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Review

Effects of Heat Treatment Processes: Health Benefits and Risks to the Consumer

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Abstract: Macroalgae are a biological group that has mainly been used in Asian countries; however, the interest shown by Western society is recent, its application in the industrial sector having increased in the last few decades. Seaweeds are filled with properties which are beneficial to our health. To use them as food and enhance these properties, heat has been used on them. This process alters the bioactive compounds. If we study the levels of moisture, they can vary according to the drying methods used. High values of moisture can lead to a short shelf life due to oxidation, microbial or enzyme activity, so controlling these values is highly recommended. Heat causes enzymatic activity as well as oxidation, which leads to degradation of phenolic compounds in comparison with freeze-drying, which causes fewer losses of these components. Due to the same occurrences, lipid content can also vary, modifying the bioactive compounds and their benefits. Pigments are some of the components most affected by heat, since, through this process, seaweeds or seaweed products can suffer a change in color. Iodine in macroalgae can decrease drastically; on the other hand, protein yield can be greatly enhanced. Some studies showed that the amount of arsenic in raw seaweeds was higher than when they were heat processed, and that arsenic values varied when different heat treatments were applied. Additionally, another study showed that heat can alter protein yield in specific species and have a different effect on other species.

Keywords: heat treatment; seaweeds; bioactive compounds; food safety; consumer health

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1. Introduction

It is estimated that the world population will grow to 10 billion in the next three decades. This will require a 70% increase in food production [1]. Moreover, the production of meat will double in the same time span. Because of this, the search for new food sources is essential [2]. Intensive farming and agriculture have contributed to the saturation of arable lands and reduced access to fresh water [3,4]. These actions are some of the causes of climate change.

Seaweeds are one of the most promising foods for sustainability. Their ability to capture CO_2 from the ocean and the atmosphere represents an excellent method to battle climate change. Furthermore, they have the potential for fast growth in the ocean, which facilitates the method of producing it while reducing the cost of production [3]. Even though seaweeds have been consumed for centuries in Eastern countries such as China, Japan and Korea, in Western societies, their introduction as food source only occurred a few decades ago. This happened after World War II when, due to the exponential population growth, it was noticed there was insufficient protein consumption. To fight that

lack of nutrients, seaweeds played a major role, being rich in several macronutrients and micronutrients, including vitamins, minerals and proteins [5,6]. Because of their polymers, such as carrageenan, agar and alginate, and their properties for gelling, emulsifying and thickening, they have been used as a novel food [7,8].

Seaweeds are an excellent source of bioactive compounds with health-promoting benefits, such as antioxidants, dietary fiber, essential fatty acids, vitamins and minerals, consumption of which has been associated with a lower occurrence of some chronic diseases, such as diabetes, obesity, heart disease and cancer [9,10]. Due to these beneficial properties, it is necessary to assess how the culinary processes influence and modify the valuable compounds that are sought after in their consumption. With the growing interest in consumption of these organisms, it is crucial to assess how culinary treatment, specifically thermal treatment, alters the bioactive content of edible algae, as the particular methodology has an impact on the biochemical composition [9].

Utilization of seaweeds normally requires post-harvest dehydration to reduce the water content, which can be up to 85–90% of the biomass [9], preventing decomposition and microbial contamination, increasing shelf life and consumer safety while also aiding the extraction of important chemical constituents [11]. Several techniques have been described for the drying of seaweeds. Sun-drying and oven-drying are the most used, due to their accessibility and relatively low operation cost [11,12]. However, solar drying is dependent on the climate and exposure to airborne contamination, which can compromise the hygiene of the product [11,12]. Oven-drying requires a large space, has high energy consumption and leads to component degradation, especially heat-labile compounds [11,12]. Other methods, such as freeze- or vacuum-drying, are not widely used for commercial purposes, as they are expensive techniques used for the extraction of specific components for specific industries. This review will focus on the available literature regarding drying processes and phytochemical alterations derived from these processes.

2. Moisture

Usually, different drying techniques will result in different moisture levels that remain after treatment. This residual moisture affects the stability of bioactive compounds in dried materials, possibly due to oxidation, enzymes or microbial activities that successfully degrade the remaining bioactive compounds, which are an important factor when considering transportation and storage [13–15].

Regarding *H. banksia* (Phaeophyceae), there is a significant difference in the impacts of physical properties under different drying treatments, with lower moisture being obtained using freeze-drying methods rather than oven-drying, with the highest residual moisture found in sun-dried samples (5.7, 7.7 and 16.2%, respectively) [16]. The extraction yield was, in comparison, higher for freeze-drying (29%), followed by oven drying (20%) and, lastly, sun drying (18%). For *A. taxiformis* (Rhodophyta), the results are the opposite, with higher moisture content obtained in freeze-dried in comparison with oven-dried samples. In a study with *Kappapychus alvarezii* (Rhodophyta) and *Sargassum polycystum* (Phaeophyceae), the moisture content of freeze-dried samples was lower than for oven-dried samples. Overall, there is a general agreement that freeze-drying results in lower moisture percentages in comparison with oven-drying techniques [9,13,16–22].

3. Phenolic Content

The phenolic compounds present in seaweed mainly include chlorogenic acid, phloroglucinol and phlorotannins, caffeic acid, kaempferol, benzoic acids, coumaric acids, cirsimaritin, ferulic acid, gallic acid and syringic acid [11,13,17,20]. The extractability of bioactive components from oven-dried *Gracillaria* sp. (Phaeophyceae), *Ulva rigida* (Chlorophyta) and *Fucus vesiculosus* (Phaeophyceae) was studied at different temperatures (25 °C, 40 °C and 60 °C) [18]. However, there was a demonstrated reduction in total phenolic and flavonoid content after drying. In *Hormosira banksia* (Phaeophyceae), total phenolic content (TPC) and total flavonoid content (TFC) were highly affected by the drying technique, with greater

preservation of the phytochemical content through freeze-drying, de-humidification and vacuum drying, compared with oven- or sun drying. For *Saccharina latissima* (Phaeophyceae), the drying temperature and humidity had a significant effect on TPC, with a reported drop by 10-fold compared with the fresh algae [13], with the highest amount of phenolic activity in freeze-dried samples and the lowest in samples dried at 70 °C. This variation is possibly due to less oxidation at lower temperatures and the absence of oxygen while vacuum-drying [20]. In accordance with these results, the drying kinetics of *Himanthalia elongata* (Phaeophyceae) when exposed to a range of temperatures was described [16]. After a 24-h drying period, a reduction of 29–51% in total phenolic compounds was observed, with the maximum reduction of 51% observed for the 25 °C drying, while a reduction of 29% was observed for drying at 40 °C. Total flavonoid content followed a similar tendency to the phenolic content in these algae [10,16].

In Badmus et al., the effects of different drying processes (oven-drying at 40–60 °C, freeze-drying and microwave drying at 385, 540 and 700 W) on antioxidant potential, protein, lipid, amino acid and fatty acid content were tested in five brown seaweeds (*Fucus spiralis*, *Laminaria digitata*, *Fucus serratus, Halidrys siliquosa* and *Pelvetia canaliculata*) [11]. The results demonstrated an overall loss of compounds, with high values of certain compounds linked to specific drying methods.

Overall, heat causes cellular damage, inducing enzymatic activity and oxidative stress, leading to thermal degradation of the phenolic compounds [20]. These heat-labile compounds are usually bound within carbohydrates, protein and the fatty acid matrix in the food structure [20]. A substantial number of phenolic compounds can be degraded due to light or oxygen exposure, which are more likely to occur in an oven-dryer system in comparison with freeze-drying. This phenolic content is associated with several of the beneficial properties present in seaweeds. Assessing the best methods is crucial for optimization, in order to minimize phenolic content loss [17].

4. Lipid Content

Seaweeds contain fats in the form of saturated fatty acids (SFA) such as myristic acid, palmitic acid and stearic acid; monounsaturated fatty acids (MUFAs) such as oleic acid, palmitoleic acid and eicosenoic acid; and polyunsaturated fatty acids (PUFAs), such as linoleic acid, stearidonic acid, arachidonic acid and eicosapentanoic acid, representing approximately 40% of the total fat/lipid content [11,20]. In regard to PUFAs, some are considered essential fatty acids because they cannot be biosynthesized by the human body and are solely obtained through the diet. The beneficial impacts and properties of these lipidic compounds is well studied, and it is important to understand the variation in these fatty acids when exposed to heat treatment. For *S. latissima* (Phaeophyceae), there was no significant difference in the lipidic content in [20] when dried under the temperature and humidity conditions tested in the study (30 °C, 50 °C and 70 °C temperature and 25–50% humidity). This could mean that under heat treatment, there is no loss of lipids through dripping or oxidation [20]. However, for *Pyropia orbicularis* (Rhodophyta), fatty acid concentration was observed to suffer modifications according to the drying method applied [13]. While there was a yield loss of SFA for sun-drying and oven-drying compared with freeze or vacuum-drying, there was no significant difference in total MUFA content with different drying techniques [13]. Interestingly, for these algae, a higher decrease in PUFA content was reported for samples treated with freeze-drying and vacuum-drying, compared with sun- or convective drying. For *F. spiralis*, *F. serratus*, *H. siliquosa* and *P. canaliculata*, the highest lipid content values tended to be obtained through freeze-drying, while for *L. digitata*, they were obtained through oven-drying at 40 °C, and the lowest value of lipid content was identified for both *Fucus* species in oven-dried batches. C16:0, C18:1 and C20:4n6 were the predominant SFA, MUFA and PUFA for all seaweeds, respectively. For SFAs, higher levels were found in *L. digitata* and *H. siliquosa* after freeze-drying and oven-drying and 40 °C, while other species showed little differences in SFA content. MUFA content was the highest in *F. spiralis* and *L. digitata* after oven-drying at 40 °C, followed

by freeze-drying and microwave treatment at 385 W. Regarding PUFA levels, *L. digitata* and *H. siliquosa* exhibited higher concentrations after microwave treatment, while both *Fucus* species had higher levels after freeze-drying [11]. The lipid content in *Aspargopsis taxiformis* [9] when exposed to oven-drying (60 °C) or freeze-drying also demonstrated important changes. Overall, total lipid yield for *A. taxiformis* was low, with slightly higher lipid preservation in freeze-dried samples. The fatty acid profile (as a percentage of total fatty acids) was characterized by a high concentration of saturated FAs (76% of total FA), with low levels of monounsaturated fatty acids (4–11% MUFAs) and even lower concentration of polyunsaturated fatty acids (0–11% PUFAs) after drying. In *A. taxiformis*, a relative higher concentration of SFA and MUFAs was obtained through oven-drying at 60 °C, with the exception of PUFAs, which demonstrated a higher concentration in freeze-dried samples [9].

Overall, there have been several results regarding total fatty acids concentrations, a variation that may have resulted from the method applied or due to the intrinsic variation between algae species. During the drying processes, oxidation and degradation of lipidic content can occur via several mechanisms, such as autoxidation, photosensitized or enzymatic reactions. In the case of PUFAs, autoxidation is specially critical, due to the intrinsic low disassociation energy [11,20].

In order to retain bioactive compounds and functional properties of dried seaweed products, it is necessary to undertake a detailed and simultaneous investigation of the seasonal variation and effects of different drying methods and conditions (humidity and temperature) on the physiological properties, phenolic and antioxidant activities of the target seaweed [11,20]. Within the same species of seaweeds, morphological and structural differences in tissues, age, size, environment and seasonality influence the phytochemical components of seaweeds [20].

Freeze-drying works on the principle of sublimation under a vacuum and removal of frozen water, while conventional oven-drying is subjected to humidity, temperature and air velocity inside the drying chamber [20]. Even though it has demonstrated better yield and quality products, in terms of maintaining the integrity or nutrient and phytochemical profile, freeze-drying is not a commercially deployed technique, as its high-energy requirements and costs make it unprofitable for large-scale operations, targeting the extraction of finer components for specific industries [11,20].

5. Rehydration and Cooking

As with most consumable dried products, there is the need for rehydration of the products prior to consumption, in order to restore the fresh properties of the dried product, usually through contact with a liquid phase. In general, this process can be divided into three phases: (1) water absorption by the dried material, (2) swelling of the dried product and (3) loss or diffusion of the soluble components [10].

Rehydration and blanching are performed to increase palatability but can cause a significant loss of phenolic content, which leaches to the boiling water. Cox et al., when studying the rehydration kinetics of *H. elongata*, observed that the rehydration time decreased as temperatures increased the magnitude of absorbed water [10]. Additionally, it was also observed that for *H. elongata*, rehydration of biomass resulted in a decrease in total phenolic compounds in the dried seaweed, from 1.21 ± 0.02 g GAE/100 g db to 0.2 ± 0.009 g GAE /100 g db when the rehydration was finished [10]. Phenolic compounds are heat-labile, and when exposed to boiling water through blanching or cooking, there can be a significant loss of such compounds. It is generally accepted that rehydration is dependent on the degree of cellular and structural disruption. When irreversible damage has been caused, large structures within the cells can collapse and reduce the hydrophilic properties, hence reducing the rehydration properties [10].

The hydration of dehydrated seaweed food products is usually applied before consumption [10]. This rehydration is a complex method used to restore, in the best possible way, the quality and properties of the original fresh product using a liquid phase, normally

an aqueous solution. This method is based on three steps: absorption of water by the dried biomass; swelling of the rehydrated product, which becomes similar to the original fresh product; and loss or diffusion of the soluble compounds (co-extraction of the compounds by the liquid phase) [23,24]. In dried raw seaweed material, the rehydration time is longer at lower temperatures. On the other hand, when the temperature is high (above 80 °C), rehydration is quick and the dry biomass regains the original moisture level more quickly; however, the compounds have greater losses in the yield and quality, mainly the bioactive compounds, such as phenolic and flavonoid compounds, which are oxidated and destroyed [10]. Cox et al. [9] demonstrated that the heat treatment at 100 °C for 40 min caused losses of about 83% and 93% in the total phenolic and flavonoid content, respectively, in *H. elongata*. Furthermore, rehydration velocity is not a constant, because in the initial stages, the rehydration is very rapid and there is a decline until equilibrium in the system is reached. In this process, as demonstrated above, the water temperature is a key factor of the rehydration process, where hot water can rehydrate the seaweed rapidly but causing a major change in the tissue structure (mainly cell wall destruction and denaturation of thermolabile compounds) and composition of the seaweed (the blanching technique used in the kitchen) [10]. Blanching is used mainly to make sea and terrestrial vegetables more palatable; however, this technique also leads to co-extraction (leaching) and denaturation of heat-sensitive compounds [25].

Every thermal process is detrimental to the integrity of plant tissues, particularly cellular membranes. Temperatures above the optimal point can lead to damage which will consequently lead to variations in response to the process applied [10].

6. Heat Treatment Influence on Chemical Structure

The heat treatment of seaweed-based ingredients and foods regularly induces a major chemical modification on their compounds, such as nutrients and bioactive molecules [26]. One of the major changes is in the pigment compounds which give color to the seaweed and, after the heat treatment, change the seaweed's color, mostly in brown seaweeds [12].

Fresh seaweeds are very perishable and start to deteriorate very rapidly after harvest, thus drying is an essential path to working with seaweeds as whole food or at food industry [16]. The most commonly used drying method is sun-drying, which reduces bulk handling and microbial growth, maintaining the characteristics if the seaweed is not directly exposed to sunlight (UV rays interfere greatly with the biochemical structure of photo-sensible compounds, such as phenolic compounds and pigments) [27]. However, when this drying method and other methods are used, the high temperatures can cause a rapid dehydration during the drying process, which can result in undesirable changes in the whole biomass (shrinkage) and chemical compound changes caused by enzymatic and non-enzymatic reactions (such as oxidation) [28]. Additionally, the water flux changes the composition, with partial destruction of the seaweed tissue, releasing various compounds, nutrients and minerals into the solution, decreasing the compounds' yield and nutritional value [29,30]. Only when considering the mineral part is the heat process important for diminishing the mineral intake to the recommended daily dosage [31].

It is well known that the bioavailability of vegetable compounds is conditioned by the species and abiotic factors (light, oxygen and temperature), and thus, their stability is essential for maintaining the bioavailability of the compounds and also changing the seaweed's nutritional profile. Heat treatment at low temperatures can also reduce the compounds availability in seaweed, as demonstrated by Gupta et al. [16], where *H. elongata* lost nearly 30% of the compounds compared with seaweeds subject to 25 °C during rehydration. Mainly, the bioactive compounds are lost in direct response to the rise in the heat, due to their chemical structures' heat sensitivity. On the other hand, the antioxidant power also demonstrated a direct response, where the heat reduced the bioactivity, mostly to denaturation of the bioactive molecules and reduction of the compounds to low-molecular-weight compounds by hydrolysis [10,32]. Thus, some heat processing methods have a

different impact on antioxidant activity, as demonstrated by Rossi et al.: using blanching increased free radical scavenging in fruits [33].

The pigments also suffer chemical deterioration, and the sugars and polysaccharides are mainly solubilized, reducing the carbohydrates in the processed seaweed; the same happens to vitamins, amino acids (proteins) and minerals [34]. Although it is known that different heat treatments and temperatures significantly change the preservation of seaweed compounds, there is a general lack of knowledge about this complex topic using chemical characterization techniques, mainly spectroscopy and chromatography [10,12]. Even when similar seaweeds were analyzed, their reaction to the same heat treatment method was very different due to the variation in the seaweeds' compounds and biochemical profile. This was demonstrated by Amorim et al. [35], using *Laminaria* sp. and *Undaria pinnatifida*, where the same bioactive compounds and antioxidants were used. For example, the polyphenol compounds of *Laminaria* sp. were more stable throughout the heat treatment compared with the polyphenols of *U. pinnatifida* [35].

In the case of proteins, one of the most important nutrients of seaweeds, the bioavailability and content depend on the species analyzed. Maehre et al. demonstrated that heat treatment does not interfere in brown seaweeds; however, in red seaweeds, the protein level was more bioavailable after heat treatment [36].The iodine content is one of main risk factors of the seaweed overdosage [37], but the blanching technique (80 °C for 120 s) reduced the iodine content in *S. latissima* from 4605 to 293 mg iodine kg^{-1} dw^{-1} [38].

On the other hand, this technique enhanced the protein yield. Using blanching technique of 60 °C for 300 s enhanced the yield of PUFAs, demonstrating that heat treatment can have various interesting results when multiple variations of time and temperature are used. In the literature, the temperature varies from 30 °C to 110 °C, and the time varies from 60 s up to 3 h. Consequently, there are several dataset with different results, indicating various hypotheses regarding seaweed's reactions to heat treatment; however, the data demonstrate that there is no linear correlation among the techniques, temperatures, durations and biochemical relations of seaweed, because the methods and techniques between the studies are not similar [16,38].

7. The Effect of Heat on Seaweed-Based Products

Seafood, including seaweeds, fishes, mollusks and crustaceans are the biggest contributors of arsenic in our diets. This chemical is highly toxic for humans. Sartal et al. [39] studied the use of heat on four different species of seaweeds to see its influence on the quantity of arsenic. This study presented the following graphic, showing the analysis made of seaweeds, before and after heat treatment.

As seen in Figure 1, in all species, the amount of arsenic reduced when the seaweeds were subjected to heat treatment. The authors also analyzed the cooking water and, as shown, these waters contained large amounts of arsenic [39].

Another study was made to evaluate the proteins in seaweeds. The seaweeds used were *Palmaria palmata* (Rhodophyta) and *Alaria esculenta* (Phaeophyceae), and they were subjected to a heat process, namely boiling. In this study, the samples were also submitted to a gastrointestinal tract simulator to see if, during digestion, the measured proteins changed. In the first species, the results showed that there was an increase from 86% to 109% in the amino acid content. This means that by boiling this seaweed for 15–30 min, the amount of protein available was much greater then when it was raw. It has also been shown that, compared with meat protein, it supplies an adequate intake of protein for our body. If we examine the data on *A. esculenta,* the proteins in this species did not change, which means that in this seaweed, the process of heating did not influence its content [36].

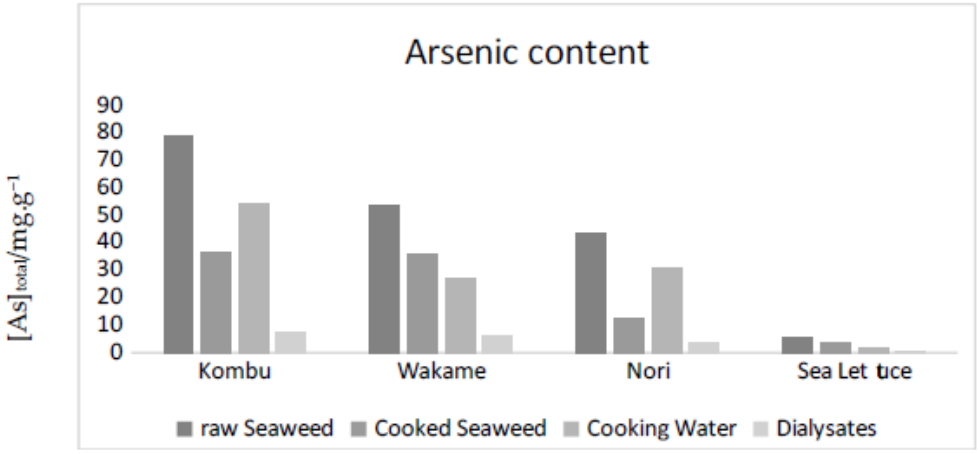

Figure 1. Total arsenic concentrations in kombu, wakame, nori and sea lettuce seaweed samples before and after being cooked, and in their cooking water and dialysates obtained after subjecting these cooked seaweeds to an in vitro gastrointestinal digestion [39].

In another study, Indonesian brown seaweeds were analyzed to see if heat treatment would affect four different components, these being fucoxanthin, antioxidant activity, total phenolic content and color stability; however, in this review, we will highlight the first and the second compounds [12]. These seaweeds were subjected to four different heat processes: boiling, blanching, steaming and sterilizing (Figure 2). Fucoxanthin is abundant in brown seaweeds and it has several health benefits. By putting the seaweeds through the four heat treatments, we obtained different results. In Figure 2, we can see these differences accordingly [12]. When raw/fresh, the amount of fucoxanthin in the seaweed was very low; however, when heated, these values increase. As we can see, the heat process that is most beneficial is blanching, followed by boiling, then steaming and sterilizing [12].

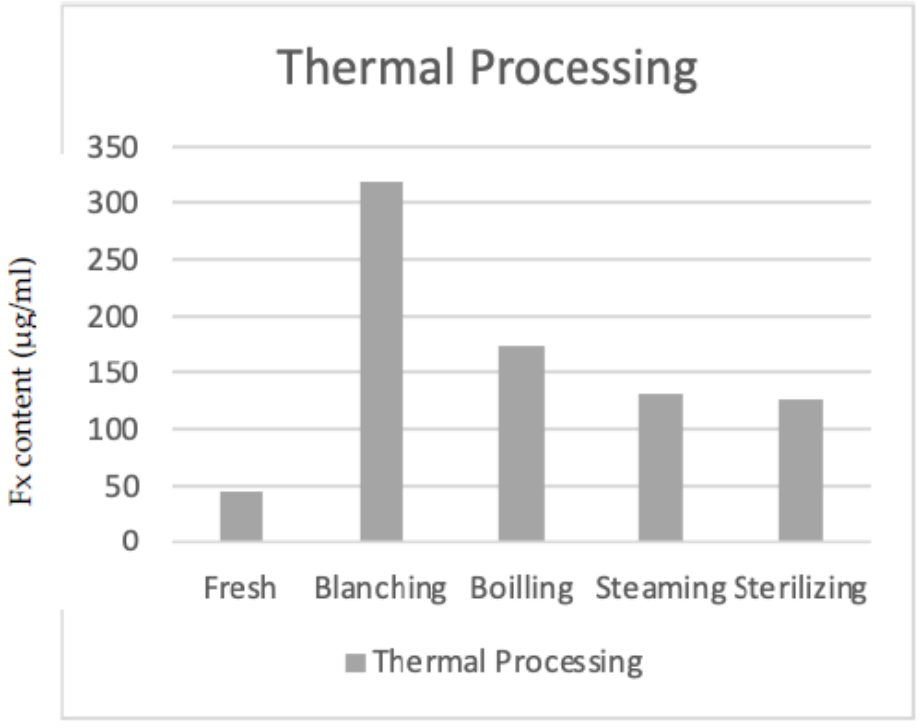

Figure 2. Fucoxanthin content in fresh and thermally processed in *S. ilicifolium*. Values are express in µg/mL [12].

Brown seaweeds contain phloroglucinol phenolics and phlorotannin, which have highly beneficial biological activities, such as anticancer, antioxidant and antidiabetic activities, and others. Therefore, finding ways to enhance these benefits is very important. In another study, the results showed that the total phenolic content decreased; however, they explained it by the high temperature that the algae were submitted to, showing that heat treatment can have benefits when applied correctly, but also have the contrary effect when applied incorrectly [12].

8. Problems of Heat Treatment Analyses and Approaches to Food Safety: A Future Road

The overall effects on the chemical structure of the compounds (mainly molecular weight, bioactivity and toxicity) when seaweed is heat-processed are not well known, due to general analysis of the compounds in their natural state and not in the hydrolysate stage (caused by heat) with low molecular weight. Moreover, this information about the kinetics of heat processed seaweed vs. stability may be essential to obtain valuable insights into the effects of the processes, providing higher food safety levels and maintaining a similar product with stable compounds which can be bioavailable for humans [3,31]. Susanto et al. demonstrated that three different ways of cooking brown seaweeds promoted different results. The blanching method promoted the stability of fucoxanthin, the boiling method produced higher antioxidant activity and steaming minimized the color change [12]. This supports the concept that chemical modification occurs during the heat process, which was demonstrated by the fucoxanthin content and the color after different types of heat process. Thus, it is important to have scientific data about the heat treatment process along with chemical characterization of the resulting product to obtain the best method of maintaining the important properties of seaweed; it is also important to find new methods of heat treatment that prevent the destruction of seaweeds' nutritional value. Furthermore, the performance of the heat treatment can make it hard to obtain purified compounds to be analyzed and characterized by a chemical method in a very rigorous manner [31]. As it is a complex compound with two distinct molecule fractions that are identified and characterized by different chemical methods, the possible combination of compounds or hydrolyzed molecules producing novel compounds can be achieved by the Maillard's reaction combining amino acids and reducing sugars, giving particular characteristics to food, such as color, texture and flavor [40].

Moreover, the presence harmful compounds, such toxins or heavy metals, in seaweeds needs to be carefully checked [41]. In this case, it was found that drying the seaweed and other types of processing (such as washing or cooking) reduced toxins and the concentration other volatile compounds (such as iodine or arsenic) in seaweeds, mainly solar drying, boiling and seaweed dehydration [42–44]. Despite these reports, there is a long road to understanding how thermal treatment affects the toxic concentration in seaweeds and, more importantly the toxic bioavailability and bioaccessibility [43]. At this moment, there is a need for more research to fully understand the effect of heat treatment on toxins and harmful compounds in seaweeds.

Above all, there is a question that remains before the scale-up of seaweed consumption, namely how the heat process affects the objectives, because the techniques have advantages and disadvantages scientifically. However, to scale up and define the best method of preparing seaweed using heat, it is also necessary to see if it is practicable at a large scale because the system/process costs cannot surpass the economic potential of the commercial method.

9. Conclusions

Even though seaweed has been consumed for hundreds of years, there is still a long way to go to reach the optimization of protocols which can maximize seaweeds' potential. Each species intended for processing has unique characteristics that vary according to environmental and/or internal factors, such as seasons, reproductive/lifecycle stage, temperature, nutrients and environmental competition, among others. On top of this, pre-

processing and processing of seaweeds also show some degree of specificity, as different species can show different behaviors under different drying and rehydration processes. Overall, for specific compounds used for niche industries that target specific and highly purified phytochemicals, such as for the pharmaceutical or cosmetic industries, freeze-drying or vacuum-drying are good solutions, demonstrating relatively good yields in comparison with fresh samples, and a good degree of compound preservation. However, the application of this technology to food or feed production is not economically sustainable; thus, the most common type of drying method is sun-drying or oven-drying/convective air-drying, though the latter is also economically challenging. While some solutions are being developed, e.g., microwave drying, these also show limitations, such as high potency and cellular damage in this specific case. Additionally, understanding how toxic metabolites can be mobilized by heat treatment is paramount. Seaweeds are known bio-accumulators that can act as concentration hubs of toxic elements, of which the most important are iodine and arsenic species.

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