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Challenges related to processing and analysis of Norwegian seaweed, focusing on Sugar kelp and Winged kelp

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Report

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Summary/recommendation:

Kelp is a new and exciting ingredient in the food industry, restaurants and in the kitchen that is receiving increasing attention, but some of the components in kelp are potentially unfortunate and should be considered when preparing food. In this report, we have focused on the kelp species sugar kelp and winged kelp, and the component iodine - which we need, but in relatively small doses -, as well as the heavy metals cadmium and arsenic which are undesirable. Several studies have shown that it is possible to remove significant parts of the iodine content from kelp using relatively simple processing methods, such as boiling. There is good reason to believe that newer methods, such as high pressure, ultrasound, and enzyme treatments, have the potential to reduce iodine and heavy metals beyond this level, and perhaps in a more selective way than boiling, which also removes several flavor compounds and nutrients from the kelp.

The amount of iodine in kelp varies depending on various conditions (species, location, season, etc.). As of today, it is difficult to predict the amount of iodine in kelp without analyzing the iodine content in each harvest. In Nofima, we are working to establish two methods, a spectroscopic and a faster method, which can be used for various research purposes related to analysis of iodine in kelp and how we can control the content of iodine.

There are various recommendations for maximum iodine intake. These seem to depend on how much iodine the population initially ingests in their food. There are few guidelines in relation to the content of iodine and heavy metals in kelp, which places demands on the food industry for controlling the contents in each product as well as for establishment of recommended portion sizes.

Based on the research done so far, we have calculated how much sugar kelp can be eaten without exceeding the maximum recommended daily intake of iodine. More than anything else, the result emphasizes the variations. There is great variation both in terms of how much iodine is found in harvested kelp and how much is removed during the cooking process. This provides a great deal of uncertainty regarding the amount of kelp one should eat and reinforces the need for frequent analyzes of specific harvests on the part of the producers, as well as calculation of recommended portion sizes. Nevertheless, it must be acknowledged that there is a need, especially among consumers, to get more clarity on how much kelp is safe to eat.

Summary/recommendation in Norwegian:

Tare er en ny og spennende ingrediens i matindustrien og på kjøkkenet som får økende oppmerksomhet, men noen av komponentene i tare er mulig uheldige og bør tas hensyn til ved tillaging av mat. I denne rapporten har vi tatt utgangspunkt i tareartene sukkertare og butare, og i komponenten jod – som vi trenger, men i relativt små doser –, samt tungmetallene kadmium og arsen som er uønsket.

Flere studier har vist at det er mulig å fjerne betydelige deler av innholdet av jod fra tare ved hjelp av relativt enkle prosesseringsmetoder, som koking. Det er god grunn til å tro at nyere metoder, som høytrykk, ultralyd, og enzymbehandlinger, har potensial til å redusere jod og tungmetaller utover dette, og kanskje på en mer selektiv måte enn koking, som også fjerner flere smakskomponenter og næringsstoffer fra taren.

Mengde jod i tare varierer mye avhengig av ulike forhold. Per i dag er det vanskelig å forutsi mengde jod i tare uten å analysere jod i hver avling. I Nofima arbeider vi med å etablere to metoder, en spektroskopisk og en hurtigere metode, som kan brukes til ulike forskningsformål knyttet til analyse av jod i tare og hvordan vi kan styre innholdet av jod.
Det finnes ulike anbefalinger for maksimalt inntak av jod. Disse synes å være avhengig av hvor mye jod befolkningen i utgangspunktet får i seg i maten. Anbefalingene tar utgangspunkt i mengder og maksimale mengder av stoffer vi bør spise, og det er få retningslinjer i forhold til innholdet i selve taren. Det setter store krav til matindustri for kontroll på innholdet i sine produkter samt for etablering av anbefalte porsjonsstørrelser.

Basert på forskningen som er gjort til nå har vi beregnet hvor mye sukkertare som kan spises uten å overstige maksimal anbefalt dagsinntak av jod. Mer enn noe annet understreker resultatene variasjonen i påviste mengder. Det er stor variasjon både når det gjelder hvor mye jod som finnes i høstet tare samt hvor mye som fjernes under kokeprosessen. Dette gir en stor usikkerhet rundt mengde tare man bør spise og forsterker behovet for hyppige analyser av spesifikke avlinger fra produsentene sin side, samt beregning av anbefalte porsjonsstørrelser. Likevel må man erkjenne at det er et behov, spesielt blant forbrukerne, for å få mer klarhet i hvor mye tare som er trygt å spise, og det er ønskelig å bidra mot dette.

Abbreviations

EFSA	European Food Safety Authority
TWI	Tolerable Weekly Intake
CEVA	Centre d'Etude et de Valorisation des Algues (Center for the Study and Valorization of Algae)
WHO	World health organization

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1 Introduction

Since 2014 there has been increased interest for cultivation of seaweeds along the Norwegian coast. In 2019, there were 163 licensing permits in operation, divided amongst 16 companies and 97 locations (The Norwegian Directorate of Fisheries, 2020, preliminary figures). Hordaland is the region with the most cultivation, with 63 licenses in operation, followed by Nordland with 56 and Sogn og Fjordane with 22 licenses. Sugar kelp (*Saccharina latissima*) dominates, closely followed by winged kelp (*Alaria esculenta*), finger kelp (*Laminaria digitate*) and dulse (*Palmaria palmata*). In this report, we have chosen to focus on sugar kelp and winged kelp - the most popular species in Norway today.

The kelp farmers are a diverse group represented by several sole proprietorships and small companies, but also large companies. As a group, they constitute a young industry and face many challenges. Even after a decade of massive research efforts, obtaining stable and high yields is challenging and the costs of cultivation are such that the visions of biodiesel production are now seen an unrealistic. Hence, the current focus is on products with a higher market value, such as ingredients in feed, food, and cosmetics.

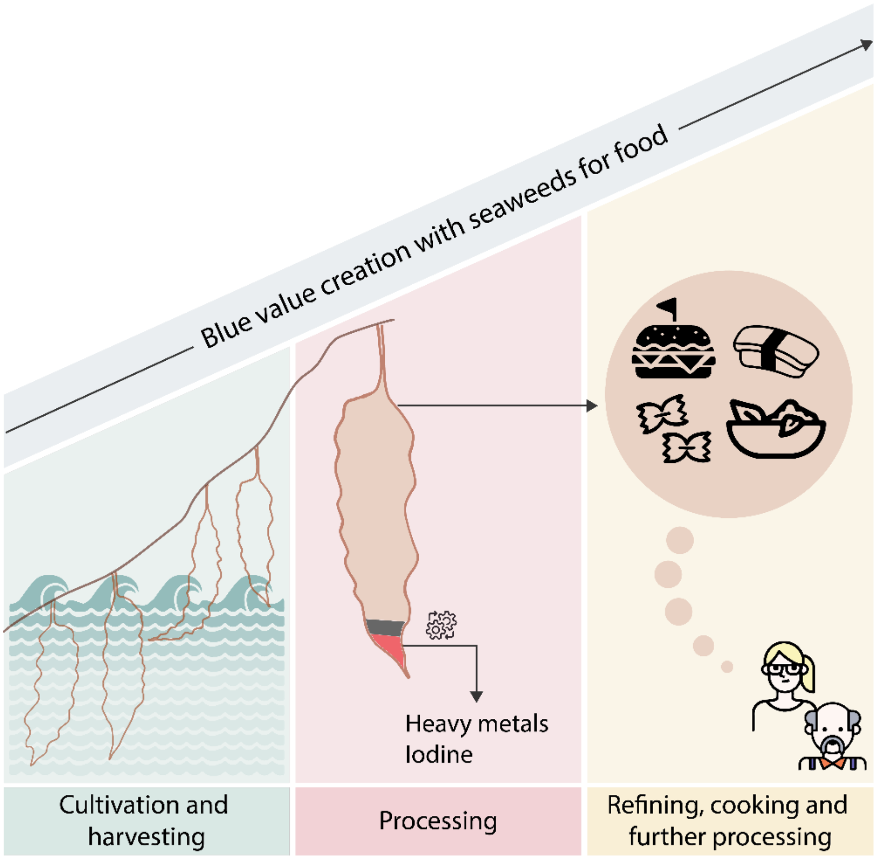

Figure 1 The value of cultivated kelp increases when it is processed into healthy and tasty products.

The main focus of Nofima is on issues related to the use of kelp in food. New products with cultivated kelp as an ingredient are introduced, and the number of such products is reaching new levels both in Norway and our neighboring countries. Tasty snack products, fish burgers with fresh colors and raw porridge with adapted iodine content are examples of products that have found their place in the marketplace. Nevertheless, as of today, there are few people in Norway who regularly eat a lot of kelp. It seems that consumers are still getting used to the idea of eating kelp, which is seen as a new ingredient in the kitchen by most Norwegians. This is a situation we should utilize to remove some bottlenecks related to the safety of kelp consumption. Seaweed contains many substances we want, but also substances we should not eat too much of. In an initial phase, in a research context, it may be a good idea to first shed light on the substances we do not want. In particular, iodine in seaweed is under vast current investigation and debate. There is a paradox here: We experience increasing iodine deficiency in Norway, but instead of highlighting kelp as an iodine-rich supplement to our diet, we are warned that we can get too much iodine if we eat a lot of kelp. Why? And are there ways to utilize kelp as a nutritious supplement in the diet without risking that we ingest too much? These are important issues that we address in this report. In addition to iodine, kelp can also contain heavy metals if present in the kelp growth area. This should also be considered when daily or weekly intake levels are estimated.

2 Contents in the relevant kelp species

2.1 General content

Kelp contains several nutritious food components, including fiber, minerals, vitamins, and polyphenols that can have antioxidant effects. Some types of kelp can also contain significant amounts of high-quality protein and healthy fatty acids. In addition, kelp contains significant proportions of flavor components, such as sugars, small peptides, and amino acids. Seaweed can also contain substances which we do not want in the food, such as heavy metals, in addition to the fact that the content of iodine in raw, unwashed kelp is very high.

In general, the nutrient content of brown algae is comparable to fruits and vegetables, but the brown algae are richer in minerals. Up to 94 % of the content is water, and ash, i.e. minerals and heavy metals (Table 1), can make up well over 15 % of the dry weight (up to about 50 %). The nutrient content of macroalgae varies with species, season, growth conditions, fertility, and from leaf to stem.

As safety is a key word in this report, we will focus on the ingredients that may have undesirable effects and the possible consequences in the following sub-sections.

Table 1 Reported values for arsenic, inorganic arsenic, cadmium and iodine in the literature.

	Heavy metals (µg/g dry weight)				
	Total arsenic	**Inorganic arsenic**	**Cadmium**	**Iodine**	**References**
Sugar kelp	39-66	0.03 - 0.4	0.1 - 3	1700 - 5300	Bruhn et al. (2019), Maulvault et al. (2015), Duinker et al. (2014), Stévant et al. (2018); Sharma et al. (2018)
Winged kelp	48-93	0.09 - 8.5	1.2 - 3.4	220 - 1798	Mæhre et al. (2014); Biancarosa et al. (2018); Kleppe (2017, master thesis)

2.2 Iodine

Iodine is an element that is closely related to chlorine and bromine, but less reactive. It was discovered in 1811 and is named after the Greek "ioeides", which means purple. It was the French chemist Bernard Courtois who, by adding sulfuric acid to seaweed ash, became the first to observe the violet gas that could condense to blue-black crystals. Solid iodine thus sublimates - goes directly from solid to gas, and vice versa. Iodine can be quite toxic. A dose of 2-3 grams is considered lethal. Like chlorine, it is also toxic to microorganisms, and it is often used dissolved in alcohol, for disinfection.

But all humans (and animals) need iodine to develop normally. The requirement is greatest in pregnant or breastfeeding women and in young children. Iodine has an important function as a component in two key enzymes that are very important, especially during the development of the brain and central nervous system, and which also control the metabolism throughout large parts of pregnancy. In adults, iodine deficiency can lead to restlessness, and in severe cases an overgrown thyroid gland - or what we call goiter (see Figure 2).

Since iodine deficiency can have significant health consequences, the iodine level in a population is often mapped by analyzing iodine in urine, since excreted iodine reflects the iodine level. Traditionally, iodine has been ingested by drinking milk and eating vegetables and fish. The authorities in many countries have contributed to increased iodine intake by adding iodine to table salt. But eating habits are changing. Among other things, we drink less milk than before, salt intake is reduced, and allergies can limit, for example, the intake of seafood.

We must therefore be given iodine through food, and there is a constant focus on iodine intake, in Norway and in the rest of the world. According to the Norwegian authorities, the daily requirement is between 150-600 µg. This is in accordance with the recommendations of most European countries. In Japan, where they eat a lot of seaweed in general and kelp in particular, the upper limit is 3000 µg/day. The effect of too high iodine intake is not as well documented and described as too low intake. But it has been seen that some people develop symptoms that are reminiscent of those seen with too little intake.

Recently, new studies have been carried out on the iodine status of young Norwegian women (MISA and LiN). The results strongly indicate that young women ingest too little iodine, and that this insufficiency, at a population level, can affect the children's learning ability. The studies also point to that young Norwegian women lack knowledge about the importance of iodine in the diet. Increased intake of seafood is one solution that has been pointed out by these researchers.

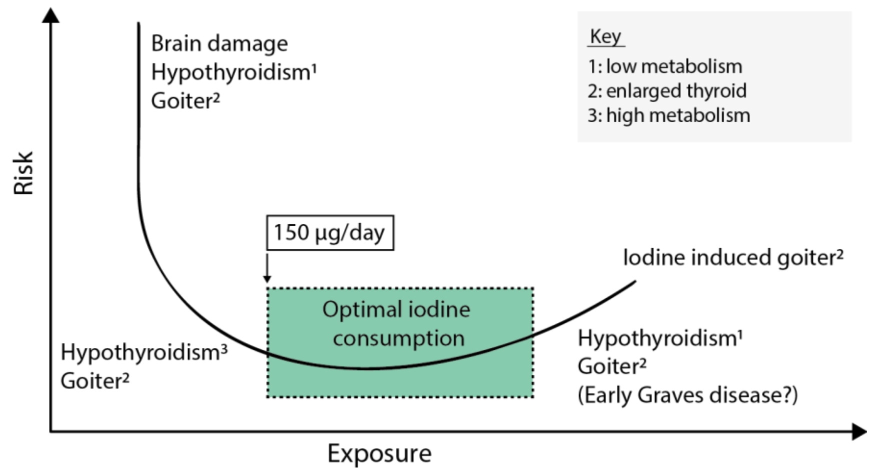

Figure 2 The relationship between exposure to a certain iodine intake over a long period of time and the risk of developing thyroid disease. The figure has been reconstructed based on Laurberg (2009), via National Council for Nutrition's (2016).

2.2.1 The iodine content of kelp

With the growing interest in utilizing the "blue field" (the sea) to increase food production, increase in iodine consumption can be highlighted as a benefit. In Norway, with large coastal areas which for many years has already been engaged in kelp harvesting, seaweed and kelp cultivation are included as important elements. However, the exploitation of these species for human consumption presents several challenges. Among other things, the natural content of iodine in kelp is sometimes so high that it limits the possibilities for human consumption, significantly. This issue is currently being studied from several angles, i.e. how to influence the iodine content of kelp in the cultivation phase. In addition, various processes and technologies that can be used to wash out iodine from kelp after harvest are investigated.

Sugar kelp grown in Norway can contain a lot of iodine, and levels from 1700 to almost 6000 mg/kg dry weight have been documented. The reasons why the content varies so much are complex and include differences between harvest locations and conditions such as available iodine in the kelp growth areas, the growth phase, the season, and the age of the kelp. There are also clear differences between different kelp species. In addition, the method used to analyze iodine content can affect the result.

2.3 Heavy metals

Data published on the contents of kelp harvested in Norway and Europe indicate that inorganic arsenic can be of potential concern in sugar kelp, and cadmium in winged kelp.

2.3.1 Inorganic arsenic

Arsenic is an element found in many different chemical forms in the environment.[1] In the marine environment, more than 100 different forms of arsenic have been identified. Inorganic arsenic enters the food chain by algae taking up arsenate from seawater. The algae can convert arsenate into organic arsenic sugars, which are further converted by other organisms higher up the food chain. In fish and other seafood, for example, the organic form of arsenic is the most common. The chemical form determines how harmful arsenic is. Inorganic arsenic (arsenite and arsenate) is more harmful than organic arsenic forms. Inorganic arsenic is classified as a carcinogen. In recent times, there has been some focus on arsenic in Norway, caused by sales of Asian rice products and algae products (Hijiki), which have a high content of inorganic arsenic. When it comes to our local kelp species, the content of inorganic arsenic in finger kelp is often very high, while sugar kelp mainly converts arsenic to organic compounds.[2]

There is no regulation for the total allowable amount of arsenic in food. For inorganic arsenic, until 2010, a temporary tolerable weekly intake (PTWI) of 15 µg/kg body weight was set. However, after a detrimental effect had been found within this area of exposure, this was withdrawn.

2.3.2 Cadmium

The heavy metal cadmium is present in the earth's crust and can be added to the environment through pollution from agriculture and industry. It is only slightly excreted from the body. The half-life, i.e. the time it takes before half of the cadmium is excreted, is between 10 to 30 years. Thus, it accumulates in the body, primarily in the liver and kidneys. It has been shown that cadmium can cause kidney damage (mostly in the elderly), and it can also have several other harmful effects.

Based on calculations of the critical concentration of cadmium in urine of people around the age of 50, EFSA has reduced the tolerable weekly amount of cadmium (TWI) from 7 µg/kg body weight/week (in 2009) to 2.5 µg/kg body weight/week. If the exposure is lower than TWI, it will ensure that the

[1] Arsenic should not be confused with arsenic trioxide (Norwegian: arsenikk), which is a known poison.
[2] Maulvault et al. (2015). https://www.sciencedirect.com/science/article/pii/S0013935115300839

cadmium concentration in the kidneys does not reach the critical level which results in reduced renal function.

Offal from animals and brown meat from crabs may contain significant amounts of cadmium, and the authorities believe that some societal groups may have an intake of cadmium that is higher than what is considered safe. High cadmium content is also a significant issue in winged kelp to be used for food (Stévant et al., 2018; Section 6.2).

3 How does processing affect the content of iodine and heavy metals?

A main objective of Nofima's work with seaweeds is to reduce the content of iodine in kelp so that including kelp in our diet can easily contribute to an optimal iodine consumption. At the same time, we aim to remove as much of the heavy metals and preserve as much of the valuable components in the kelp as possible. To achieve this, more research is required, but there are already some exciting results that show some of the possibilities for both traditional processing and new processing methods.

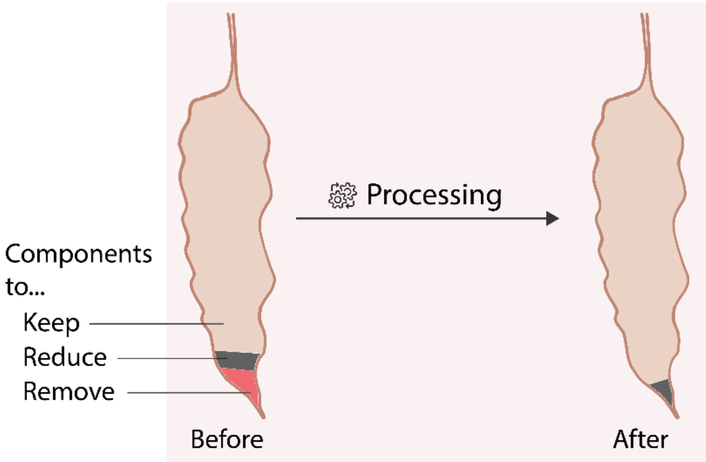

Figure 3 The ideal scenario for processing, where undesirable compounds (heavy metals) are removed, the components we want to limit (iodine) are reduced, and the desirable compounds (bioactive components, flavor compounds) are retained.

3.1 Traditional processing

There are several studies investigating how different processing methods affect the content of iodine in the kelp after harvest. One method that proves to be very effective is to immerse the kelp directly in water, especially if water temperatures above 32 °C are used (> 85 % reduction). Blanching and boiling may reduce the iodine content by up to 94 % (Table 2).

The disadvantages of immersing kelp directly in water are that other substances can also leak out, such as pigments and polyphenols, which many consider to be beneficial and health-promoting components. Problems regarding visual appearance due to e.g. unwanted color changes if the kelp is placed directly in lukewarm water after harvest, have also been documented. The color change that occurs can also be a positive quality change if it is evenly distributed throughout the blade. Even coloring may be achieved by ensuring that all the kelp has equal exposure to the water. In practice, this means using plenty of water compared to the amount of kelp. In addition, it is important to think about controlling the growth of unwanted microorganisms, which often grow faster at temperatures between 30 and up to 60 °C.

When blanched at 60 °C for 2-5 minutes, the iodine content was reduced by more than 90 %, and the kelp treated using these conditions also showed high activity of polyphenols and antioxidants (Nielsen et al., 2020). Based on this study, a similar processing regime seems promising in terms of chemical content and health-promoting components alone.

Table 2 Summary of published results on the iodine reduction from kelp during processing.

Method	Species	Iodine reduction	Source
Boiling (10 min)	Sugar kelp	77 %[3]	Lüning & Mortensen (2015)
Boiling (15 min)	Sugar kelp	38 %[4]	Bruhn et al. (2019)
Blanching (>2 min, 45-80 °C)	Sugar kelp	90 - 94 %	Nielsen et al. (2020)
Soaking (30-32 °C)	Sugar kelp	78 - 85 %	Stévant et al. (2018); Nielsen et al. (2020)
Washing	Winged kelp	Approx. 10 %[5]	Nitschke & Stengel (2016)
Drying, soaking and boiling	Winged kelp	75 %	Nitschke & Stengel (2016)
Drying (70 °C)	Sugar kelp	25 %	Stévant et al. (2018)
Fermentation	Sugar kelp	65 %	Bruhn et al. (2019)

Other methods have also been shown to reduce the content of iodine, but not to the same extent as boiling and blanching. Fermentation of sugar kelp can reduce the iodine content significantly (-65 %), and at the same time reduce other undesirable substances, such as mercury, cadmium and salt.

Traditional drying has a certain effect on the reduction of iodine. About 25 % reduction has been reported following drying at 70 °C, and with the use of lower drying temperatures, less loss of iodine has been found. Free iodine can sublimate or evaporate at low pressures (vacuum), such as during freeze-drying. Iodine that is bound in kelp will not automatically sublimate under vacuum and this is one of the reasons why more knowledge about how iodine is bound in kelp is of interest.

Nofima will investigate these issues in more detail, and in particular the combination of different technologies, and whether the use of newer technologies can have an effect beyond what is achieved with traditional technology.

3.2 Emerging technologies

Consumers are constantly demanding healthy, safe, and minimally processed foods. To meet the growing demand, new, innovative technologies based on, for example, high pressure, microwaves, ultrasound or electric fields, have received considerable attention in the last decade. Such technologies have been recognized for contributing to increased food safety and quality, as well as increased production efficiency in the form of, for example, reduced processing time or improved resource management. The new technologies are also interesting from a sustainability perspective, as these technologies often require less water or energy, reduce greenhouse gas emissions, or can help reduce food waste.

In addition, the technologies can be interesting for removing iodine and heavy metals from kelp. The way they work at the cellular level suggests that removing unwanted substances by using new techniques may be more selective than using traditional processing, so that it may be possible to find process conditions that remove unwanted substances while preserving other substances. Currently, little research has been done specifically on seaweed and kelp, but there are already some promising

[3] This sugar kelp contained profoundly low amounts of iodine initially, 380 mg iodine/kg dry weight.

[4] This study provides a very different result regarding reduction in iodine during boiling compared to other studies. The difference in results demonstrate well the large variations, and that there is remaining work to be done to understand why. The original content of iodine in this seaweed was 2630 mg/kg dry weight.

[5] Average reduction, but not significant compared to untreated samples (large biological variations).

findings. For example, microwaves and ultrasounds have been used to remove iodine from edible seaweed. The use of enzymes may also be necessary to break down the proteins in the seaweeds, so that iodine is released and can be more easily removed using other technologies. In addition, microwaves, and ultrasound, often combined with mild heat treatment or solvents, have succeeded in removing heavy metals from edible seaweed, crab and fish. EDTA, which is an authorized additive in the EU, binds selectively to metal ions, and it has been shown that it can be used to remove metals from kelp.

Nofima continues to work with new technologies and technology combinations in several ongoing projects. The goal is to find process conditions that provide products that have high quality, optimal content of iodine, and low content of heavy metals. We want to achieve a "toolbox" – an overview of how the process conditions change the properties and ingredients of kelp, so that we can assist companies with advice during product development.

4 Analysis of iodine

As mentioned previously, iodine was first detected in kelp, and kelp has long been an important source of pure iodine extraction. This is related to iodine being washed out into the sea from the earth's crust. In the ocean, there are iodine (I^-) or iodate (IO_3^-) ions in a concentration of just above 50 µg/L. Seaweed, especially brown algae, absorbs iodine from seawater in abundant amounts. This is brilliant for iodine extraction, but not so beneficial for human consumption. Without reducing the iodine content before kelp is used for food, such levels place limits on how much can be consumed.

In order to reduce the iodine content of kelp (Section 3), it is crucial to be able to measure the effect of the treatments being studied. And to be able to do that, one has to analyze the content of iodine. In kelp, iodine is present as ions, but also bound to protein. So, the first step in an analysis must release iodine from other compounds and dissolve it in an aqueous solution. This is often done at high pH, as it counteracts the formation of free iodine (I_2), which can diffuse from the solution (as a gas).

Until recently, there was an analytical method (Sandell–Kolthoff) used as a reference for the determination of iodine in kelp. The method is time consuming and involves the use of carcinogenic reagents. Currently, it seems that the analysis of iodine is mainly performed using advanced instruments (ICP-MS and HPLC). For most people in the kelp industry, this means sending samples, waiting for analytic results and significant costs.

Nofima is currently working on the issue related to analysis of iodine content. Driven by a wish for obtaining a simple and fast in-house method, we are currently establishing two methods that work for measuring iodine in different sample matrices.

5 Regulations and recommendations

5.1 Are seaweeds new food?

In 1997, the EU introduced the so-called Novel Food Regulation. In practice, the regulation means that foods that are considered new after 15 May 1997 must go through a bureaucratic, comprehensive process in order to be approved as food on the Norwegian and European markets. It is therefore gratifying that the vast majority of seaweed and kelp species that are considered food by Norwegian actors are labeled "not new" by the EU. On this list of approved food algae, we find, among other species, sugar kelp, winged kelp, finger kelp, knobbed wrack (*Ascophyllum nodosum*), sea spaghetti (*Himanthalia elongate*), and dulse. It is worth noting that pennant weed (*Laminaria hyperborea)* is not marked as "not new", and therefore it is possible to imagine that the sale of this species as food can present problems. But microalgae have been approved as "novel food" in the EU on the basis of similarity to approved species, so we can imagine that something similar is also possible for pennant weed if a similar basis for similarity between, for example, pennant weed and finger kelp is approved.

5.2 Recommendations and limits for intake of iodine and heavy metals

Table 3 Recommended daily intake and upper iodine intake for adults.

	Recommended daily dosis (µg)	Recommended maximum intake (µg/day)[6]
Norway	150	600
EFSA	-	600
France	150	500-600
USA	150	1100
WHO	150	1000
Japan	130	3000

In Norway and in the rest of the world, it is recommended that adults[6] consume around 150 µg of iodine per day, as shown in Table 3. It is recommended that children consume less, and that pregnant and breastfeeding women consume more iodine. This is described in more detail in the report Risk of iodine deficiency in Norway, published by the National Council for Nutrition (2016, in Norwegian)[7]. With regard to the upper recommended limit for iodine, the recommendations are more diverse worldwide. In Norway and the EU, a maximum of 600 µg per day is recommended, while the limits are higher in the USA and especially in Japan. This is justified by the fact that there is a greater risk of severe symptoms with high single doses of iodine if the population initially lacks iodine. Intake of around 600 µg per day is considered safe even for people with iodine deficiency. Recommended maximum values for arsenic and cadmium are described in Sections 2.3.1 and 2.3.2, respectively.

[6] Calculated for an adult, non-pregnant and non-breastfeeding reference person weighting 65 kg.
[7] The WHO report, *Iodine deficiency in Europe - A continuing public health problem* (2007) will give some of the same information, but from a more general European perspective.

5.3 Limits for iodine and heavy metals in seaweeds

Few limit values have been proposed for the content of iodine and heavy metals in kelp. The exception is the agency CEVA in France, who has established elaborate guidelines, whereas the EU has set limits for the content of cadmium, mercury and lead. In Table 4 below, the ingredients that are the greatest threat to food safety for the most important brown algae are included. This issue is also thoroughly discussed in Pierrick Stévant's PhD dissertation (2019) at NTNU[8], see especially Chapter 5.4. In order to establish a sustainable global industry with kelp, the establishment of food safety standards and regulations specific to kelp are areas that must be improved, as highlighted in the newly published manifesto *Seaweed revolution: A manifesto for a sustainable future* (2020)[9].

Table 4 Limits for content of iodine and heavy metals in seaweeds.

Agency	Maximum content (mg/kg dry weight)		
	Iodine	**Inorganic arsenic**	**Cadmium**
CEVA	2000	3	0.5
EU	-	-	3.0

When discussing the content of iodine in kelp, the question of bioavailability – how much iodine you are able to absorb in the body – is frequently brought forward. Animal studies indicate that the bioavailability of iodine from raw kelp is relatively low, which may mean that you can eat more kelp than the equivalent of 600 µg/day. However, insufficient human studies have been performed to ascertain that this also applies to us. In addition, it is also possible that bioavailability varies from person to person, depending on factors such as the composition of microbes in the intestinal system, as well as the other components of the diet. The issue of bioavailability quickly becomes very complicated, and before we know more about this issue, we must calculate recommended daily doses based on 100 % bioavailability of iodine from kelp.

8 Accessible from: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2606704
9 Accessible from: https://unglobalcompact.org/library/5743

6 How much seaweed can we eat?

6.1 Considering the content of iodine

The content of iodine in kelp is very variable, even within the same species. If you eat fresh sugar kelp without processing or drying, you need between 8-20 g of kelp to reach the recommended maximum limit of 600 micrograms of iodine per day, depending on the original iodine content in the kelp. If you eat dried sugar kelp that has not been boiled or processed in other ways than drying, you can reach the maximum recommended daily dose of iodine already at 0.12 g sugar kelp (Stévant et al., 2018)[10], which is around ¼ teaspoon (Figure 4).

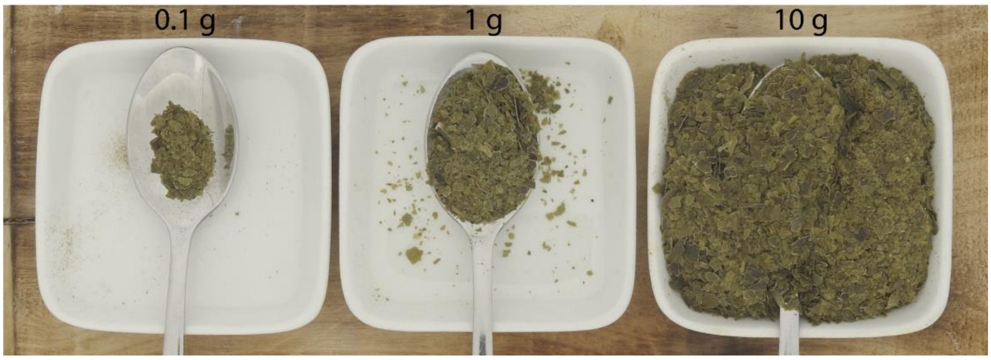

Figure 4 Illustration showing the amounts of dried sugar kelp (weight) compared to a teaspoon.

Very different amount of iodine reduction during processing have been found in various studies of sugar kelp using similar processing methods. The differences are clearly shown in Figure 5, where how much iodine kelp contains (in wet weight) after different types of processing is plotted. The figure is based on the iodine and dry matter values given in three studies: Nielsen et al. (2020)[11], Bruhn et al. (2019)[12] and Stévant et al. (2018)[13]. All studies examine the effect of reduction in iodine concentration during treatment of sugar kelp in water at different temperatures, and in the study by Bruhn et al. the effect of fermentation is also investigated.

The study with the most promising results in relation to the use of sugar kelp as a vegetable, is the study by Nielsen et al. (2020). In this study, blanching, i.e. heat treatment in water for a short time, and usually at temperatures below 100 °C, was thoroughly investigated. The results show that blanching can give an iodine reduction in sugar kelp of 94 % between 45-80 °C and heat treatment of 2 minutes or more. At the same iodine concentration in raw kelp as the kelp used in this study, 4600 mg/kg dry weight, an adult will then be able to eat 163 g of fresh blanched sugar kelp per day, and still keep within the limit of the maximum recommended intake of iodine[14] (Figure 5). The researchers have investigated several combinations of time and temperature, and the results show that it takes less

[10] Accessible from: https://link.springer.com/article/10.1007/s10811-018-1451-0
[11] Accessible from: https://www.mdpi.com/2304-8158/9/5/569
[12] Accessible from: https://link.springer.com/article/10.1007/s10811-019-01827-4
[13] Accessible from: https://link.springer.com/article/10.1007/s10811-017-1343-8
[14] Here and in the other examples in this Section, it is assumed that the iodine consumption from other foods is negligible. The major sources of iodine in the Norwegian diet are white fish and milk, and to reach the daily requirement of 150 µg iodine you can eat 160 g cod, 125 g pollock, or drink approx. 7,5 dl milk.

time to reduce the amount of iodine at higher temperatures, but when the blanching time is 2 minutes or more, the temperature does not, as long as it is above 45 °C.

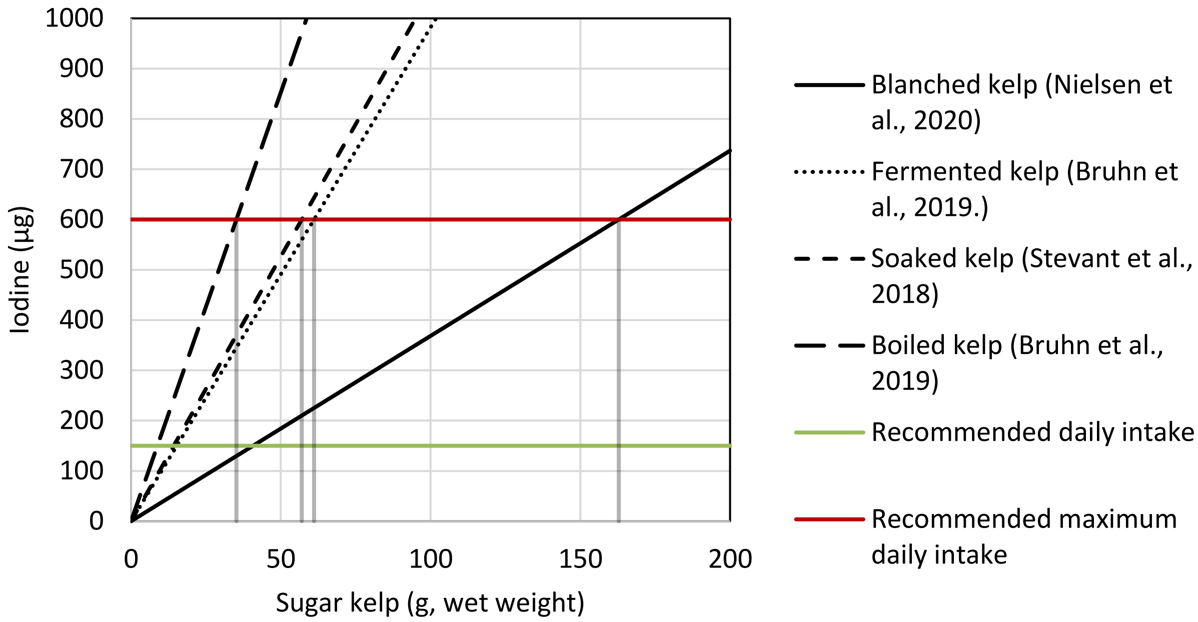

Figure 5 Iodine content in sugar kelp (wet weight), including recommended limits of consumption.

While the results of Nielsen et al. (2020) are very promising for using sugar kelp as a vegetable in cooking, other results point in the opposite direction. Bruhn et al. (2019) investigated the effect of both boiling and fermentation on the content of iodine in sugar kelp. The iodine reduction during boiling in this study was 38 %. The sugar kelp used by Bruhn et al. had an iodine content of 1600 mg/kg dry weight after cooking for 15 minutes, which means that you can only eat up to 35 g boiled kelp to keep within the maximum limit (Figure 5). Fermentation resulted in a much larger reduction in the content of iodine, by 65 %, which means that you can safely eat almost twice as much - 61 g - sugar kelp if it is both boiled and fermented. Stévant et al. (2018) soaked freshly harvested kelp in fresh water with a temperature of 32 °C for 1 hour and received a reduction from 6600 mg/kg iodine per dry weight of the sugar kelp to around 1000 mg/kg iodine. The reduction of around 84 % iodine means that you can eat 57 g of fresh, soaked kelp if you want to be within the recommended limit for iodine. What is particularly interesting here is that the study by Nielsen et al. shows that iodine in sugar kelp is reduced more at temperatures above 45 °C than at 30 °C, while the opposite emerges when comparing the studies of Stévant et al. (2018) on soaking kelp in lukewarm water and Bruhn et al. (2019) on boiling kelp. This may indicate that more in-depth studies are needed. Maybe factors like if and if so, how the kelp is frozen and thawed before cooking is of importance? Or maybe iodine is bound in different ways for kelp harvested at different locations with different genetics, which will affect how easily iodine disappears during processing?

6.2 Considering the content of arsenic and cadmium

The content of cadmium and inorganic arsenic has been pointed out as factors that can limit the amount of kelp which can safely be used in food and feed (Duinker et al., 2016).[15] For sugar kelp it is mainly the content of iodine that limits the amount for recommended consumption (Section 6.1), but for winged kelp, cadmium is the biggest limitation. Stévant et al. (2018)[13] found a cadmium content of 2.0 mg/kg dry weight. With an intake of 3.3 g of dried winged kelp (approx. 3 teaspoons, Figure 4), this constitutes 27 % of the tolerable daily dose of cadmium for a 70 kg person. Other studies have found between 0.1 and 0.6 mg/kg dry weight, and based on the highest documented content, 3.3 g of dried winged kelp may contain 54 % of the tolerable daily dose of cadmium for a 70-kg person. As with sugar kelp, winged kelp contains a lot of water (around 90%), so when consuming winged kelp in wet weight (fresh, boiled or soaked) you can eat about 10 times more (weight basis) than dry winged kelp to achieve the same proportion of the tolerable daily dose.

The amount of inorganic arsenic found in sugar kelp and winged kelp is generally within the limit values established by CEVA. A clear exception to this has been found in wild winged kelp harvested outside Bergen, where between 8.0 and 9.6 mg/kg dry weight was found (Kleppe, 2017)[16], which is three times as high as the CEVA limit of 3 mg/kg dry weight inorganic arsenic in kelp. Other findings in the same work are far lower and in line with the findings in other studies, between 0.1 to 0.4 mg/kg dry weight. This example clearly shows that the content of unfortunate substances in kelp can vary greatly and must be carefully controlled. To reduce the content of heavy metals, seaweeds are cultivated and harvested from locations with low heavy metal content in the seawater, which gives a lower content in the food.

[15] Accessible from: https://www.mattilsynet.no/mat_og_vann/produksjon_av_mat/fisk_og_sjomat/rapport_makroalger_2016_nifes.23097/binary/Rapport%20makroalger%202016%20Nifes

[16] Master thesis written by Malin Kleppe at the University of Bergen (2017). Accessible from: http://bora.uib.no/bitstream/handle/1956/16728/Masteroppgave--01-09-2017--Malin-Kleppe--08-59-.pdf?sequence=1&isAllowed=y

7 Conclusion

Seaweed is a new and exciting ingredient in the food industry, restaurants and in the kitchen. More and more kelp products are being introduced on the market and there is a lot of focus on the possibilities of using kelp as a substitute for salt, as a flavor enhancer and overall, as a healthy ingredient.

Some of the components in kelp are potentially harmful and should be considered when preparing food. This report focuses on the kelp species sugar kelp and winged kelp, and three of the components in these kelp species. Iodine is a substance we need, but in relatively small doses. The heavy metals cadmium and arsenic are undesirable.

Several studies have shown that the composition of kelp changes during processing, and research efforts have so far been focused on traditional methods, including simple and inexpensive methods such as blanching and cooking. More advanced methods (Section 3.2) can also be promising candidates for the control of components in kelp, in addition to combinations of technologies.

The recommendations for how much iodine we need are clear (Section 5.2), but the limit for the maximum recommended intake varies depending on how much iodine the population initially ingests via food. There are few guidelines in relation to the content in the kelp itself. This places great demands on the food industry for controlling the content of its products as well as the establishment of recommended portion sizes.

As there is considerable variation both in terms of content of iodine, arsenic, and cadmium - both in harvested kelp and what has been found in kelp after various methods of processing - it is currently demanding to establish a general recommendation as to how much kelp should be consumed. Boiling significantly reduces the proportion of iodine in kelp and hence will increase the amount of sugar kelp and winged kelp you can safely consume. When consuming dried kelp, small amounts are needed to reach the recommended maximum daily dose of iodine, if drying is not combined with other processing methods.

7.1 Research needs

The research front moves quickly, and the knowledge regarding which components are found in seaweed and what kind of variations we can expect is continually increasing. However, a lot of research is still needed to achieve the goal of controlling the content of various components in kelp. This requires further studies that go more into details and which take the sources of inherent variations into account.

With increased knowledge of how iodine and heavy metals are bound in kelp, and which mechanisms are needed to release the components, this will enable us to better perfect the processing methodologies and create new foods that are healthy and sustainable, in addition to enjoy seaweed as a decorative flavor enhancer.

Using various processing methods, it is possible to optimize the content of iodine in kelp. In further work, we must take into account both limiting iodine and removing heavy metals, as well as other undesirable substances such as allergens, in addition to retaining the components that are desirable, such as nutrients, vitamins, functional components and flavor components.

8 Recommended sources for further reading

Some of the sources are only available in Norwegian (NO).

Iodine and iodine deficiency in Norway

Risiko for jodmangel i Norge. Identifisering av et akutt behov for tiltak. Nasjonalt råd for ernæring. 2016 (NO)
https://tidsskriftet.no/2019/01/oversiktsartikkel/er-inntaket-av-jod-i-befolkningen-tilstrekkelig (NO)

Basis for establishing dietary guidelines:

Nordic Nutrition Recommendations 2012. Integrating nutrition and physical activity (EN)

Cadmium:

https://www.fhi.no/ml/miljo/miljogifter/fakta/kadmium-i-mat-og-miljo--faktaark/ (NO)

Arsenic:

https://www.ntfe.no/i/2017/1/tfe-2017-01b-699 (NO)
http://www.efsa.europa.eu/en/press/news/140306 (EN)
https://vkm.no/risikovurderinger/allevurderinger/vurderingavuorganiskarseninorskkosthold.4.773639b215c8657f2a497396.html (NO)

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