both food hazards and consumer intake makes it difficult to perform proper risk assessments that include both consumption and levels of hazards.

The EU Commission has asked EFSA to deliver a scientific report by 2022, with a consumer exposure assessment for arsenic, cadmium, lead, mercury, and iodine in seaweed, and also an overview of the available occurrence data of these components.

Risk management, including development of legislation

Legislation on seaweed for use as food is sparse, both globally and in Europe. In risk management and future development of regulations and standards on food safety of seaweeds, it is important to take into account the biology and the properties of these organisms.

Compared to other organisms used as food, such as terrestrial plants like vegetables, fruits and mushrooms, seaweeds have different properties and growth environments and might also differ in terms of bioavailability of the food hazards. In addition, seaweed may be consumed in different amounts and patterns than other foodstuffs. The great variation between seaweed species, the effect of age, growing conditions, and processing methods on the levels of food hazards should also be considered.

The authors of this report strongly recommend development of a harmonised legislation on food safety in seaweed, in which seaweed should be classified as a specific group of foodstuffs, with subgroups for different seaweed species.

In the near future, the EU Commission is expected to evaluate risk management options for heavy metals and iodine in seaweed. This work will be welcomed by the food authorities in Denmark, the Faroe Islands, Iceland, Norway, and Sweden.

6 Development of guidance documents

This report can be used as reference material when drawing up guidance documents on risk management of food safety in seaweed. Guidance documents will be valuable for both food agencies and business operators in the Nordic countries.

A Nordic guidance document will not be prepared within this project, due to variations between the Nordic countries in terms of types of production, advice to consumers, and management of iodine intake in the population.

In addition, the rapid development of use of seaweed in food production, research on food safety aspects, and ongoing legislative developments in the EU necessitate frequent updates of guidelines, which will be more easily accomplished at national level.

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A Nordic approach to food safety risk management of seaweed for use as food

Current status and basis for future work

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