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Original article

Effects of culinary treatments on the physicochemical properties of *Ulva lactuca* collected from Tabuk coast of Red sea in Saudi Arabia

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ABSTRACT

The increasing demand for healthy, natural, and sustainable food led scientists to take advantage of marine resources and promote interest in culinary and the use of algae that give a variety of colours, textures and flavours from the seaweed. However, few studies have been done on the effect of culinary treatments. Therefore, the aim of the present study is to evaluate the effect of the most popular culinary treatments (boiled, steamed and sous vide) on the physicochemical properties of *Ulva lactuca*. The treatments were applied at temperatures of 100 °C in the case of both boiling and steaming whereas 50 and 75 °C on sous vide culinary. Results illustrated that both the chemical composition and physical properties of *Ulva lactuca* greatly affected depending on the culinary method and time. The culinary processes produce an increase in water activity (0.962–0.989) with respect to the raw algae (0.952). All the applied culinary treatments showed an increase in the content of pH, chlorophylls and carotenoids compared to the raw algae, and the highest rise was after boiling for 5 min, although this effect decreases slightly at longer times of boiling. The same about ash, protein, fat, minerals (K, Ca, and Mg), and poly unsaturated fatty acids (PUFAs) boiling is a culinary method that greatly influences and on the contrary, sous vide culinary is a technique that respects and can even improve the nutritional value of raw algae.

1. Introduction

The functional food market is booming, increasing an annual rate of 15–20% (Bagchi and Nair, 2016). Increased consumer demand for healthy foods has stimulated interest in further investigation of the nutritional value of seaweed and its application in food products (Chan and Mattangoon, 2017; Cotas et al., 2020). Since ancient times, coastal inhabitants have been able to make use of marine plants to cover their food needs and amend the soil as fuel and animal fodder. Traces of algae found in ash from prehistoric homes suggest that very early humans turned to algae to make a living. The consumption of algae as food is very old. In Chile, at the Monte Verde site dating back more than 12,000 years, fossilized traces of algae confirm their use by populations (Burtin, 2003; Markou et al., 2018). Japanese texts, dating back more than 6000 years, specify the use of seaweed as a remedy. Likewise in China, where texts dating from the 6th century BC mention varieties of seaweed with a fine taste to figure on the menu of kings (Bolton et al., 2007). Algae are an abundant, inexpensive and attractive resource to be used as food or food ingredients, otherwise, seaweed is increasingly seen as a natural resource rich in ingredients that promote health (including high-quality protein, dietary fiber, polysaccharides, polyunsaturated fatty acids (PUFAs), minerals, vitamins, pigments, and phytochemicals such as polyphenols (Chan and Matanjun, 2017; Mohamed et al., 2012). These characteristics provide seaweed with great potential as a food supplement functional or extraction of a great variety of bioactive compounds (Chan and Matanjun, 2017; Tanna and Mishra, 2019). Numerous studies have shown the benefits of its consumption as well directly or as a dietary supplement, they contribute to health (Cotas et al., 2020). On top of that, algae also have technological properties that make algae amenable to developing different products (Chan and Matanjun, 2017; Marti-Quijal, et al., 2018), for example algae protein contributes to the technical and functional properties of food products and can act as emulsifiers and texture modifiers, as well as aiding in fat and water absorption (Ogunwolu et al., 2009). The incorporation of algae extracts in the diet can improve shelf life and properties, nutritional, sensory, and hygienic for food products (Arulkumar et al., 2018).

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The algae are used as "vegetables", for example, *Ulva lactuca* (or sea lettuce) which usually contains protein, minerals and vitamins. The *Laminaria vesiculosus, Undaria pinnatifida* and *Porphyra tenera*, algae currently marketed in Japan and Europe under the respective names of Kombu, Wakamé, and Nori, are used in soups, jams, and cheeses (R3uperez et al., 2002). Blue-green microalgae *Spirulina* and *Chlorella* marketed as a food supplement, are particularly rich in proteins and vitamins (Markou et al., 2018). Ansari and Ghanem (2019) mentioned the possibility to exploit the marine brown algae *Padina pavonica* as a resource for food industrial and medicinal purposes, especially for commercial and sustainable development.

During a thermal process, algae can lose cellular and tissue integrity, reaching even to lose the epidermal layer of the surface (Maehre et al., 2016), this variation in cell wall causes several biological, physical, chemical, technological and nutritional modifications in the algae properties (Maehre et al., 2016). On the other hand, natural bioactive compounds such as carotenoids released with breaking down the cell wall (Hidalgo and Zamora, 2017; Rajauria et al., 2010). According to numerous authors, heat treatments such as boiling or steaming increase the content of algae in pigments and the antioxidant capacity as in the cases of the red algae *Chondrus crispus* (Pina et al., 2014), and the green algae *Ulva sp*. (Chen and Roca, 2018). In addition of macronutrients especially those soluble in water are sensitive to heat and change with heat treatments (Roy et al., 2009; Zhao et al., 2019). The present study aimed to evaluate the effect of the most popular culinary methods (boiled, steamed, sous vide) on the physical properties (water activity and pH) and chemical composition retention (chlorophyll and carotenoids, antioxidant capacity, moisture, ash, proteins, fats, minerals, and fatty acids profile) of the most consumed algae species in the world *Ulva lactuca* collected from the coasts of the Red Sea in Haql city, Tabuk region, Saudi Arabia.

2. Material and methods

2.1. Sample collection

About (10 kg) samples from *Ulva lactuca* were collected from coastal zone of the Red Sea in Haql city, Tabuk region, Saudi Arabia in March 2020, at a depth of 0.5–1.0 m, 8–10 m from the coast and were stored in plastic bags with sea water to avoid dehydration during transport in refrigerated boxes to the laboratory. In the laboratory, the remains of impurities and sand were carefully removed through the first washing with sea water and then the second washing after with fresh water, then the samples were divided to two sections, the first section was freeze at −80 °C once the samples were frozen, dried under a 10–15 Pa vacuum at 4 °C in a cold chamber of freeze dryer (LGJ-25C, China) and then the samples were ground for laboratory analysis to estimate the properties of raw algae. The second section was split into 12 portions each portion undergo a culinary method (boiled, steamed and Sous vied) while retaining a portion of the raw algae as a control. All chemicals, solvents and standards were of analytical grade and purchased from Sigma (St. Louis, MO, USA).

2.2. Heating treatment

The most common algae culinary methods were selected, each treatment was carried out on approximately 700 g of fresh algae. The treatments included the following: a) Boiling at 100 °C for 5, 10 and 15 min, b) Steam culinary under the same boiling conditions in terms of temperature and time, but without direct contact with water, c) Sous vide culinary algae samples were placed in vacuum bags and immersed in a water bath in (Anova Precision Cooker Nano) at two different temperatures (50 and 75 °C) still required operating temperature was reach at the same time 5, 10 and 15 min.

At the end of each method, the samples were rapidly cooled down using cold water. Once cooled, part of the sample was directly used to determine water activity (a_w) and pH changes. The remainder was frozen at −80 °C and lyophilized with a freeze dryer and then the samples were ground for laboratory analysis with stainless steel grinder (Model RT-34, WHL Machinery, Selangor, Malaysia).

2.3. Physical properties

Water activity (a_w) was measured at 25 °C (±0.2 °C) using a hygrometer (Testo, UK); the pH was measured directly by using pH meter model (microprocessor HI931401, Hanna Instruments) after calibration with buffer solution of pH 4 and 10.

2.4. Chemical composition

Moisture, crude protein, ash and lipids content of algae samples were carried out according to the analytical methodology of AOAC (2005) No. 930.15 for moisture, AOAC 984.13for crude protein, AOAC 942.05 for ash and AOAC 2003.05 for lipids. The results are expressed on a % dry basis.

2.5. Mineral composition

The concentration of (K, Mg, Na, Ca, Zn and Fe) in all samples were determined after digestion by using Atomic Absorption Spectroscopy (Perkin-Elmer Model 2380 manufacture, USA) according to the method described by **(**Bharathi et al., 2021) and the results are expressed in mg/100 g of dry sample.

2.6. Extraction of chlorophyll and carotenoids

According to the non-maceration method of **(**Hiscox and Israelstam, 1979**)** 500 mg of dried and minced algae sample was suspended in 2 mL of dimethyl sulphoxide (DMSO) in test tubes then incubated at 60° C for 20 min. The supernatant was decanted and repeat the incubation with another 3 mL of DMSO. The supernatants were collected, and the volume was made up to 10 mL by adding DMSO. The chlorophyll extract was transferred to a cuvette and the absorbance was read in a Spectrophotometer (UV-180, Shimadzu, Japan) at 645 and 663 nm against DMSO blank. Total chlorophyll was calculated by using the following formula:

$$\text{Total chlorophyll}(\mu g/\text{ml}) = 20.2(\text{A645}) + 8.02(\text{A663})$$

Where, A = Absorbance at respective wavelength

The amount of Carotenoid was estimated by the method of Kirk and Allen, 1965.The same chlorophyll extract was measured at 480 nm in spectrophotometer to estimate the carotenoid content as formula:

$$\text{Carotenoids}\left(\frac{\mu g}{g}\right) = \text{A480} + (0.114 \times \text{A663}) - (0.638 \times \text{A645})$$

2.7. Antioxidant activity

Antioxidant activity was determined using the stable 1,1-Diphenyl-2-picryl-hydrazyl (DPPH) according to Hwang et al. (2014). The absorbance at 517 nm was measured by UV–Vis **spectrophotometer** (model UV-180, Shimadzu, Japan) against a blank of pure methanol. The antioxidant activity was expressed as Trolox equivalents (μmol TE g^{-1}).

2.8. Fatty acid analysis

The fatty acids were determined from the lipid extraction of the section previous. Once the extraction was carried out, it was methylated following the method AOAC (2005). The methyl esters of fatty acids were identified by gas-liquid chromatography (Perkin Elmer Auto system XL) technique. The results of fatty acids are presented as mg/g of algae oil extract then sum of SFAs, MUSFAs and PUSFAs are calculated as percent.

2.9. Nutrients retention

Nutrient retention refers to the proportion of nutrient retained relative to the amount of nutrient present in a known weight of the raw food (i.e., before cooking) (Murphy et al., 1975). Nutrient retention factors represent percentage adjustments in nutrients which account for the effect of cooking on the weight or nutrient content of a given food. Present of true retention (TR) in algae after different culinary treatments calculated according to (Murphy et al., 1975) using the following formula:

$$\%TR = \frac{\text{Nutrient content per g of cooked food} \times \text{g of food after cooking}}{\text{Nutrient content per g of row food} \times \text{g of food before cooking}} \times 100$$

2.10. Statistical analysis

Data were presented as the mean ± standard deviation, with determinations by triplicate. Statistical significance was by one-way ANOVA, with values of ($p < 0.05$) considered significant. The data were processed using the statistical package SPSS 17.0 (SPSS, Chicago, IL, USA).

3. Results

The values of water activity, pH, moisture, crude protein, ash and lipids of raw and cooked with different culinary methods and times for *Ulva lactuca* are presented in Table 1. The culinary processes produce a slight significance ($p < 0.05$) in water activity (0.962–0.989) with respect to the raw algae (0.952). However, differences are observed significant ($p < 0.05$) a mong all culinary conditions that applied in present study. On the other hand, the studied culinary treatments produce significant ($p < 0.05$) changes in the pH value of the algae specially in the case of boiling where it increased significantly ($p < 0.05$) from 6.58 (raw algae) to 8.87 after boiling for 10 min. Proximal chemical composition of *Ulva lactuca* (Table 1) illustrated that the moisture content of the samples subjected to the different thermal treatments presented slight significant ($p < 0.05$) differences with respect to the raw sample (90.64%), especially for the boiled after 10 min of treatment (96.7%). Ash content presented significant ($p < 0.05$) differences between the raw samples (17.2%) and the different treatments applied in the study, as well as between the different culinary time ($p < 0.05$)

The protein content in raw algae was 16.8%, db this value rise to 18.7%, db after 5 min heat treatment at sous vide 75 °C. As seen in Fig. 1, the total chlorophyll content of raw *Ulva lactuca* was 4.06 μg/ml then increases significantly ($p < 0.05$) in all applied thermal culinary processes, regardless of the culinary time treatment. The highest content of chlorophyll (17.33 μg/ml) recorded after boiling algae for 5 min. In the case of carotenoids, the same significant ($p < 0.05$) increase was observed, especially in the case of boiled samples. The carotenoids content increased from 0.24 μg/ ml in raw algae to 2.56 μg/ ml in boiled algae for 5 min.

Considering the antioxidant activity (Fig. 1), all heat treatments significantly ($p < 0.05$) increase with respect to the raw algae, except the steamed algae for 10 min.

The effects of different heat treatments of *Ulva lactuca* on the minerals content (K, Mg, Na, Ca, Zn and Fe) are shown in Table 2. K content in raw algae recoded 653.76 mg/100 g (db) this content increased significantly ($p < 0.05$) to 767.25 mg/100 g (db) after cooking under vacuum by using sous vide 75 °C/10 min while decreased significantly ($p < 0.05$) after 10 min boiling to 133.5 mg/100 g (db). The same behaviour found for Mg content reached 2417.5 mg/100 g (db) in raw algae and increased to 2462.03 mg/100 g (db) with sous vide 75 °C/10 min and significantly ($p < 0.05$) decreased to 1203.5 mg/100 g (db) after boiling for 10 min. Na content increased after boiling for 5 min to the maximum (713.16 mg/100 g). The highest value of Ca (3363.69 mg/100 g) was reported after sous vide 50 °C/10 min. Significant ($p < 0.05$) differences found in iron content among all treatments. The calculated retention rate for Fe ranged between 83.5 and 125% for boiling/min and sous vide 75 °C/5 min, respectively. Finally, the Zn content was mainly influenced significantly by the boiling for 5 min treatment, presenting high retention values greater than or closely 100% among all culinary treatments.

Table 1
Effect of culinary treatments on water activity, pH, moisture, protein and lipid content.

Culinary treatments methods time (min)		Water activity	pH	Moisture (%,fb)	Ash (%,db)	Protein (%,db)	Lipid (%, db)
Raw algae		0.952 ± 0.004c	6.58 ± 0.02f	90.64 ± 0.2b	17.2 ± 0.3a	16.8 ± 0.6b	6.5 ± 0.7a
Boiling	5	0.964 ± 0.005b	8.17 ± 0.03c	93.9 ± 1.2ab	10.4 ± 0.2d	13.5 ± 0.6 cd	6.4 ± 0.4a
	10	0.962 ± 0.006b	8.87 ± 0.08[a]	96.7 ± 1.3a	9.7 ± 0.1d	10.4 ± 0.5e	5.7 ± 0.6b
	15	0.977 ± 0.006ab	8.71 ± 0.05b	93.6 ± 1.3ab	11.1 ± 0.2c	10.1 ± 1.1e	4.9 ± 0.3c
Steam	5	0.963 ± 0.004b	6.87 ± 0.02d	92.0 ± 1.4ab	11.7 ± 0.5c	11.9 ± 3.6d	6.3 ± 0.2a
	10	0.966 ± 0.005b	6.73 ± 0.02e	92.25 ± 1.5ab	11.7 ± 0.3c	11.9 ± 0.9d	5.9 ± 0.6ab
	15	0.975 ± 0.002ab	6.73 ± 0.03e	91.4 ± 2.3b	15.6 ± 0.9b	12.1 ± 2.5d	5.5 ± 0.6b
Sous vide (50 °C)	5	0.975 ± 0.006ab	6.42 ± 0.03f	90.31 ± 1.3b	13.0 ± 0.5b	16.9 ± 0.8b	6.7 ± 0.3a
	10	0.971 ± 0.007b	6.30 ± 0.02 g	93.1 ± 1.2ab	14.3 ± 0.3b	15.4 ± 0.3bc	6.3 ± 0.6a
	15	0.983 ± 0.002a	6.30 ± 0.08 g	93.5 ± 1.4ab	14.3 ± 0.7b	17.1 ± 0.2b	6.0 ± 0.5a
Sous vide (75 °C)	5	0.986 ± 0.004a	6.26 ± 0.03 g	92.5 ± 1.12ab	13.6 ± 0.4b	18.7 ± 0.3a	5.9 ± 1.1ab
	10	0.971 ± 0.003b	6.51 ± 0.03f	91.8 ± 1.4ab	17.3 ± 0.7a	16.3 ± 0.1b	5.9 ± 0.1ab
	15	0.972 ± 0.009b	6.63 ± 0.02e	91.5 ± 0.8b	15.4 ± 0.9b	15.6 ± 0.8bc	5.6 ± 0.2b

Letters (a -g) indicate differences significant between the different culinary treatments and cooking time according to the Tukey test ($p < 0.05$). The data show mean values ($n = 3$) with SD.

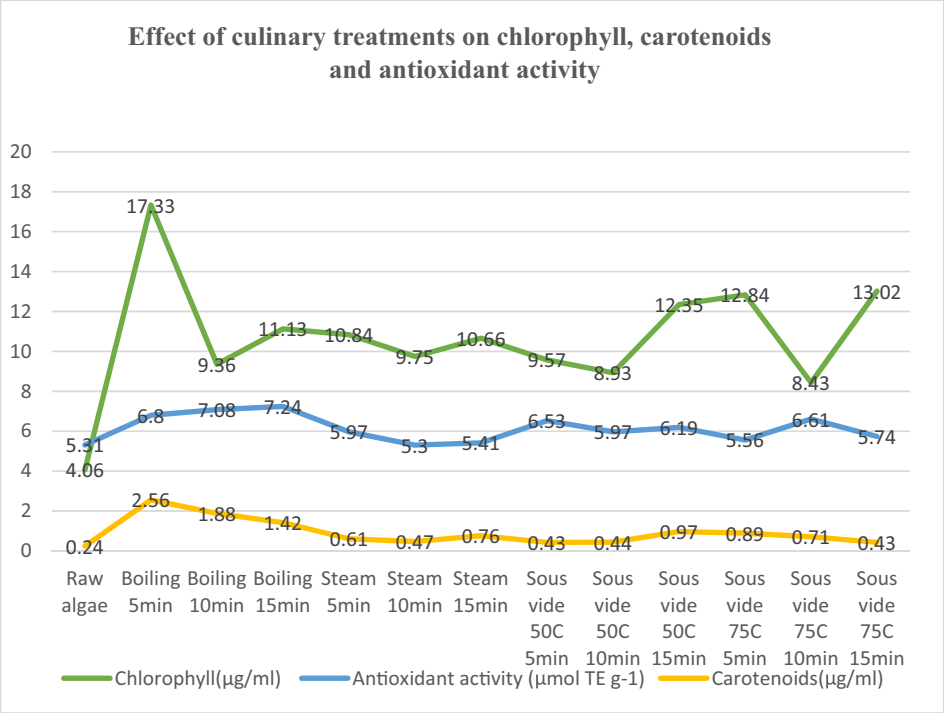

Fig. 1. Effect of culinary treatments on chlorophyll, carotenoids and antioxidant activity (The data show mean values of triplicate).

Table 2
Effect of culinary treatments on minerals content (mg/100 g, db).

Culinary treatments methods time (min)		K	Mg	Na	Ca	Zn	Fe
Raw algae		653.76 ± 16.2ab	2417.5 ± 42a	636.84 ± 8.2 cd	2198.47 ± 21cde	61.21 ± 3.3c	36.54 ± 1.3bc
Boiling	5	146.76 ± 11.7ef	1203.5 ± 21f	713.16 ± 12.7a	1692.39 ± 29e	55.11 ± 2.9d	30.52 ± 0.76d
	10	133.5 ± 8.61f	1432.62 ± 36ef	685.15 ± 5.5ab	1861.08 ± 24de	71.01 ± 6.4b	41.04 ± 2.5ab
	15	218.24 ± 8.93ef	1553.54 ± 17ef	626.21 ± 10.4cd	1924.34 ± 31de	73.29 ± 3.1ab	45.25 ± 3.2a
Steam	5	285.3 ± 13.4def	1678.44 ± 24de	620.41 ± 24.6 cd	2641.3 ± 11bc	77.25 ± 2.5a	44.65 ± 7.3a
	10	445.21 ± 15.8cde	1768.34 ± 25cde	556.16 ± 37.2ef	2809.99 ± 20b	62.53 ± 1.3c	33.83 ± 3.9cd
	15	630.18 ± 24.5abc	2109.63 ± 24bc	634.9 ± 7.7cd	2767.82 ± 39b	62.69 ± 4.8c	36.24 ± 4.0bc
Sous vide (50 °C)	5	476.16 ± 6.26bcd	1696.74 ± 32de	536.84 ± 21.5f	2951.6 ± 41b	61.87 ± 3.4c	31.52 ± 2.4d
	10	665.55 ± 30.4ab	2097.69 ± 26bc	638.29 ± 28.6cd	3363.69 ± 34a	60.99 ± 2.7c	34.73 ± 3.8cd
	15	548.38 ± 14.7bc	2038.82 ± 37bcd	563.41 ± 11.0ef	3020.86 ± 26ab	59.57 ± 1.5cd	34.43 ± 1.6cd
Sous vide (75 °C)	5	546.17 ± 22.5bc	1975.98 ± 15bc	603.99 ± 5.6de	3084.12 ± 28ab	79.33 ± 2.8a	45.85 ± 2.5a
	10	767.25 ± 13.3a	2462.05 ± 25a	661.96 ± 17.4bc	2599.12 ± 46bc	64.25 ± 2.1bc	37.14 ± 3.1bc
	15	641.23 ± 17.4abc	2354.65 ± 41ab	698.19 ± 13.6ab	3057.6 ± 32b	59.15 ± 5.6cd	34.01 ± 1.6cd

Letters (a-f) indicate significant differences between the different culinary treatments and cooking time according to the Tukey test ($p < 0.05$). The data show mean values ($n = 3$) with SD.

The fatty acids results obtained in the present work show that the effect of the different culinary treatments depends also on the fatty acid type, observing significant ($p < 0.05$) effect on MUFAs and PUFAs than on SFAs (Table 3). The highest SFAs found are palmitic acid (C16: 0) and stearic acid (C18: 0) and effects are only observed on sous vide culinary for 5 min at both studied temperatures ($p < 0.05$). In all treatments applied, with the exception of boiling from 10 min and sous vide culinary at 75 °C for 15 min, an increase more than 100% obtained for the MUFAs content (Fig. 2).

PUFAs content (Table 3) presents significant ($p < 0.05$) differences between the different treatments.

4. Discussions

Water activity is a parameter used by the food industry to determine the amount of available water in food, for the development of chemical and enzymatic reactions, and growth microbial. Therefore, the increase in water activity that occurs in the algae with the culinary treatments can be related to cell breakdown and the release of free water or available from the cellular interior. This effect is more pronounced the longer the culinary time takes place in both boiled, steamed and sous vide vacuum cooked samples at 50 °C in sous vide. Increasing in the pH value of the algae especially in the case of boiling maybe due to direct contact

Table 3
Effect of culinary treatments on fatty acids profile (mg/g oil extract).

Fatty acids	Raw alga	Boiling			Steaming			Sous vide at 50 °C			Sous vide at 75 °C			SD
		5 min	10 min	15 min	5 min	10 min	15 min	5 min	10 min	15 min	5 min	10 min	15 min	
C 8:0	0.052	0.342	3.393	6.930	0.079	0.107	0.131	0.712	1.939	2.664	4.428	6.315	7.352	2.68
C 10:0	0.802	0.289	8.854	19.802	0.975	0.862	0.694	0.072	7.263	6.770	8.854	6.691	10.820	5.58
C 11:0	0.131	0.942	1.731	2.146	0.160	0.161	0.165	0.098	1.267	1.860	4.260	5.880	6.532	2.14
C 12:0	3.262	1.652	13.922	11.281	2.759	5.327	3.223	3.579	5.515	5.950	3.065	5.950	7.738	3.42
C 13:0	2.047	0.763	6.355	5.515	2.368	1.613	1.455	1.771	3.095	5.762	4.018	5.762	6.641	2.04
C 14:0	37.06	29.983	68.266	55.865	32.653	34.559	31.837	39.254	42.469	45.199	37.827	44.607	50.968	10.44
C 15:0	44.021	23.159	48.577	37.898	31.506	29.227	21.055	29.857	35.211	40.382	29.471	33.521	38.728	7.57
C 16:0	612.51	614.190	496.619	536.878	617.754	610.468	607.815	483.278	542.547	534.034	479.817	514.315	554.540	50.68
C 17:0	5.446	3.490	6.157	5.160	5.683	4.976	5.076	6.503	7.135	8.054	6.386	8.360	10.790	1.79
C 18:0	214.266	265.7	318.728	299.415	210.376	225.647	259.963	309.245	262.824	260.561	296.807	274.268	224.959	34.92
C 20:0	4.043	3.372	3.796	3.951	8.350	4.392	4.883	5.851	5.831	8.121	5.792	7.876	9.723	1.98
C 21:0	0.822	0.605	0.398	0.299	0.401	0.506	0.556	0.378	0.595	1.287	0.207	0.872	5.653	1.38
C 22:0	14.88	11.492	9.765	5.979	10.241	16.036	11.336	11.472	13.266	34.016	19.592	20.373	43.184	10.10
C 23:0	0.329	0.457	0.002	0.002	0.012	0.230	0.348	0.003	0.002	0.002	0.067	Nd	Nd	0.17
C 24:0	1.158	1.277	0.427	0.467	0.595	0.817	0.921	0.526	0.911	3.016	Nd	Nd	Nd	0.72
C 14:1	0.014	0.002	Nd	Nd	0.002	0.003	0.002	0.003	0.002	0.002	7.520	5.356	2.709	2.53
C 15:1	0.032	0.002	Nd	Nd	0.002	0.002	0.002	0.002	0.002	0.002	29.630	19.612	8.044	9.67
C 16:1 n-7	13.00	5.149	0.990	0.438	7.659	8.953	7.607	3.915	2.986	0.427	9.061	1.415	1.227	3.92
C 17:1	3.816	1.179	0.002	0.002	1.583	1.682	0.921	0.743	0.477	0.062	0.091	0.062	0.002	1.05
C 18:1 n-9	20.03	19.433	11.896	7.830	44.364	29.993	21.637	98.368	60.506	38.017	51.179	38.017	9.881	24.19
C 20:1	0.259	0.447	0.062	0.064	0.269	0.348	0.417	0.477	0.388	0.437	0.022	0.042	0.072	0.17
C 22:1	2.344	2.935	0.012	0.062	1.010	1.800	1.751	0.391	0.694	1.544	0.002	0.002	Nd	0.97
C 18:2 n-3	1.660	1.109	0.003	0.002	1.642	2.255	1.949	1.099	1.534	0.704	0.704	0.496	0.309	0.71
C 18:2 n-6	1.870	1.126	0.003	0.002	1.632	2.245	1.899	1.158	1.534	0.674	0.743	0.200	0.121	0.76
C 18:3 n-3	15.307	10.365	0.032	0.005	17.478	16.937	13.786	1.198	1.909	0.447	0.447	0.002	0.002s	7.21
C 20:3 n-3	0.042	0.003	0.002	0.002	0.022	0.042	0.035	0.007	0.002	0.002	0.002	0.002	Nd	0.02
C 20:3 n-6	0.081	0.042	0.002	Nd	0.072	0.125	0.072	0.005	0.012	0.002	0.002	Nd	Nd	0.04
C 20:4 n-6	0.141	0.062	0.002	0.002	0.111	0.159	0.147	0.002	0.022	0.002	0.002	0.002	0.002	0.06
C 20:5 n-3	0.566	0.378	0.002	0.002	0.239	0.526	0.319	0.032	0.062	0.002	0.002	0.002	0.002	0.21
SFAs (%, db)	94.08	95.777	98.699	99.159	92.391	93.493	94.946	89.260	92.987	95.768	90.059	93.479	97.763	2.90
MUFAs(%, db)	3.951	2.915	1.296	0.840	5.489	4.278	3.234	10.390	6.505	4.049	9.751	6.451	2.194	2.83
PUFAs(%, db)	1.967	1.308	0.005	0.002	2.120	2.229	1.821	0.350	0.507	0.183	0.190	0.070	0.043	0.87

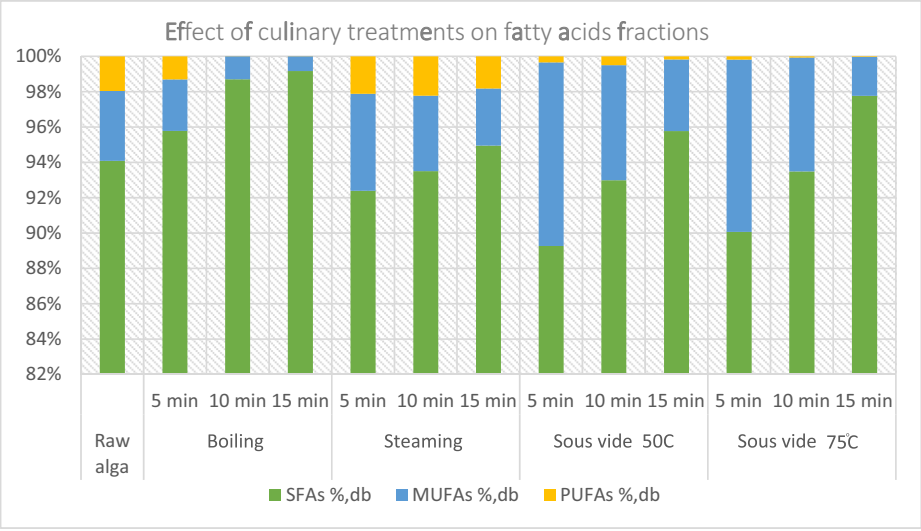

Fig. 2. Effect of culinary treatments on SFAs, MUFAs, and PUFAs content.

between the algae and water, which helps absorb water during boiling as it occurs in many vegetables (Florkiewicz et al., 2019; Podsedek, 2007). In the steaming, a slight increase in pH was observed, while the pH values decrease during sous vide treatments maybe due to the release of acids produced during the thermal process (Chen and Roca, 2018). The absorption of water from the medium during boiling caused increasing in moisture content in comparison to the raw sample. The ash content was clearly affected by the treatments, the culinary methods in the presence of water produced more ash losses, up to 43.6% and 35.6% ash losses after algae boiling or steaming, respectively. In both treatments, direct or indirect contact with water caused the soluble components of the ash to be lost or diluted, and the effect was more pronounced when in contact with boiling water during prolonged culinary (Florkiewicz et al., 2019; Podsedek, 2007). In sous vide treatments, there was no contact with boiling or steam water, ash losses reached 24 and 20% for cooking at 50 and 75 °C, respectively. The application of heat in the presence of water causes a

weakening of the structure of the algae, decreasing its stiffness and hardness (Sharma et al., 2012) and increases the bio accessibility of its components (Hidalgo and Zamora, 2017). If these components are soluble, they can also leach into the water and decreasing its content in the algae, as occurs in the samples boiled and steamed. A similar effect of the treatments is observed on protein content, being again the boiling and steam culinary treatments, which lead to a loss of 39.8 and 29.1%, respectively, while the protein losses are only 8.3 and 7.1% for the sous vide treatments at 50 and 75 °C, respectively. Regarding lipid content (Table 1), in general, the effect of the different treatments on lipid content is less than on other components of algae, also boiling is the treatment that most affected the lipid content (loss rate has reached 24.6%), followed by steam (loss rate has reached 15.4%) and culinary by sous vide at 75 °C with losses of 13.8%, respectively. Sous vide culinary at 50 °C belong all boiling time and steaming treatments for 5 min show stability in lipid content with respect to the raw algae. Therefore, at higher temperatures and long culinary times, lipid losses are acute either by leaching and/or degradation phenomena.

It is clear that chlorophylls and carotenoids contents are greater after culinary treatment with boiling for 5 min than those in raw algae, although this effect decreases slightly at longer times of boiling. Many authors have been able to verify that culinary treatments can increase the pigment content (chlorophylls and carotenoids) in algae in comparison with raw samples (Amorim et al., 2012; Pina et al., 2014). This is because the heat treatment causes the decomposition of the cellulose from the cell wall, caused the extraction and bioavailability of chlorophylls and carotenoids (Amorim et al., 2012; Zhao et al., 2019). The chlorophyll content differed from what was expected based on a study by Chen and Roca (2018) on *Ulva lactuca* when boiled for 20 min and found that the chlorophyll content decreased from 74 to 16% after cooking. Probably the applied times in the present study encourage the cell wall degradation and therefore, the extraction of chlorophylls, while at longer treatment times, promotes chlorophyll breakdown into pheophytins or chlorophylls oxidative, which would explain the results obtained by Chen and Roca (2018). For carotenoids, most of them are *trans* isomers and when the temperature used is high enough, maybe helping to degrade the crystal structure of β-carotene (Imsic et al., 2010). Many scientific researchers (Schieber and Carle, 2005; Amorim-Carrilho et al., 2014; Burgos et al., 2012; Kao et al., 2012) abstracted that bioactive compound are affected by culinary treatments such as microwave, baking, or boiling and proven that the heat treatments produce an increase in *cis* isomers of carotenoids which causes changes in the bioavailability of these compounds. Also, the thermal stability of carotenoids is affected by the culinary conditions and the nature of the food matrix. Scientific researchers (Kita et al., 2013; Zhao et al., 2019) pointed out that, during culinary, heat induces numerous chemical reactions that lead to the formation of compounds with antioxidant capacity, causing increased antioxidant activity in cooked products. However, Amorim-Carrilho et al. (2014), observed that steaming for 40 min of *Himanthalia elongate* had a negative influence on the antioxidant activity. Generally, the type of culinary and the culinary time influence the antioxidant activity of cooked seaweed, boiling being the highest treatment on antioxidant activity in agreement with a previously observed by (Amorim-Carrilho et al., 2014; Rajauria et al., 2010).

Heat treatments of *Ulva lactuca* brought various changes in minerals content that maybe increased or decreased according to the culinary method and the duration of exposure to heat. About the greatest losses occur in K content, in more than 79.6%, and in Mg content, in more than 50% with the boil treatment. As it happens in other foods, K does not bind to the food matrix, solubilizing with certain ease when the culinary medium is aqueous. Regarding Mg, the results show similar behaviour in the steam and sous vide cooked algae, with the levels closer to the raw algae. The results of Na indicate that Na is a more stable mineral with different culinary treatments, the highest percentage of loss reached 15% after 5 min cooking in sous vide 50 °C, and this rises positive impact of the sous vide method especially for hypertension patients. As in previous studies carried out with other macroalgae species (Hwang, 2013; Santoso et al., 2006), the Na content is maintained after different culinary treatments. On the contrary, the retained Ca presents higher values 100% in all treatments, except in boiled samples, which produces a loss of up to 23% by leaching. Ca is a fixed mineral found in food, and less soluble in water, hence its loss is less. Differences in iron content among all treatments maybe due to high retention percentages of iron, García-Sartal et al. (2013), observed a retention percentage of 49.7, 54.3, and 64.1% in Fe, Cu and Zn respectively, for dried samples of *Ulva lactuca* alga and subjected to boiling for 5 min. In other species such as *Laminaria sp*. Alves et al. (2018), found that fresh steamed (105 °C) wrapped in aluminium foil for 15 min did not affect the Fe and Zn contents. Minerals results show that the percentage of retention of minerals is not only influenced by the species, type of mineral and the culinary methods but also the pre-treatment carried out, such as dehydration and rehydration, which aid the degradation of the algae matrix and, therefore, allows a greater release and leaching of minerals even at culinary times of 5 min, as occurs in the studies carried out by García-Sartal et al. (2013).

Previous studies have shown that cooked fish or vegetables present different profile of fatty acid comparison to raw products depending on the culinary method and the species (Fabbri and Crosby, 2016; Nieva-Echevarría et al., 2017; Weber et al., 2008). In the case of algae, and specifically *Ulva lactuca*, there are no previous studies on the effect of culinary processes on its fatty acid profile, considering the trend of consumers towards algae and in light of the continuous increase in vegetarian consumers. It should be noted that the levels MUFAs and PUFAs will be related due to the quantification method used based on percentages, so that by significantly ($p < 0.05$) reducing the content of one of them consequently increases the percentage of the other. The SFA content of the alga *Ulva lactuca*, very elevated in the raw state and not affected by the different culinary treatments, at levels similar to those of other studies (McCauley et al., 2016; Ortiz et al., 2006; Yaich et al., 2011), This indicates that saturated fatty acids are very stable against culinary heat treatments regardless of the culinary methods and time. The content in MUFAs is affected by the different culinary treatments and applicable culinary time. The highest retention percentage of MUFAs is reached after 5 min cooking regardless of the culinary treatment, although it was more pronounced for the sous vide culinary at 50 and 75 °C. The most abundant MUFAs compounds in *Ulva lactuca* crude oil are oleic acid (C 18: 1) and palmitoleic acid (C16: 1) with values similar to those obtained by (McCauley et al., 2016; Yaich et al., 2011) for *Ulva* species. Both fatty acids are affected by different culinary treatments and their duration, showing significant differences ($p < 0.05$) with respect to the raw algae. Palmitoleic acid (C16: 1) is considerably reduced in all cases and in greater proportion as culinary time increases. Steaming is present the lowest losses of MUFAs with a retention percentage varied from more than 100% and 82% depending on the duration of the treatment, the losses come up to 79% after boiling algae for 15 min. About the significant ($p < 0.05$) different effect occurs to oleic acid (C 18:1) observed with boiling with continuous loss by over culinary time. Sous vide culinary at 50 °C being more concentration of C18:1 after 5 min but among the longer culinary time the retention of oleic acid was decreased. The retention percentage of PUFAs in the algae samples after culinary treatments shows that the steaming treatment is the least lose and retention rates of more than 90% are achieved according to the culinary time. Boiling for 5 min decreased the retention of

PUFAs up to 66.5%, but at the longer culinary time the levels of polyunsaturated fatty acids decrease quickly to values less than 0.1%. Also, sous vide culinary methods negatively affect in PUFAs content maybe due to degradation and loss of unsaturated fatty acids. PUFAs content loss increases with increasing temperature and culinary time. The major compounds within PUFAs are linolenic acid (C 18:3, n-3) and linoleic acid (C 18: 2, n-3 & n-6) as in other previous studies of *Ulva lactuca*, the high levels of both linolenic acid and linoleic acid are distinctive characteristics of green algae (McCauley et al., 2016; Yaich et al., 2011; Holdt and Kraan, 2011). Culinary treatments considerably reduce the levels of linolenic and linoleic acids with the exception of steam culinary until they are practically undetectable, as is the case with the rest of the PUFAs. In steam culinary, the content of PUFAs is practically maintained or slightly decreased (Costa et al., 2015). Also, sous vide culinary at different temperatures significantly ($p < 0.05$) decrease the PUFAs content. This is because unsaturated fatty acids are highly susceptible to oxidation, especially at high temperatures and long application times (Domínguez et al., 2014; Jiménez-Monreal et al., 2009). In General, sous vide culinary algae at 50 and 75 °C (for 5 and 10 min.) have nutritional values much higher than other culinary methods and even more than raw algae. This indicates that sous vide culinarily is a style that respects the nutritional properties of raw seaweed and can even improve it.

5. Conclusions

The different culinary treatments used in present study significantly ($p < 0.05$) effect on the physicochemical composition of *Ulva lactuca*. The effect on the composition depended on the culinary treatment, culinary time and the type of compound or characteristic. Of all the treatments, boiling is the one that produces the greatest changes over time, highlighting the loss of ash, proteins, lipids, K, Ca, Mg, MUFAs, and PUFAs. Contact of algae with boiling water can promote cell rupture and migration of soluble compounds. Based on the findings, cooking algae using the sous vide method is suggested. Sous vide culinary is a respected technique and can improve the nutritional value and physical properties of raw algae. It develops rapidly during culinary, which is a phenomenon that must be taken into account, in addition to its nutritional and functional properties when preparing dishes or products based on this species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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