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Postharvest processing of *Sargassum duplicatum* for tea products

Nahdlotul Fauziyah[1] · Fermanto[1] · Muhamad Nur Ghoyatul Amin[1,2] · Mochammad Amin Alamsjah[2] · Sri Subekti[2] · Dwi Yuli Pujiastuti[1,2]

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Abstract

Postharvest processing is crucial to success in utilizing *Sargassum* sp. as a raw material in tea production. Postharvest pre-treatment and drying processes can cause fishy flavor and nutrition loss; therefore, these effects need to be understood and managed. In this study, we evaluated the effect of deodorization technique and drying method on the final quality of dried algal samples. *Sargassum duplicatum* harvested from Talango Island, Sumenep, was used in the study. Algal samples were immersed in a water suspension of *Tectona grandis* charcoal at concentrations of 5, 10, and 15 %w/v for 6, 12, and 18 h, and then dried using three different drying methods: oven drying, sun drying, and air drying. The study showed that immersion in a suspension of 15% w/v charcoal for 18 h was the best method to deodorize the algal samples reducing the amount of phenols, flavones, and fishy flavor; however, future work on optimization of deodorization of brown algae by using charcoal suspension was suggested. Different drying methods generated different final dried algal sample characteristics such as the amount of phenols, flavones, antioxidant activity, and profile of volatile compounds. Air drying was found to be the best method in this study in retaining the total phenolic content and total flavonoid content, followed by sun drying and oven drying. Overall, deodorization using charcoal from *T. grandis*, followed by air drying was demonstrated to be a set of traditional approaches successful for postharvest processing of brown seaweed for use as a tea raw material.

Keywords Brown algae · Deodorization · Drying · Phenols · Flavones · Flavor

Introduction

As the largest archipelagic country in the world, Indonesia has diverse natural marine resources such as macroalgae, which have potential for future commercial use. Indonesia has more than 500 species of macroalgae which are not widely used today due to lack of scientific evidence on their functionality. There are only two genera which are currently used commercially, *Gracilaria* and *Eucheuma*, which are respectively sources of agar and carrageenan gum.

Sargassum spp. are among Indonesia's most abundant macroalgae. They are members of the brown algae containing compounds such as fucoxanthin pigment (Wu et al. 2014), polysaccharides (fucoidan and alginate), and secondary metabolites such as phenols and flavones (Lim et al. 2017). These compounds in brown seaweed have a variety of health benefits. For example, phenols and flavones exhibit low-density lipoprotein oxidation inhibiting activity, inhibition of angiotensin-converting enzyme (ACE), α-amylase, α-glucosidase (Nagappan et al. 2017), and anticancer activity (Padua et al. 2015). In China and Japan, *Sargassum* is extracted to obtain alginate and fucoidan which are used in the food, pharmaceutical, and cosmetic industries as stabilizers, emulsifiers, biomaterials, and fortification. Unfortunately, not many industries adopt their technologies due to high costs. Therefore, a traditional approach which uses the whole macroalgae could be more cost-friendly.

Based on its beneficial physical properties and chemical components, we focused on the use of brown seaweed as a tea product. "Tea" products are those for which the dry matter of plant tissue is infused in hot water to release chemical components from the plant often used for health benefits. The challenges in using brown algae as a raw material for tea are its fishy odor and the stability of the targeted extracted compounds. Therefore, postharvest processing of brown algae

✉ Mochammad Amin Alamsjah
alamsjah@fpk.unair.ac.id

1 Undergraduate Program of Fisheries Product Technology, Faculty of Fisheries and Marine, Universitas Airlangga, Mulyorejo, Surabaya, East Java 60115, Indonesia

2 Department of Marine, Faculty of Fisheries and Marine, Universitas Airlangga, Campus C UNAIR Jl., Mulyorejo, Surabaya, East Java 60115, Indonesia

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for use as a tea raw material is crucial to produce tea with desired functional properties (health benefits) and customer-friendly flavor attributes.

Postharvest processing of seaweed consists of washing, screening, desalting, deodorization, and drying. In the present study, we evaluated deodorization of wet material and determined the most appropriate conventional drying process. In contrast with common tea products, tea made from brown algae has a strong, non-desirable flavor. Previously Maes et al. (2010) showed that non-desirable flavor in fish oil could be reduced by simply pouring activated carbon onto fish oil and heating at 70 °C. Furthermore, Khalafu et al. (2017) studied deodorization of fucoidan using active carbon and $CaCO_3$ as adsorbents. Both approaches, however, resulted in nutrition loss (Khalafu 2017). While these methods are useful in reducing the fishy odor, the nutrition loss and processing costs are prohibitive for future industrial application. Therefore, the choice of another, more affordable, adsorbent is crucial. Charcoal could be a potential alternative to replace the use of active carbon as it was shown in a state-of-the-art review article by Ahmaruzzaman (2008) to reduce the amount of anti-nutritional compounds in wastewater treatment via adsorption. In the present study, charcoal played role as deodorizing agent for algal samples by immersing the algal samples in the charcoal suspension in water.

After deodorization, drying is carried out. Charles et al. (2019) demonstrated that the use of some drying techniques such as freeze drying, vacuum drying, sun drying, and oven drying affect the chemical and functional properties of the algae samples. One affordable, traditional technique not investigated as part of this study was air drying. In our study reported herein, we performed work focusing on requirements of tea products such as bioactive components, flavor information, and antioxidant activity. The objective of our study was to determine the effect of deodorization of the brown alga *Sargassum duplicatum* on its chemical components and flavor as well as determine the most appropriate conventional drying method to retain bioactive compounds possessing antioxidant activity.

Materials and methods

Preparation of brown algae

Sargassum duplicatum was collected from Talango, Sumenep, Madura Island (3° 31′ 55″ S107° 38′ 35″ E) and harvested on 05 February 2019. Characterization was confirmed by the Oceanology Laboratory of the Indonesian Research Centre, Jakarta, Indonesia. Fresh algae were washed with tap water to remove sand and debris, and then the algae were copped and blanched at 85 °C for 2 min. Algae were then drained before deodorization.

Deodorization of brown algae

Charcoal of *Tectona grandis* was purchased from a traditional market in Surabaya. The charcoal was then pulverized and sieved. The suspension of charcoal was prepared by dispersing the charcoal into tap water at three different concentrations: 5%, 10%, and 15% w/v. Algae samples were fully immersed in the charcoal suspensions to optimize the deodorization process. Deodorization was carried out in a glass bottle for 6, 12, and 18 h under ambient temperature. After deodorization, samples were washed with tap water until no charcoal remained and then air-dried until fully dry. The air-dried algal samples were stored in a plastic bag with silica gel before further use and analysis.

Selection of drying method

Algae samples were washed and blanched based on the above method followed by deodorization using the selected combination of charcoal suspension of 15% w/v for 18 h. The samples were then dried using either oven drying at 60 °C, sun drying, or air drying. Samples were dried until reaching the targeted moisture content of commercial dry tea leaves which is less than 8% w/v (Indonesian Quality Standardization, SNI 3836:2013).

Total phenolic content determination

Determination of total phenolic content was carried out using the reference method of Sharma and Gujral (2014). A 0.5-g dried algal sample was dispersed in 10-mL distilled water and then homogenized. The dispersion was then centrifuged at 3000 rpm for 10 min. One milliliter of supernatant was then taken out, poured into a tube and 5 mL water was added. Subsequently, 0.6 mL of the resulting solution was reacted with 1.5 mL of 10% Folin-Ciocalteu solution and 1.5 mL sodium carbonate 6% (w/v). The sample was then incubated at room temperature for 60 min. The absorbance was measured using a UV-VIS spectrophotometer with a wavelength (λ) of 725 nm. Gallic acid was used as a standard solution at 5 different concentrations: 5, 10, 15, 20, and 25 ppm. Total phenolic content is expressed in gallic acid equivalents using the following equation, where C, V, Df, and G are the approximate phenol concentration, sample volume, dilution factor, and sample weight, respectively.

$$\text{Total phenolic content}\left(\text{mg}\frac{\text{GAE}}{100\ \text{g}}\right) = \frac{C \times V \times Df}{G}$$

Total flavonoid content determination

The colorimetric aluminum chloride ($AlCl_3$) method of Chang et al. (2002) was adopted to determine total flavonoid content.

A 0.5-g sample was dissolved in 10 mL of ethanol and homogenized using a vortex for 2 min. The solution was then centrifuged. Approximately 0.6 mL of supernatant was then mixed with 1.5 mL of ethanol 95%, 0.1 mL of $AlCl_3$ 10%, 0.1 mL of potassium acetate 1.0 M, and 2.8 mL of water. The mixture was then incubated at room temperature for approximately 30 min. The absorbance of the reaction mixture was measured using a UV-VIS spectrophotometer at a wavelength of 415 nm. Quercetin was used for the standard calibration curve for total flavonoid content determination. Total flavonoid content was expressed in milligrams of Quercetin equivalents per gram dry weight (mg QE $(100\text{ g})^{-1}$), determined by using the following equation, where C, *V*, *Df*, and *G* are the approximate flavonoid concentration, sample volume, dilution factor, and sample weight, respectively

$$\text{Total flavonoid content}\left(\text{mg}\frac{\text{QE}}{100\text{g}}\right)=\frac{C\times V\times Df}{G}$$

Antioxidant activity determination using 2,2-diphenyl-1-picryl-hydrazyl-hydrate inhibition

Antioxidant activity of the algal sample was performed according to Brand-Williams et al. (1995). 10 g of the algal sample was macerated in 100 mL ethanol for 2 h and then centrifuged at 4000 rpm for 10 min at 5 °C. The supernatant was decanted and evaporated at 45 °C for 30 min to obtain the crude extract. The extract was then diluted to 50, 100, 150, 200, and 250 ppm. Approximately 1 mL of each concentration of the diluted extract was poured into a glass tube covered with aluminum foil, three mL of 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) added, and the sample was incubated at room temperature in a dark room. The absorbance was then measured using a UV-spectrophotometer at a wavelength of 517 nm. Absorbance of each concentration was then calculated using the following equation before further use for IC_{50} determination (a high linear regression near to 1.0 was considered)

$$\%AA=\frac{A0-A1}{A0}\times 100$$

where $\%AA$, A_0, and A_1 are the % inhibition, blank absorbance, and sample absorbance, respectively. Butylated hydroxytoluene (BHT) in ethanol was used as the antioxidant agent at 5, 10, 15, 20, and 25 ppm. The method of determination of IC_{50} towards BHT was similar to the algal sample extract.

Analysis of flavor components in algae

The flavor components in algae samples were analyzed on a headspace solid-phase micro-extraction gas chromatography-mass spectrometry (HS-SPME-GC-MS) system (GC 7890A; MS 5975C, Agilent Technologies, USA), based on Laohakunjit et al. (2014). The algal sample was placed into a 22-mL vial and heated to 60 °C for 10 min in a GC-MS heating block for headspace analysis. Volatile compounds were absorbed onto an SPME fiber (50/30 μm DVB/Carboxen/PDMS StableFlex; Supelco, USA) for 20 min. After equilibrium, the SPME fiber was desorbed into the injector port at 250 °C for 20 min. The injector was operated in splitless mode. Helium was used as the carrier gas at a constant velocity of 1.0 mL min^{-1}. Volatile compounds were separated using a DB-WAX capillary column (30 m × 250 μm × 0.25 μm; J&W Scientific Inc., USA). The oven temperature program was as follows: initial temperature of 55 °C; increased to 180 °C at 5 °C min^{-1}, increased to 200 °C at 8 °C min^{-1} and held at 200 °C for 10 min. Volatile compounds were detected using MSD (scan range of m/z 29–550) at 230 C. MS results were then recorded using electron impact ionization at 70 eV. The total ion count (TIC) was yielded and used for data identification and quantification (area). The TIC was compared to the spectral component database known in the GC-MS library (NIST-14). The identified flavors were then described by using a flavor information database at www.flavornet.org and published references.

Sensory evaluation using QDA (quantitative descriptive analysis)

QDA was used to quantify the fishy odor intensity of deodorized algal samples, based on Kemp and Hort (2009). We recruited ten panelists who were familiar with QDA from the Faculty of Fisheries and Marine Universitas Airlangga, Surabaya. Water infused samples, prepared by infusing the algal samples in hot water, were presented to panelists to facilitate odor inhalation. A scale of 0–9 was used to quantify the fishy odor intensity of the algal samples. A non-deodorized algal sample was used as the reference sample, graded 9. QDA was conducted at a controlled temperature of 24 °C.

Results

The effect of deodorization on fishy flavor intensity, phenols, flavones, and volatile compounds

According to the results of QDA (Fig. 1), different combinations of charcoal concentration and deodorization time yielded different fishy flavor intensity for the algal samples. Higher charcoal concentrations and longer deodorization times yielded lower fishy flavor intensity. Furthermore, the higher the charcoal concentration, the faster the reduction of the fishy flavor. The plot in Fig. 1 shows that a concentration of 5% for

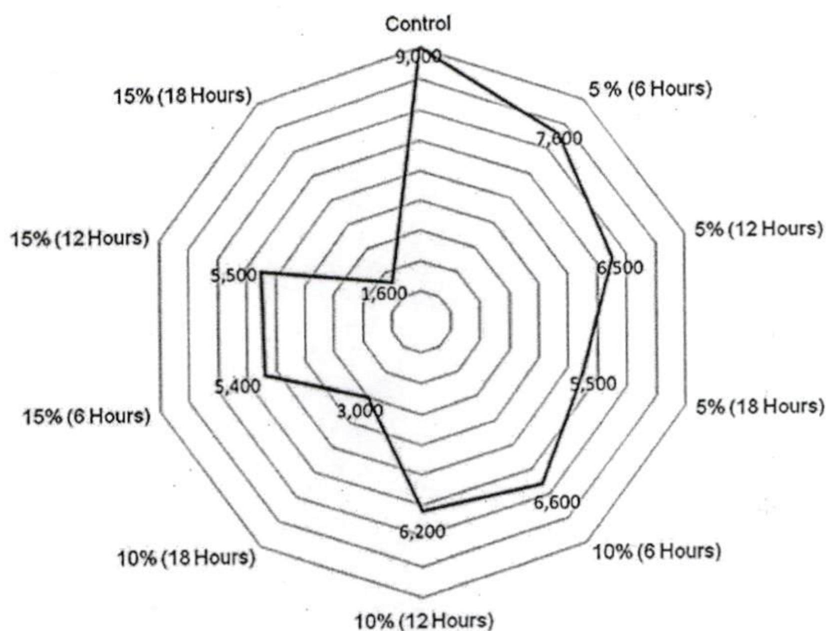

Fig. 1 Sensory evaluation (quantitative descriptive analysis) of deodorized *Sargassum duplicatum*

6 h yielded was the least effective in reducing fishy intensity. Increasing charcoal concentration to 10 and 15% gave further reduced fishy flavor intensities of 6.6 and 5.4, respectively. The use of 5% charcoal concentration reduced the intensity to a minimum of 5.5 after an 18-h period, while 10 and 15% yielded minimums of 3.0 and 1.6 over 18 h, respectively.

The highest total phenolic content and total flavonoid content were obtained with a charcoal concentration of 5% and duration of 6 h, while the lowest total phenolic content and total flavonoid content were obtained by charcoal concentration and durations of 15% for 18 h and 15% for 6 h, respectively (Tables 1 and 2). Samples with the lowest fishy flavor intensity, generated with a charcoal concentration of 15% and duration of 18 h, were characterized by using GC-MS with a DB-WAX column. Results showed that most detected compounds in the non-deodorized samples were also detected in the deodorized samples. More specifically, the area of the peak of most compounds reduced due to deodorization, demonstrating that deodorization in the present study was able to reduce the compounds generating the native flavors of the algal samples (Table 3).

The effect of different drying techniques on the phenols, flavones, antioxidant activity, and volatile compounds

Following deodorization, drying was an important step in preparing *S. duplicatum* for tea material. Table 4 shows that the final moisture content of the algal samples dried using the techniques of oven drying, sun drying, and air drying was 6.88, 7.47, and 7.74, % w/w, respectively, demonstrating that all three techniques can achieve the maximum moisture content allowed for dry tea material (< 8%). Oven drying was the most efficient in reducing the moisture content, followed by air drying and sun drying. The level of remaining phenols and flavones were also crucial factors in determining the best drying method. Table 3 shows that, among the different drying methods studied, the most effective at retaining phenols and flavones was air drying followed by sun drying and oven drying. Similar to the results for phenol and flavone retention, highest antioxidant activity was retained by algal samples dried by using air drying, followed by sun drying and oven drying.

Table 1 Total phenolic content (mg GAE (100 g)$^{-1}$ dry sample) of deodorized *Sargassum duplicatum*

Charcoal concentration (% w/v)	Duration of deodorization (h)		
	6	12	18
5	8.28 ± 0.07	8.05 ± 0.13	7.75 ± 0.12
10	7.63 ± 0.06	7.82 ± 0.10	7.37 ± 0.12
15	7.25 ± 0.44	7.33 ± 0.22	7.12 ± 0.22

Data expressed as mean ± SD ($n = 3$)

Table 2 Total flavonoid content (mg QE (100 g)$^{-1}$ dry sample) of deodorized *Sargassum duplicatum*

Charcoal concentration (% w/v)	Duration of deodorization (h)		
	6	12	18
5	4.19 ± 0.14	3.85 ± 0.74	3.76 ± 1.00
10	3.72 ± 0.62	3.70 ± 0.65	3.70 ± 0.80
15	3.57 ± 1.00	3.58 ± 1.00	3.58 ± 0.90

Data expressed as mean ± SD ($n = 3$)

Table 3 Volatile components of non-deodorized and deodorized *Sargassum duplicatum*

Compound name	Area		Flavor description*
	Non-deodorized	Deodorized	
Hydrocarbon			
Pentadecane	1,075,615,103	541,599,098	Mild odor
Heptadecane	554,835,401	214,599,504	Alkane
Benzaldehyde	79,568,534	143,682,471	Sweet, oily, nutty, woody
2,6,10-Trimethyl-pentadecane	182,545,101	115,117,788	Mild odor
1-Heptadecene	56,903,651	57,368,962	Alkenes
4-Methyl-pentadecane	136,517,779	38,222,553	Mild odor
2-Methyl-octadecene	22,410,818	17,086,180	Fuel-like
4-Methyl-octadecene	49,178,174	15,436,362	Fuel-like
3-Methyl-pentadecane	216,506,320	116,347,379	Mild odor
Naphthalene	151,871,134	140,119,901	Coal tar
Eicosane	52,120,813	27,352,324	Waxy
1,1'-Oxybis-hexadecane	108,852,646	46,372,743	Gasoline-like
4-Ethyl-2,6-dimethyl-pyridine	28,446,046	30,330,453	Meaty, roasted
4-Methyl-tetradecane	410,992,703	153,142,977	Gasoline-like
8-Heptadecene	53,649,278	29,289,406	Fatty
1-Pentadecene	108,607,215	24,692,413	Mild
Caryophyllene oxide	7,695,687	15,329,675	Spicy, woody, terpenic
Lilial	11,157,619	14,589,891	Floral, muguet, watery, green, powdery, cumin
(E)-2-Tetradecene	61,009,597	56,072,253	-
3-Methyl-heptadecoulde	158,477,278	90,957,558	Oily, fuel-like
Versalide	10,493,090	7,508,313	Sweet, musk
6-Propyl-tridecoulde	230,632,321	95,584,887	Gasoline-like
Diisobutyl phthalate	4,960,766	2,738,698	Ester odor
2,6,11-Trimethyl-dodecoulde	47,395,822	35,876,819	Gasoline-like
Tetratriacontyl pentafluoropropionate	22,821,679	15,555,795	-
1-Acetyl-4,6,8-trimethylazulene	11,510,666	10,313,734	Green, spicy, sweet
2-Methyl-1-propyl-naphthalene	14,236,209	9,244,296	Sweet, floral, woody
2-Ethylhexyl salicylate	10,688,168	11,240,222	Mild, orchid, sweet, balsam
Aldehyde			
Nonanal	271,703,424	232,350,341	Geranium, plastic, marine
Hexanal	68,340,693	117,331,733	Fishy, grassy, leafy, green
(E)-2-Octenal	40,039,247	34,137,322	Fishy, dandelion, fat, fruit, grass, green, spice, oily
Heptanal	27,392,770	46,167,470	Fat, citrus, rancid
(E,E)-2,4-Decadienal	58,039,475	39,291,042	Burnt fat, citrus, rancid
2-Heptadecenal	37,107,877	13,121,888	Seaweed-like
2-(Phenylmethylene)-octanal	7,579,072	6,333,604	Grassy, leafy, green, fatty
Alcohol			
2-Phenoxy-ethanol	52,811,281	74,583,049	Mild, rose, balsam, cinnamyl
Phenol	10,868,726	10,868,726	Phenol-like
2,4-Di-tert-butylphenol	35,150,991	38,320,638	Fermented sausage
Ketone			
Trans-β-ionone	64,954,658	47,589,051	Cedar wood, violet

*Flavor descriptions were cited from www.flavornet.org

Table 4 Chemical properties and antioxidant activity of dried *Sargassum duplicatum*

Drying technique	Drying time (*d*)	Moisture content (%)	Total phenolic content (GAE mg (100 g)$^{-1}$ dry sample)	Total flavonoid content (mg QE (100 g)$^{-1}$ dry sample)	IC_{50} (mg L^{-1})
Oven	0.58	6.88 ± 0.15	2.48 ± 0.09	1.98 ± 0.65	171.19 ± 23.05
Sun	7.00	7.47 ± 0.08	3.00 ± 0.10	5.05 ± 0.24	162.10 ± 25.23
Air dry	0.88	7.74 ± 0.14	5.16 ± 0.06	9.46 ± 0.65	149.82 ± 16.72

Data expressed as mean ± SD ($n = 3$)

The different drying methods in this study impacted the profiles of volatile compounds in the algal samples (Online Resource 1). The original compounds in the wet algal samples were reduced and even disappeared due to drying. In particular, compounds producing alkane odor such as pentane, 3-ethyl-2-methyl-pentadecane, 7-methyl, tetradecane, 4-methyl, tetradecane, 3-methyl-, heptadecane, hexadecane, 2-methyl, completely disappeared, although most other compounds originally in the wet sample were retained. Within the observed drying scenarios in this present study, algal samples dried using sun drying generated the greatest detected number of compounds.

Discussion

The reduction of fishy flavor intensity of deodorized algal samples was related to decreasing the level of compounds responsible for forming the fishy flavor. This finding was supported by the volatile compounds profile of the deodorized algal samples, where most compounds identified by GC-MS in this study showed reduction in level due to deodorization. However, the compounds were not eliminated by deodorization as most compounds in the control sample were also identified in the deodorized samples. In general, deodorization reduced the fishy flavor intensity of the algal samples; however, deodorization also triggered loss of phenols and flavones which are valuable components of tea. The reduction of fishy flavor intensity, most volatile compounds, and phenols and flavones was due to the capacity of charcoal as an adsorbent (Goud et al. 2005). The use of water as the solvent in preparing the charcoal suspension potentially reduced the number of compounds investigated in this study, since most compounds were polar, and water is a good solvent to elute polar compounds from biomass samples. According to Dhar et al. (2017), phenols are negatively charged with hydrophilic circular carbon rings. Therefore, during deodorization those compounds were diffused to the charcoal. A comparison report on several natural adsorbents by Ahmaruzzaman (2008) demonstrated that charred material indeed had a phenols-adsorbing capacity, which was relatively lower than other adsorbing material. Moreover, the adsorbing capacities of each individual char depended on the plant source and their pore size (Dutta et al. 2001; Wu et al. 2005). Therefore, we suggest in-depth analysis on the use of different char sources and even other adsorbents in deodorizing algal samples.

Following deodorization, drying is a crucial step in preparing tea raw material. In general, drying at high temperature triggers the oxidation and degradation of functional compounds such as phenols and flavones in plant biomass (Prathapan et al. 2009; Sandra and Chong 2013). Vatai et al. (2009) demonstrated that phenols are very sensitive, unstable, and highly susceptible to degradation. The loss of compounds with antioxidant activity from plant biomass is caused by the oxidation of lipid components of the protective layers of plant tissue such as lipid droplets or liposome. Therefore, the antioxidant activity of the plant biomass declines with enhanced antioxidants loss (Pokorny and Korczak 2001). In addition to thermal effects of the drying process, radiation also triggers the degradation of flavones (Schmidt et al. 2009). Therefore, it is logical that the reduction of total phenolic content and flavonoid content was due to sun drying. Interestingly, Tiwari et al. (2006) and Bartley and Jacobs (2000) demonstrated that drying and heating could intensify the phenolic content of plant biomass, but the antioxidant activity is low. This phenomenon shows that enhanced phenols are not always possessing antioxidant activity. The results from our study show that air drying is the most recommended drying technique among those studied.

The results presented in "Online Resource 1" show that some volatile compounds detected in wet samples were lost while some new compounds were detected following drying. In general, the volatile compound loss in this study could be due to oxidation that occurs during drying. However, oxidation could also be intensified by applying high temperature or heating (Venskutonis et al. 1996; Díaz-Maroto et al. 2002). The formation of new volatile compounds such as linalool, anethole, 1-octen-3-ol, safrole, benzothiazole, and 1-hexanol was in line with the studies of Ding et al. (2012) and Qu et al. (2019). Karabacak et al. (2018) stated that the formation of new volatile compounds during drying was due to reaction of enzymes present in the samples, where the enzymes were

inactivated due to thermal stimulation during drying. Therefore, this present study speculated that use of oven drying might cause the lowest number of newly detected compounds compared to other drying methods.

Our detected volatile compounds, such as hydrocarbons (heptadecane and hexadecane), ester hydrocarbons (heptacosyl acetate, heptacosyl acetate, propyl phenylacetate, methyl (3-oxo-2-pentylcyclopentyl) acetate, 4-tert, butylcyclohexyl acetate), alcohols (1-Octen-3-ol and phenol), aldehydes (hexanal, nonanal, heptanal and hexenal), and ketones (trans-β-ionone, β-ionone epoxide, 6-methyl-β-ionone, α-ionone isomethyl, 6-methyl)-2-heptanone, were previously revealed as typical algal volatile compounds. Heptadecane and hexadecane were detected in the wet samples but not detected in dried samples in this present study (Online Resource 1). Both compounds were previously investigated in brown and red algae by Kamenarska et al. (2002), while hexadecane was investigated in *Undaria pinnatifida* (Balbas et al. 2015). Bravo-Linares et al. (2010) showed that hydrocarbon compounds were produced in dark conditions. Our air and sun drying scenarios were partially conducted under illumination. Oven drying, however, was principally conducted in dark conditions where the temperature effect could stimulate degradation. Pina et al. (2014) stated that hydrocarbons are thermo-labile. The ester hydrocarbon investigated in this present study contributed to the macroalgae's sweet and fruity odor (Sun et al. 2012). 1-Octen-3-ol, a branched-chain alcohol, was associated with fishy and grassy aromas and is a significant contributor to the aroma in macroalgae. It is derived from unsaturated fatty acids via peroxidation reaction of carbohydrates by glycolysis or from amino acids as previously demonstrated in Wakame and Kombu algae (Ferraces-Casais et al. 2013; Peinado et al. 2014). Our present study demonstrated that 1-octen-3-ol was only present in the dried algal samples likely due to peroxidation reaction occurring during the drying process.

Hexanal, nonanal, heptanal, and hexenal were the predominant volatile compounds in *Pterocladiella capillacea*, *Osmundaria obtusiloba*, *Palmaria palmata*, *Porphyra umbilicalis*, *Saccharina latissima*, *Ulva lactuca*, and *U. pinnatifida* and contribute to the green color and herbaceous odor (López-Pérez and Picon 2017). Kamenarska et al. (2002) investigated those compounds in species of brown algae from the Black Sea. Trans-β-ionone, β-ionone epoxide, 6-methyl-β-ionone, α-ionone isomethyl, 2-heptanone, and 6-methyl were ketone group compounds detected in this present study. These were previously investigated in seven species of dehydrated edible seaweeds coming from carotenoids such as lycopene and phytoene by oxidative cleavage. Those compounds contributed to floral, fruity, and sweet notes of the algal samples. Our study detected some ketones only in the dried algal samples, suggesting that oxidation may occur upon drying (Sun et al. 2012).

Conclusion

This study shows that deodorization by immersion in a suspension of 15% w/v charcoal for 18 h was the best technique to reduce the amount of phenols, flavones, fishy, and other flavors in algal samples, although future work to optimize this deodorization condition was suggested. Furthermore, different drying methods such as air drying, sun drying, and oven drying generated dried algal samples with different levels of phenols, flavones, antioxidant activity, and profile of volatile compounds. Air drying was determined to be the best drying method in this study, followed by sun drying and oven drying. Overall, deodorization using charcoal of *Tectona grandis*, followed by air drying was shown to be the best set of traditional approaches for brown seaweed postharvest processing for tea raw material.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10811-021-02370-x.

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