Effect of drying methods on bioactive compounds, nutritional, antioxidant and antidiabetic potential of brown alga *Durvillaea antarctica*

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The effects of vacuum, solar, convective, infrared and freeze drying (VD, SD, CD, IRD, FD) on *Durvillaea antarctica* were evaluated in terms of nutritional composition, color, bioactive components, and antioxidant and anti-diabetic activities. Nutritional composition of the dried seaweeds scarcely varied, while a tendency to lose the reddish tone occurred. CD-seaweed had highest phytochemical and vitamin contents, while FD-samples showed best retention of pigments. Both samples also exhibited the strongest antioxidant and antidiabetic activities. The highest essential amino acids and polyunsaturated fatty acids contents were found in IRD- and SD-samples respectively. In general, FD and CD proved to be viable drying options for *D. antarctica*.

Keywords: brown seaweed *Durvillaea antarctica*; drying methods; bioactive components; antidiabetic properties; amino acids; fatty acids

1. Introduction

The brown seaweed *Durvillaea antarctica* belongs to marine organisms that are autotroph and proliferate in seas and oceans [1]. Owing to their high content of dietary fibre, vitamins, minerals [2-5], bioactive compounds [4, 6, 7], complex sugars and polysaccharides [1], marine algae have been used for their anti-tumour bioactivity, antiviral activities as well as for their capacity to prevent obesity, large intestine cancer and diabetes [8, 9]; they are valuable raw materials for the foods, pharmaceutical and cosmetic industries [10]. However, before extraction of the phytochemicals, the algae are traditionally prepared through sun drying in open air. Although this method is most commonly used, it is vulnerable to weather uncertainties and infestation by insects, rodents or birds [11] that lead generally to low quality in terms of nutritional composition and hygiene [12]. During sun-drying that is a slow and labor-intensive

process requiring large land area, adverse weather conditions and slow drying rate may lead to high product losses due to inadequate drying, fungal growth causing deterioration and decomposition of the product [13], encroachment of insects, birds and rodents, which have led to construction and design of solar dryer in an attempt to harness solar energy to reduce the adverse issues [13, 14]. However, the dehydration of marine algae by solar methods requires long drying periods, so that a desired increase in production rates can only be through application of industrial drying methods [15], which should be selected based on product quality obtained at optimal cost and yield [16, 17]. In this respect, several drying methods, such as solar, convective hot-air, microwave, vacuum or freeze drying [18-20] have been applied to seaweeds and their corresponding effects on nutritional and bioactive properties have been reported; hydrothermal drying methods have been applied to *Himanthalia elongata*, *Laminaria saccharina* and *Laminaria digitata* [21]; freeze-drying, oven drying and greenhouse drying to brown seaweeds *Sargassum muticum* and *Bifurcaria bifurcata* [22]; or sun drying, oven drying and freeze-drying to *Sargassum hemiphyllum* (Turn.) C. Ag. [23] among others. Effects of hot air-drying temperatures on *D. antarctica* have also been reported by Uribe et al. [7], but the impact of different drying techniques on *D. antarctica* is not known. The processing time and drying temperature are important variables that affect product's quality [23, 24] and are characteristic of drying methods. Studies on drying process and the effect of drying on the nutritional properties or on the phytochemical constituents such as polyphenols and flavonoids of edible Chilean brown seaweeds are not available in literature, so that assessing the changes in such properties due to drying is congruent with industrial needs [7, 25]. Therefore, the current study aimed to determine the impact of different drying methods on the phytochemical components, nutritional and anti-diabetic properties of the brown seaweed *D.*

antarctica. Specifically, the contents of soluble and insoluble dietary fiber, chlorophyll, carotenoids, vitamin C and E, total phenolics, total flavonoids, as well as color, amino acids and fatty acids profiles, antioxidant activity (by DPPH and ORAC assays) and anti-diabetic potential of the brown seaweed were investigated. The results of the present study would be useful in deciding the appropriateness of a drying technique based on required nutritional quality, allowing a positive assessment of available resources and pertinence of investment.

2. Materials and methods

2.1 Raw material and drying assays

Assays were conducted on brown seaweeds *D. antarctica* harvested in the coastal locality of Punta Lengua de Vaca, Puerto Aldea, Region of Coquimbo, Chile (latitude: -30.2439° and longitude: -71.6303°). Frond stems of seaweeds free from foreign matter and having typical color were selected, washed with drinking water, cut into pieces of 2 cm. The initial material for all drying assays were from the same variety and batch and had an average moisture content of 79.21 ± 0.37 g/100 g on a wet basis. The seaweed samples were then stored under freezing conditions at -20 ± 1 °C before drying assays; freeze-drying (FD), convective drying (CD), vacuum drying (VD), solar drying (SD) and infrared drying (IRD) were chosen for the assessment, being relevant methods for industrial purposes. Moreover, these types of dryer are readily available on the market, being also easily designed upon request. All differently dehydrated samples were powdered using a basic analytical mill (IKA A-11, USA) and passed through a 35-mesh sieve (U.S. Standard Sieve Series, Dual Manufacturing Co., USA). The powdered samples (<35 mesh) were kept at 5 °C protected from sunlight and vacuum-sealed in low-density polyethylene bags (freezer bags, Ziploc® Brand, S. C. Johnson & Son, Inc.,

USA) until analysis. All drying assays were performed in triplicate.

FD of the fresh seaweeds (0.500 kg) was performed using a freeze-dryer (Virtis Advantage Plus, Gardiner, NY, USA). The sample was first frozen at -80 °C for 24 h, then placed horizontally onto two drying trays at a charge density of 6.08 kg/m² and dried in the primary drying phase programed from -50 to 20 °C followed by the secondary drying phase at 20 °C under vacuum (0.027 kPa) for 72 h. CD was performed in a convective dryer as described by Uribe et al. [10] at 60±0.2 °C with 1.200 kg fresh samples evenly arranged on two stainless steel trays at a load density of 6.28 kg/m² under a constant air flow of 1.5±0.2 m/s. VD was performed at 60±0.2 °C and 15 kPa in a vacuum oven (Mettmert VO400, Schwabach, Germany) for 480 min with the samples (0.500 kg) placed on stainless steel trays at a load density of 4.13 kg/m². SD was performed in a solar dryer [26] designed at the Department of Food Engineering, Universidad de La Serena, Chile, consisting of a drying chamber equipped with a glass sheet as a transparent cover, stainless steel plates for the samples (3.000 kg) and recirculated drying air heated by a solar collector that used a copper plate to absorb incident solar radiation. The variable drying conditions, at the site of the assays with about 10 h sunshine, were recorded with a data logger (Lascar EL-USB-2, Whiteparish, England) with temperature ranging from 31.0 to 49.9 °C and air humidity from 20 to 45%. Samples were dried for 500 min. IRD was performed in a dryer designed and constructed at the Department of Food Engineering of University of La Serena, Chile; it was equipped with two IR incandescent lamps of 175 W (Philips, PAR38 IR 175W E27 240V CL 1CT/12) installed inside the oven as radiation sources. The seaweeds samples (0.300 kg) were placed on a holding tray (21 x 30 cm) facing the IR lamps at 20 cm. Drying was carried out at a fixed temperature of 60 °C for 250 min.

2.2 Proximate analysis, dietary fiber and minerals

The proximate analysis was performed following AOAC methods [27]; content of moisture by AOAC n° 934.06, fat by AOAC n° 960.39, crude fiber by AOAC n° 962.09, crude ash by AOAC n° 923.03 and total protein content by AOAC N° 960.52 but using a conversion factor Nx5 according to Angell et al. [28]. Water activity (a_w) of samples was measured at 25 °C using an AQUA LAB equipment (4 TE, Pullman, WA, USA). The samples were also analyzed for soluble (SDF) and insoluble dietary fiber (IDF) fractions using an assay kit for total dietary fiber (TDF100A; Sigma-Aldrich, St. Louis, MO, USA), an enzymatic digestion unit and a filtration system (VELP Scientifica, GDE - CSF6, Usmate, Italy) following the gravimetric enzymatic AOAC method n° 991.43. The total dietary fiber (TDF) was calculated as the sum of SDF and IDF and expressed in g/100 g dry matter (dm). Minerals, classified as macroelements (Na, K, Mg and Ca) and microelements (Cu, Fe, Mn and Zn), were determined in the crude ash after digestion with a mixture of H₂SO₄, HNO₃ and HClO₄ using an atomic absorption spectrophotometer (AAS, Shimadzu Instruments, Inc., SpectrAA-220, Kyoto, Japan). The mineral contents were expressed as g/100 g dm for the macroelements or mg/kg dm for the microelements. All analyses were performed in triplicate.

2.3 Color determination

Surface color of fresh and dehydrated *D. antarctica* samples was determined in five replicates using a colorimeter (Hunter Lab, MiniScan TM XE Plus, Reston, VA, USA) and CIE chromatic coordinates, L , a and b at standard illuminant D65 and 10° observer angle. Total color difference $\Delta E = ([L - L_0]^2 + [a - a_0]^2 + [b - b_0]^2)^{1/2}$ was calculated with L_0 , a_0 and b_0 as control values of fresh seaweeds [25]. Hue $h = \arctan (b/a)$ and chroma

$\Delta C = (\Delta a^2 + \Delta b^2)^{1/2}$ were also determined [29].

2.4 Determination of total phenolic, total flavonoids and antioxidant activity

The extraction of the brown seaweed was performed following the method described by Uribe et al. [7] with some modifications. The powdered seaweed's sample (2 g) was extracted at room temperature in 50 mL aqueous methanol (60% v/v) for 24 h under continuous stirring at 200 rpm on an orbital shaker (Boeco, OS-20, Germany). Afterwards, the mixture was centrifuged (Eppendorf, 5804 R, Germany) at 2870×g for 5 min. The supernatant was filtered (Whatman filter paper N° 1) and the filtrate dried at 37 °C on a rotary vacuum evaporator (Büchi R-210, Switzerland). The extracts were reconstituted in 25 mL volumetric flasks with 60% v/v aqueous methanol and newly filtered before use for analysis of content of total phenolic (TPC), total flavonoids (TFC) and antioxidant activity. Extraction assays were performed in triplicate.

TPC was determined using Folin-Ciocalteu (FC) reagent [7]. Briefly, 0.5 mL aliquot of seaweed extracts transferred to a Falcon centrifuge tube was mixed with 0.5 mL of FC reagent; after 5 min 2 mL Na₂CO₃ solution (200 mg/mL) were added and vortexed for 20 s. The reaction proceeded at ambient temperature in the dark for 15 min, before adding 10 mL of ultra-pure water. The precipitate formed was removed by centrifugation (Eppendorf, 5804 R, Germany) at 2870×g for 5 min. Finally, the absorbance was measured at 750 nm (SpectronicTM 20 Genesys, NY, USA) and compared to a gallic acid calibration curve. Results were expressed as mg gallic acid equivalent (GAE)/100 g dm. All reagents were purchased from Merck (Merck KGaA, Darmstadt, Germany). All measurements were performed in triplicate.

TFC was measured by a colorimetric assay [30]. Briefly, 0.5 mL aliquot of seaweed extract was added to a volumetric flask containing 2 mL double distilled water

(ddH₂O) and 0.15 mL aqueous NaNO₂ solution (5 g/100 mL). After 5 min, 0.15 mL aqueous AlCl₃ solution (10 g/100 mL) was added. After further 6 min, 1 mL molar NaOH was added and the mixture in the reaction flask was diluted to volume with the addition of 1.2 mL of ddH₂O and thoroughly mixed. Absorbance of the mixture was determined at 415 nm against a water blank using a spectrophotometer (Spectronic TM 20 Genesys, NY, USA). Total flavonoid content was expressed as mg catechin equivalent (CE)/100 g dm.

Free radical scavenging activity of the samples was determined using the DPPH (2,2-diphenyl-1-picryl-hydrazyl) method according to Brand-Williams et al. [31] with some modifications. Different dilutions of the extract were prepared in triplicate. For the analysis 3.9 mL of a DPPH-radical solution, prepared using 2 mg dissolved in 100 mL 80% (v/v) methanol, were vortex-mixed for 30 s with 0.1 mL of the seaweed extract prepared at different concentrations and the reaction mixture was left to stand for 20 min in the dark at room temperature. The absorbance was measured at 517 nm (Spectronic® 20 Genesys TM, Illinois, USA) and compared to a methanol blank. Calibration was performed within a linear range between 0.1 and 1.0 mM Trolox (6-hydroxy-2,5,7,8- tetramethylchroman-2-carboxylic acid). Results were expressed as µmoles Trolox equivalent (TE)/100 g dm.

The ORAC assay was performed according to Zulueta et al. [32]. Briefly, AAPH (2,2'-azobis(2-amidinopropane) dihydrochloride) was dissolved in 10 mL 75 mM phosphate buffer (pH 7.4) to a final concentration of 153 mM. A fluorescein stock solution (4 µM) was made in 75 mM phosphate buffer (pH 4.0) and stored; the stock solution was diluted 1:1000 with phosphate buffer. 150 µL of working sodium fluorescein solution were added. In addition, blank wells standards received 25 µL of 75 mM phosphate buffer (pH 7.4), while standards received 25 µL of Trolox dilution and

samples received 25 μ L of seaweed's extracts (diluted 1:100). A fluorescence spectrophotometer was used at 485 nm excitation and 535 nm emission. Reaction was initiated by the addition of 25 μ L of AAPH reagent. The ORAC values were calculated using the regression equation between Trolox concentration and the net area under curve and expressed as Trolox Equivalent Antioxidant Capacity (TEAC) in μ moles TE/100 g dm.

2.5 Determination of vitamins and pigments

Vitamin C was determined as ascorbic acid using the NBS (N-Bromosuccinimide) method described by Vega-Gálvez et al. [33] with some modifications. Briefly, 2 g of powdered sample was mixed in a Falcon tube with 50 mL distilled water and 0.2 g of oxalic acid by agitation on an orbital shaker (Boeco, OS-20, Germany) at 200 rpm for 4 min. The mixture was then centrifuged for 5 min at 2870 $\times$ g to obtain the supernatant, to which 30 mL petrol-ether were added and left in the dark for 30 min until phase separation. Then 5 mL of aqueous phase were removed, mixed with 5 mL 4% KI solution, 2 mL 10% acetic acid, 0.2 g oxalic acid dissolved in 30 mL distilled water and 3 drops of starch solution, and the mixture was titrated against NBS solution. All analyses were performed in triplicate and expressed in g/100 g dm.

Vitamin E was determined as α -tocopherol in the lipid extracts of the brown seaweeds [7]. The powdered seaweeds (25 g) was first mixed with hexane in a ratio of 1 to 3, using an orbital shaker (OS-100, HiLab, Indonesia) at 280 rpm for 60 min and afterwards left to macerate for 24 h. The mixture was then centrifuged for 5 min at 2870 $\times$ g and the supernatant was filtered (Whatman filter paper N° 1) and concentrated on a rotary vacuum evaporator (Büchi RE 121, Switzerland). HPLC analysis was performed with a fluorescence detector (Merck-Hitachi F-1050), chromatographic

column LiChroCART® 250-4 LiChrospher® Si 60 (5 µm) (Merck, Darmstadt, Germany) following a standard AOCS method (AOCS-Ce8-89/1993). The mobile phase consisted of propan-2-ol in hexane (0,5:99,5 v/v) at a flow rate of 1 mL/min. Peaks were detected at excitation and emission wavelengths of 290 and 330 nm respectively. Contents of vitamin E was expressed in mg/100 g dm.

The content of chlorophylls was determined using a mass of 0.2 g of powdered sample that was extracted for 12 h at 4 °C with 25 mL 90% acetone. The mixture was then centrifuged at 2870×g for 5 min and the absorbance of the supernatant was measured using 1-cm cell path-length at 630 and 664 nm with a spectrophotometer (Spectronic® 20 Genesys TM, Illinois, USA). The spectrophotometric equations of Jeffrey and Humphrey [34] were used to calculate in µg/g dm the contents of chlorophyll a (*CHLa*) and chlorophyll c₁+c₂ (*CHLc₁+c₂*) respectively. In Equations 1 and 2 the symbol E_x denotes the measured extinction at wavelength x.

$$\text{Chlorophyll a:} \quad CHLa = 11.47 E_{664} - 0.40 E_{630} \quad (1)$$

$$\text{Chlorophyll c}_1+\text{c}_2: \quad CHLc_1+c_2 = 24.36 E_{630} - 3.73 E_{664} \quad (2)$$

Total carotenoids were determined following a method described by Chan and Matanjun [35] with some modifications. The powdered seaweed sample (3.0 g) was extracted at room temperature for 1 h with 75 mL of hexane/acetone/ethanol (2:1:1 v/v). The mixture was filtered, and filtrate made up to 100 mL with extraction solvent. 25 mL distilled water were then added and after agitation the mixture was left to separate in an organic and an aqueous layer for 30 min in the dark. The absorbance A of the organic layer was measured at 470 nm, and total carotenoids content (*TCC*) was calculated using Equation 3, with $A^{1\%} = \{2600 \cdot (\beta\text{-carotene extinction coefficient in hexane})\}$, V

total volume of extract (mL) and w sample weight (g). Results were expressed in $\mu\text{g/g}$ dm.

$$\text{Total carotenoids: } TCC = (A / V 104) / (A^{1\%} w) \quad (3)$$

2.6 Determination of amino acids and fatty acids profiles

A HPLC system (Agilent 1200 series, Santa Clara, CA, USA) equipped with a UV detector and post-column in hydrin derivatization was used to determine amino acids profile. Before injection in the HPLC system, samples were first hydrolyzed under nitrogen in 6M HCl buffered to pH 2.2 for 22 h. As quantitative internal standard norleucine was used [36]. Altogether 17 amino acids were analyzed: alanine, arginine, aspartic acid, cystine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, proline, phenylalanine, serine, threonine, tyrosine, and valine.

Fatty acids profile was obtained through conversion of lipids into fatty acid methyl esters (FAME) by employing acetyl chloride and gas chromatographic analysis, according to the method described by Aubourg et al. [37]. A Perkin-Elmer chromatograph (model 8700) employing a fused silica capillary column SP-2330 (0.25 mm i.d. 630 m; Supelco, Bellefonte, PA, USA) was used. Nitrogen at 10 psi as carrier gas and a flame ionization detector (FID) at 250 °C were used. Peaks corresponding to fatty acids were identified by comparing retention times related to standard mixtures (Qualmix Fish, Larodan, Malmo, Sweden; FAME Mix, Supelco). Peak areas were automatically integrated, with 19:0 fatty acid being used as internal standard for quantitative analysis.

2.7 Inhibition assays of α -glucosidase

The antidiabetic potential of *D. antarctica* was evaluated through the inhibition assays

of α -glucosidase. The powdered seaweed sample (5.0 g) was homogenized at room temperature in 15 mL of 69% aqueous acetone using an orbital shaker (Boeco, OS 20, Germany) at 200 rpm for 30 min, then centrifuged at 4000 $\times$ g for 5 min in a Hettich® centrifuge (Universal 320R, Germany); the supernatant was removed, and extraction procedure repeated thrice. The combined supernatants were evaporated at 37 °C using a rotary evaporator (Büchi RE 121, Switzerland) and the dried residue was resuspended in 5 mL methanol-formic acid (99:1) for use as extract in the analysis of enzymatic activity of α -glucosidase that was determined as described by Unnikrishnan et al. [38] with some modifications. A total of 50 μ L diluted extract at varying concentrations (0-0.5 mg/mL) and 100 μ L α -glucosidase from *Saccharomyces cerevisiae* (Sigma G5003, USA) solution (0.5 U/mL) were added in 0.1 M phosphate buffer (pH 6.9) and incubated in 96-well plates at 25 °C for 10 min. After preincubation, 50 μ L of 4-nitrophenyl α -D-glucopyranoside (Sigma N1377, Switzerland) in 0.1 M phosphate buffer (pH 6.9) were added. The absorbance readings were recorded at 405 nm using a Victor TM χ 3 Multilabel Plate Reader and compared to control (50 μ L buffer solution) that corresponds to highest enzymatic activity. The measurement was read every 30 s during 10 min. The experiments were performed in triplicates for all samples of different concentrations. The α -glucosidase activity was calculated as a percentage obtained from the slope of each exponential curve.

2.8 Statistical analysis

Analysis of variance (ANOVA) was performed to determine significant differences among treatments using the software Statgraphics Centurion XVI (Statistical Graphics Corp., Herndon, USA). Means were compared by least significant difference (LSD) test at $p < 0.05$. Furthermore, the multiple range test (MRT) was used to demonstrate the

existence of homogeneous groups within each of the parameters. Data were average values from three treatment replicates and reported as mean $\pm$ standard deviation.

3. Results and discussion

3.1 Drying behavior and effects on composition

The variation of moisture ratio (MR , dimensionless), calculated as the ratio of moisture content at any instant to the initial moisture content, can be seen in Figure 1. The fastest drying rate occurred during CD, which further declined in the following order: IRD, VD and SD. The drying time to achieve equilibrium moisture tended to be similar for CD and IRD, being respectively 225 and 250 min, while VD showed a slightly higher drying rate than SD, with equilibrium moisture achieved after 450 min in VD and after 480 min in SD. The longer drying time for SD was probably due to the fluctuating sunlight and/or ambient temperature with a predominating laminar air flow over the product during the whole drying period [39]. This contrasted with CD that had a continuous hot air circulation inside the oven contributing to a faster removal of moisture. In all cases a classical drying curve was obtained, with an initially rapid drying rate period followed by a slow falling rate period at MR below 0.2, which usually occurs under similar conditions as reported for other CD processes [25, 40]. However, during IRD the slow falling rate period occurred at MR below 0.1 and was much shorter than in the other 3 drying methods.

As expected, different drying rate patterns with different final moisture contents (Table 1) were observed in the four drying methods and the differences may be assigned to dryer designs, heat input mechanisms or operating pressure and temperature conditions, among others. In all drying processes, the achieved equilibrium moisture content X was dependent on the prevailing outlet relative humidity of the drying air, and

X could be correlated to the corresponding water activity a_w (Table 1) by the power law equation ($X = 19.607 a_w^{0.884}$) with a coefficient of determination of 0.9405.

In Table 1 the proximate composition together with contents of dietary fibers and minerals as affected by the different drying methods can be seen. Although in all dryer types the operating conditions are all different, the composition of the dried seaweeds showed scarce variations. Ash content, an important constituent of the brown seaweed *D. antarctica*, was unaffected by the drying techniques ($p < 0.05$). However, contents of lipids, IDF, SDF and microelements showed noticeable variations, with lipid as the component showing greatest differences. It is interesting to note that the highest lipid retention was observed in SD samples, followed by CD, VD, IRD and FD. The SD samples retained a content of lipids almost equivalent to that of fresh seaweeds, reported in literature to be around 4% based on dry matter [41]. The occurrence of this difference in lipids content after drying may be associated to the heat input mechanism of the different drying techniques and to the presumable occurrence of membrane lipids at the surface of the seaweeds, as lipids are known to provide insulation from the environment [42]. SD, CD as well as VD were all related to higher exposure of the samples to superficial heat that would favor initial fusion of the lipids that diffused inside the seaweed. On the contrary, during FD or IRD and to some extent also during VD, pressure and/or thermal driving forces were initially present, which did not favor internal diffusion. In IRD due to heat penetration by radiation, water vapor diffused from the interior to the external surface; in FD a similar water vapor diffusion occurred as a result of sublimation. In the case of VD, a balanced diffusion in both direct directions took place; a diffusion from inside to outside due to a pressure difference caused by the reduced outer pressure and a simultaneous temperature rise at the surface

that favored lipid fusion and caused a lipid diffusion towards the interior. This observation may be supported by the fact that VD samples had a median lipid content.

The content of dietary fiber in fresh brown seaweed *D. antarctica* has been reported to be around 57.1 ± 0.7 g/100 g dm with predominance of IDF at a level of 76% of TDF [7], which corresponded to a high level of dietary fiber, characteristic for seaweeds [43]. Highest level of TDF was observed in FD and CD samples (Table 1), which was within the level between 29.3 and 62.3 g/100 g dm reported for marine algae [44]. Compared to these samples, SD caused the greatest loss especially in SDF. In IRD samples a noticeable loss ($p < 0.05$) in IDF was observed, which could be due to the intense heat irradiated inside the seaweeds [45-47] causing disintegration and favoring a relative increase in the SDF fraction (Table 1).

As can be seen in Table 1, the contents of macroelements (Na, K, Mg and Ca) in the seaweed samples hardly varied during any of the drying processes. On the other hand, a noticeable difference ($p < 0.05$) was observed between the contents of microelements (Cu, Fe, Mn and Zn) in FD samples and seaweed samples of the other 4 drying processes. This showed a better retention of microelements during FD (Table 1). In VD, SD, CD and IRD samples loss of manganese was not significant ($p < 0.05$). However, iron content was most affected by SD and CD maintaining respectively values of only 67% and 74% of the corresponding content in FD samples. In the case of copper and zinc contents more drastic changes were observed, with greatest loss of copper occurring especially during IRD, and that of zinc during CD. This observation is probably due to damage that occurred during IRD and CD methods to the bound sites of these two metal ions within the structural polysaccharides of the brown seaweed and these minerals were carried away with produced fine particles of these drying processes.

3.2 Changes in color parameters

The chromatic coordinates and surface color of the fresh and the differently dried seaweed *D. antarctica* are shown in Table 2. The *L*-value that is an indicator of brightness of the samples was higher in all dried products. The *L*-value of the FD samples almost doubled that of the fresh sample, while in the other samples it was at least 50% higher, which is typical for the plane glossy surface that the dried seaweed *D. antarctica* acquired [7]. The *a*-value that represents in the CIE Lab system the redness-greenness axis, with increasing positive or negative values indicating increase in the red or green directions respectively, showed a tendency of the seaweed to lose the reddish color during drying, departing from an *a*-value of 7.78 ± 0.03 for the fresh sample to 2.07 ± 0.06 for the FD samples. The *b*-value that represents in the same CIE color space the yellowness-blueness axis (yellow [positive] and blue [negative]), showed an increase in the yellow direction to a value of 14.53 ± 0.36 for the FD samples. The loss of the red component and gain of the yellow component conferred to the FD samples a paler appearance, which was also reflected in the highest *L*-value and highest color difference ΔE with respect to the fresh sample (Table 2). The ΔC -value, related to chroma [29] of the samples, showed a tendency to saturation of the yellow tone. A higher hue value for the dried samples also showed greater color difference compared to the fresh sample, resulting in a pale tone, as the combination of green and yellow conferred to the seaweed a lighter brownish tone. ΔE , which is the colorimetric difference between the sample and the white standard reflectance plate [29], increased during all drying processes, and was congruent with a chroma saturation. The least difference in color occurred in IRD samples that also retained more of the red component with a darker brown tone. It is generally accepted that color changes are basically a direct consequence of pigment destruction [25, 48, 49]. However, in the case

of IRD although high thermal load may cause degradation of pigments, the effect is mainly concentrated in the interior and surface color did not changed significantly.

3.3 Bioactive components, antioxidant activity and antidiabetic potential

The analysis of the brown seaweed samples showed that the drying processes had a significant effect ($p < 0.05$) on TPC and TFC (Table 3). The low level of phenolic compounds as determined in the samples may be due to environmental conditions, such as temperature, salinity, light intensity that affect growth and reproduction of the marine algae and consequently its composition and nutritional quality [50]. According to Flodin et al. [51] phenol content of seaweed may also vary depending on sunlight and climate, such that analogous seaweeds species may contain different levels of phenolic compounds. Nonetheless, TPC and TFC showed a general decrease during all drying processes. In the VD and IRD samples TPC and TFC were not significantly different ($p < 0.05$) but a higher loss was observed compared to the other 3 drying methods. A total loss of 47% of TPC has been reported for *D. antarctica* [7] dried by CD at 60 °C and a loss of almost of the same order was observed during CD, SD and FD. The loss of natural antioxidants may probably be due to the relative instability of most of these compounds during heating [52] or to a presumable alteration in the chemical structure or binding of the polyphenols with proteins [24]. On the other hand, the loss of TPC and TFC in the freeze-dried samples was not expected, although it has been reported for freeze-dried fruits [53]. Loss of TPC of 24.1% for starfruits, 23.2% for mango, 39.7% for papaya, 10.4% for muskmelon and 48.2% for watermelon has been reported to happen during freeze-drying at -50 °C for 3 days [54]. A presumable explanation would be the disruption of cell wall by ice crystals during freezing and liberation of enzymes, substrates and activators, and increased enzymes activity might cause degradation of

phenolics [54, 55].

Vitamin E and vitamin C are both groups of compounds; however, α -tocopherol and ascorbic acid were determined as indicators of these vitamins. Degradation of the vitamins occurring during the drying processes was significantly different (Table 3). The content of α -tocopherol in the lipid fraction was highest in CD and IRD samples but a large standard deviation was observed. In comparison, in VD samples a lower average content of α -tocopherol was determined but it was statistically not significantly different ($p < 0.05$) to either CD or IRD samples. The contents of α -tocopherol in FD and SD samples were not significantly different, but standard deviation was higher for the SD samples. The relatively high content of α -tocopherol could be due to a shielding effect of the lipid fraction against thermal destruction [7]. On the other hand, the lower content of α -tocopherol in FD samples could be a result of uneven lipid distribution in the samples and consequently to uneven exposure to operational factors responsible for degradation, which is reflected in the large standard deviation determined for the drying method. With respect to ascorbic acid, its destruction was expected to occur during IRD due to the high thermal load that accumulated within the sample (Table 3). The significant differences found between CD and VD samples, could be a consequence of the porous nature of the dried brown seaweed that would explain uneven heat diffusion, hence inherent fluctuations during measurement should be expected.

Chlorophyll a, chlorophyll c1+c2 and total carotenoids were analyzed as pigments of the brown seaweed. The lowest contents of both chlorophyll types and total carotenoids were found in the IRD samples, while FD samples had highest content of all 3 pigments (Table 3). The contents of chlorophyll c1+c2 and total carotenoids in VD samples were found to be as low as that of IRD samples without any significant difference ($p < 0.05$). A probable cause could be inhomogeneity in pigment distribution

within the sample and overexposure to thermal destruction. Likewise, variation in values of antioxidant activity, as determined through DPPH and ORAC assays also showed a non-expected pattern (Table 3). CD and/or SD samples showed no significant differences between each other or to FD samples. In the FD samples the presence of phenolic compounds may be responsible for the antioxidant activity, while in the SD or CD samples apart from non-destruction of phenolic compounds due to uneven heat diffusion, formation and accumulation of melanoidins as well as Maillard reaction products with assigned antioxidant activity may have been favored [56]. ORAC values of VD and IRD samples were lowest and not significantly ($p < 0.05$) different from one another. While in IRD samples intense heat transfer would have destroyed antioxidant compounds, in the VD samples an overexposure during a relatively long drying time may be the cause for the observed decrease.

Antidiabetic potential of the differently dried brown seaweed samples was also evaluated through inhibition assays of α -glucosidase, a known carbohydrate-hydrolyzing enzyme in the digestive tract. Inhibition of the enzyme could be effective for regulation of Type II diabetes, by controlling glucose absorption. The inhibition of α -glucosidase activity would slow down the breakdown of disaccharide to simple glucose and would subsequently reduce the postprandial plasma glucose rise [8, 57, 58]. In Fig. 2 the determined activity of α -glucosidase as a function of concentration of the sample used for the inhibition assays can be seen. All samples showed a dose-dependent enzymatic activity of α -glucosidase in the concentration range between 0 and 0.6 g/mL, with IRD samples retaining an enzymatic activity of approximately 35% at a sample concentration of 0.5 g/mL, while VD samples showed at 0.2 g/mL an activity of approximately 27%. In the case of FD, CD and SD samples, the enzymatic activity was totally suppressed at a concentration of about 0.1 g/mL. The inhibition of α -glucosidase

activity may be related to phenolic constituents which may be exhibiting either an additive or a synergistic effect with nonphenolic constituents [58]. These experimental results indicate the antidiabetic potential of dried *D. antarctica*, which could be an asset in dietary management of diabetes but further investigations at molecular level to identify the potential enzyme inhibitor compounds should be conducted [57].

3.4 Amino acids and fatty acids

The individual amino acids (AAs) determined in the dried samples of the brown seaweed *D. antarctica* from different methods can be seen in Table 4. AAs are important for their multiple regulatory functions in cells, apart from being building blocks for proteins and crucial nutrients for growth, development, and health of animals and humans [59]. In the dried brown seaweed *D. antarctica* five traditionally known as essential AAs (leucine, isoleucine, phenylalanine, threonine and valine) have been determined. The functional AAs, arginine, leucine and proline, known to regulate key metabolic pathways, necessary for maintenance, growth, reproduction and immunity [59], were also found. The results in Table 4 shows significant differences ($p < 0.05$) between individual AAs contents from the different drying methods. Histidine was found to predominate in the analyzed samples, while other five AAs were not found, which differed from the amino acid profile reported for the same brown seaweed *D. antarctica* from other location [7, 60, 61]. In this study 7 lowest values for AAs content were obtained in VD samples, while in FD, SD and IRD samples 8 highest values for the AAs content were found. This variation resulted from the different drying methods with different thermal treatments that have been reported to presumably improve, reduce or maintain essential AAs content depending on drying conditions or the amino acid itself [62]. While during VD thermal destruction occurred due to long exposure

time at high temperature, during SD for similar drying time at lower temperature (< 50 °C) AAs were not destroyed, which was congruent with occurrence during CD and even IRD where similar temperature conditions prevailed but for shorter drying time, as can be seen in Fig. 1. An increase in AAs content might also occur due to possible progress of proteolysis during the drying process [63]. Nonetheless *D. antarctica* still remains a valuable source of AAs after drying by any of the assessed methods.

In Table 5 the profiles of fatty acids determined in the dried brown seaweed *D. antarctica* can be seen. Regardless of the drying methods employed, seaweed lipids only contained < 20% of monounsaturated fatty acids (MUFA), mostly oleic acid (C18:1 ω 9). The major saturated fatty acid (SFA) was palmitic acid (C16:0), while arachidonic (C20:4 ω 6), eicosapentaenoic (C20:5 ω 3) and alpha-linolenic acid (C18:3 ω 3) represented the predominant polyunsaturated fatty acids (PUFA). Some fatty acids such as margaric (C17:0), arachidic (C20:0), gamma-linolenic (C18:3 ω 6), docosanoic (C22:0) and dihomogamma-linolenic (C20:3 ω 6) acids that could be expected in brown seaweed were not detected in the samples being below the level of 0.01 g/100 g of sample. A similar pattern has been previously reported [64-67] for different brown seaweed species such as *Colpomenia sinuosa*, *Dictyota dichotoma*, *Padina pavonica*, *Cystoseira tamariscifolia*, *Pelvetia canaliculata*, *Fucus serratus*, *Fucus vesiculosus*, *Ascophyllum nodosum*, *Himanthalia elongata*, *Laminaria digitata*, *Saccharina latissima*, *Nizamuddinina zanardinii*, *Cystoseira indica*, *Sargassum horneri*, *Sargassum siliquastrum*, *Cystoseira Hakodatensis*, *Ecklonia kurome*, *Sargassum crassifolium*, *Padina australis* and *Turbinaria ornate*.

Levels of PUFA ranged from 41.63 to 46.18 g/100 g of sample, with the highest level in SD-seaweed. These results are consistent with those reported by Uribe et al., [26] who showed that SD maintained the highest PUFA content in *Pyropia orbicularis*

compared to other methods. They also reported that the presence of compounds with antioxidant activity reduced the level of lipid oxidation. Therefore, it is probable that the high antioxidant activity found in the SD-sample may have acted as a shield against oxidation of the PUFA (Table 3). SFA content was also highest in the SD samples, although not significantly different ($p < 0.05$) to the other samples, except for CD samples that had the lowest value. On the other hand, MUFA content was lowest compared to the other dried samples. Apparently, the fluctuating low temperature associated with SD and longer drying time led to significant degradation of oleic acid, the main MUFA in *D. antarctica*. The ratio of $\omega 3$ to $\omega 6$ fatty acids is an important determinant for health aspects [68] and it is recommended that an appropriate intake should be at a ratio of dietary $\omega 3$ to $\omega 6$ fatty acids of about 1/1 to 1/2 [68]. In all dried samples this ratio was not significantly affected, so that any of the drying methods could be used when considering this quality aspect.

4. Conclusion

All analyzed samples of *D. antarctica* from the different drying methods could be considered to retain a high nutritional value, with bioactive compounds having relatively high antioxidant activity, so that the selection of a drying method would rather rely on available resources and pertinence of investment. CD provided the fastest drying rate, but the lowest water content and water activity would be achieved through FD. The least ΔE value would occur during IRD, with retention of the red component. Lipid content could be best retained during SD, while FD and IRD would produce dried samples with lowest lipid content, however, in all assessed drying methods the relationship between $\omega 3$ to $\omega 6$ fatty acids would remain below 1. Soluble dietary fiber would be most affected during SD, while insoluble dietary fiber would be least affected

during FD and CD. While macroelements (Na, K, Mg and Ca) would not significantly be affected by any of the assessed drying methods, FD would best retain the microelements Cu, Fe Mn and Zn. VD and IRD would cause highest reduction in TPC and TFC. Greatest loss of vitamin E would occur during SD, while IRD would cause highest reduction of vitamin C. The pigments chlorophyll c1+c2 and total carotenoids would be most affected during VD and IRD. Highest reduction in antioxidant activity would also occur during VD and IRD. Long exposure time at 60 °C as it occurred during VD would lead to highest reduction of the content of amino acids, while lowest reduction would occur during SD for similar drying time at temperature below 50 °C. All dried samples of *D. antarctica* showed antidiabetic potential, although FD, CD and SD samples showed inhibitory effect on α -glucosidase at a lower concentration than VD and IRD samples.

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Authors declare no conflict of interest.

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Table and figure captions

Table 1. Nutritional characteristics of *D. antarctica* after different drying treatments.

Table 2. Color parameters of *D. antarctica* after different drying treatments.

741 Table 3. Bioactive components and antioxidant activity of *D. antarctica* after different
742 drying treatments.

743 Table 4. Amino acids in brown seaweed *D. antarctica* after different drying treatments.

744 Table 5. Fatty acid composition of *D. antarctica* after different drying treatments.

745 Figure 1. Drying behavior of *D. antarctica* during different drying processes.

746 Figure 2. Effect of drying methods on α -glucosidase activity of *D. antarctica*.

Figure 1

Figure 2

Table 1. Effect of different drying methods on nutritional composition of *Durvillaea antarctica*. FD: freeze drying; VD: vacuum drying; SD: solar drying; CD: convective drying; IRD: infrared drying. Values are expressed as mean $\pm$ standard deviation.

Parameters	Drying method				
	FD	VD	SD	CD	IRD
Proximate (g 100 g⁻¹ DM)					
¹ Moisture	7.35 $\pm$ 0.08 ^d	11.05 $\pm$ 0.10 ^b	8.58 $\pm$ 0.13 ^c	8.25 $\pm$ 0.17 ^c	11.85 $\pm$ 0.32 ^a
Fat	1.37 $\pm$ 0.25 ^c	2.20 $\pm$ 0.11 ^{bc}	3.85 $\pm$ 0.51 ^a	2.68 $\pm$ 0.71 ^b	1.57 $\pm$ 0.01 ^c
Ash	26.07 $\pm$ 0.99 ^a	25.35 $\pm$ 0.74 ^a	25.27 $\pm$ 0.13 ^a	24.75 $\pm$ 1.51 ^a	26.37 $\pm$ 0.62 ^a
² Crude protein	7.22 $\pm$ 0.84 ^a	7.29 $\pm$ 1.02 ^a	6.65 $\pm$ 0.07 ^a	7.48 $\pm$ 0.31 ^a	6.46 $\pm$ 0.17 ^a
Crude fiber	3.11 $\pm$ 0.04 ^b	3.65 $\pm$ 0.05 ^{ab}	2.98 $\pm$ 0.27 ^b	2.45 $\pm$ 0.05 ^b	4.22 $\pm$ 0.38 ^a
Insoluble dietary fiber	50.51 $\pm$ 2.97 ^{ab}	46.04 $\pm$ 0.75 ^c	47.73 $\pm$ 0.89 ^{bc}	51.56 $\pm$ 0.57 ^a	41.78 $\pm$ 0.00 ^d
Soluble dietary fiber	10.14 $\pm$ 0.69 ^c	12.35 $\pm$ 0.46 ^b	7.40 $\pm$ 0.51 ^d	9.90 $\pm$ 0.28 ^c	16.26 $\pm$ 0.75 ^a
Total dietary fiber	60.65 $\pm$ 3.66 ^a	58.40 $\pm$ 0.29 ^{ab}	55.13 $\pm$ 0.38 ^b	61.46 $\pm$ 0.85 ^a	58.05 $\pm$ 0.75 ^{ab}
³ Water activity, a _w	0.319 $\pm$ 0.023 ^d	0.546 $\pm$ 0.005 ^a	0.395 $\pm$ 0.006 ^c	0.399 $\pm$ 0.009 ^c	0.524 $\pm$ 0.005 ^b
Macroelements (g 100 g⁻¹ DM)					
Sodium, Na	0.51 $\pm$ 0.09 ^b	0.50 $\pm$ 0.05 ^b	0.62 $\pm$ 0.04 ^a	0.57 $\pm$ 0.02 ^{ab}	0.57 $\pm$ 0.04 ^{ab}
Potassium, K	0.16 $\pm$ 0.02 ^a	0.18 $\pm$ 0.01 ^a	0.18 $\pm$ 0.01 ^a	0.16 $\pm$ 0.02 ^a	0.17 $\pm$ 0.02 ^a
Magnesium, Mg	0.09 $\pm$ 0.01 ^a	0.09 $\pm$ 0.01 ^a	0.09 $\pm$ 0.01 ^a	0.09 $\pm$ 0.00 ^a	0.09 $\pm$ 0.00 ^a
Calcium, Ca	0.19 $\pm$ 0.01 ^a	0.13 $\pm$ 0.02 ^{bc}	0.12 $\pm$ 0.01 ^c	0.14 $\pm$ 0.01 ^b	0.14 $\pm$ 0.01 ^b
Microelements (mg Kg⁻¹ DM)					
Copper, Cu	7.42 $\pm$ 0.95 ^a	2.67 $\pm$ 0.91 ^b	2.14 $\pm$ 0.27 ^{bc}	1.44 $\pm$ 0.22 ^c	1.17 $\pm$ 0.15 ^c
Iron, Fe	27.95 $\pm$ 0.35 ^a	24.65 $\pm$ 2.05 ^{ab}	18.7 $\pm$ 3.30 ^c	20.8 $\pm$ 2.40 ^{bc}	23.15 $\pm$ 3.45 ^{bc}
Manganese, Mn	5.49 $\pm$ 0.70 ^a	5.10 $\pm$ 0.48 ^a	5.03 $\pm$ 0.55 ^a	4.87 $\pm$ 0.61 ^a	4.94 $\pm$ 0.58 ^a
Zinc, Zn	108.0 $\pm$ 4.00 ^a	42.5 $\pm$ 1.48 ^c	50.7 $\pm$ 4.42 ^b	28.7 $\pm$ 1.40 ^d	48.4 $\pm$ 2.60 ^{bc}

Different letters in the same row indicate significant differences ($p < 0.05$) according to multiple range test (MRT). Standard deviation was calculated on three replicates.

¹Expressed as g 100 g⁻¹ sample.

²Nitrogen $\times$ 5 (Angell et al., 2016).

³Dimensionless.

Table 2. Effect of different drying methods on color parameters of *Durvillaea Antarctica*. FD: freeze drying; VD: vacuum drying; SD: solar drying; CD: convective drying; IRD: infrared drying. Values are expressed as mean $\pm$ standard deviation

Color Parameter	Drying method					
	Fresh	FD	VD	SD	CD	IRD
L^*	22.68 ± 0.12^f	44.11 ± 0.27^a	33.83 ± 1.67^d	36.10 ± 1.42^b	34.97 ± 0.52^c	32.29 ± 0.26^c
a^*	7.78 ± 0.05^a	2.07 ± 0.06^c	4.96 ± 0.21^b	3.06 ± 0.18^d	3.43 ± 0.11^c	5.05 ± 0.16^b
b^*	8.74 ± 0.30^c	14.53 ± 0.36^a	9.67 ± 0.70^b	7.27 ± 0.47^e	9.75 ± 0.14^b	7.63 ± 0.44^d
ΔE	-	22.92 ± 0.35^a	11.56 ± 1.62^d	14.32 ± 1.40^b	13.08 ± 0.50^c	10.07 ± 0.37^e
h^*	0.84 ± 0.02^f	1.43 ± 0.00^a	1.09 ± 0.04^d	1.17 ± 0.03^c	1.23 ± 0.01^b	0.99 ± 0.02^e
C^*	11.71 ± 0.22^b	14.68 ± 0.36^a	10.88 ± 0.58^c	7.89 ± 0.46^f	10.34 ± 0.11^d	9.15 ± 0.43^e

Different letters in the same row indicate significant differences ($p < 0.05$) according to multiple range test (MRT). Standard deviation was calculated on five replicates

Table 3. Effect of different drying methods on antioxidant potential of *Durvillaea antarctica*. FD: freeze drying; VD: vacuum drying; SD: solar drying; CD: convective drying; IRD: infrared drying. Values are expressed as mean $\pm$ standard deviation

Parameters	Drying method				
	FD	VD	SD	CD	IRD
Phytochemicals					
TPC (mg GAE 100 g ⁻¹ DM)	315.2 $\pm$ 28.39 ^a	139.8 $\pm$ 12.60 ^b	319.8 $\pm$ 18.85 ^a	336.0 $\pm$ 30.71 ^a	159.5 $\pm$ 16.38 ^b
TFC (mg CE 100 g ⁻¹ DM)	27.26 $\pm$ 2.54 ^b	17.82 $\pm$ 1.40 ^c	29.73 $\pm$ 2.92 ^b	33.46 $\pm$ 3.15 ^a	19.44 $\pm$ 1.14 ^c
Vitamins					
α tocopherol (mg 100 g ⁻¹ lipids)	607.3 $\pm$ 47.1 ^b	818.2 $\pm$ 2.2 ^{ab}	428.5 $\pm$ 147.2 ^b	1698.4 $\pm$ 468.5 ^a	1692,6 $\pm$ 622.3 ^a
Vitamin C (mg 100 g ⁻¹ DM)	528.5 $\pm$ 36.7 ^a	296.4 $\pm$ 16.1 ^c	417.3 $\pm$ 36.1 ^b	586.9 $\pm$ 24.5 ^a	181.0 $\pm$ 11.7 ^d
Pigments					
Chlorophyll <i>a</i> (μ g g ⁻¹ DM)	701.2 $\pm$ 10.4 ^a	499.7 $\pm$ 15.6 ^b	489.4 $\pm$ 13.4 ^b	527.4 $\pm$ 54.7 ^b	376.8 $\pm$ 7.73 ^c
Chlorophyll <i>c</i> 1+ <i>c</i> 2 (μ g g ⁻¹ DM)	46.7 $\pm$ 2.72 ^a	7.67 $\pm$ 0.67 ^c	26.35 $\pm$ 1.94 ^b	26.89 $\pm$ 2.56 ^b	9.32 $\pm$ 0.14 ^c
Total carotenoids (μ g g ⁻¹ DM)	36.91 $\pm$ 2.18 ^a	8.03 $\pm$ 0.64 ^c	15.13 $\pm$ 0.89 ^b	16.19 $\pm$ 0.62 ^b	6.55 $\pm$ 0.31 ^c
Antioxidant capacity					
DPPH (μ mol TE 100 g ⁻¹ DM)	352.4 $\pm$ 27.8 ^b	376.9 $\pm$ 23.3 ^b	450.5 $\pm$ 38.7 ^a	455.8 $\pm$ 24.6 ^a	362.3 $\pm$ 22.0 ^b
ORAC (μ mol TE 100 g ⁻¹ DM)	3194 $\pm$ 34.1 ^a	1248 $\pm$ 91.4 ^c	3041 $\pm$ 86.1 ^a	2729 $\pm$ 184.0 ^b	1118 $\pm$ 151.5 ^c

Different letters in the same row indicate significant differences ($p < 0.05$) according to multiple range test (MRT). Standard deviation was calculated on three replicates

Total phenolic content (TPC); Total flavonoid content (TFC); 2,2-diphenyl-1-picrylhydrazyl (DPPH); Radical Absorbance Capacity (ORAC). Gallic acid equivalents (GAE); Catechin equivalents (CE); Trolox equivalents (TE).

Table 4. Effect of drying methods on amino acid profile of *Durvillaea Antarctica*. FD: freeze drying; VD: vacuum drying; SD: solar drying; CD: convective drying; IRD: infrared drying. Values are expressed as mean $\pm$ standard deviation.

Amino acids (g 100 g ⁻¹ protein)	Drying method				
	FD	VD	SD	CD	IRD
Aspartic acid	6.54 $\pm$ 0.29 ^b	4.95 $\pm$ 0.32 ^c	5.85 $\pm$ 0.30 ^{bc}	5.96 $\pm$ 0.55 ^b	9.53 $\pm$ 0.82 ^a
Glutamic acid	ND	ND	ND	ND	ND
Serine	1.88 $\pm$ 0.25 ^b	1.22 $\pm$ 0.14 ^c	2.30 $\pm$ 0.11 ^a	1.80 $\pm$ 0.11 ^b	2.12 $\pm$ 0.30 ^{ab}
Glycine	4.06 $\pm$ 0.48 ^c	4.16 $\pm$ 0.40 ^c	8.99 $\pm$ 0.16 ^a	5.06 $\pm$ 0.46 ^b	8.84 $\pm$ 0.11 ^a
Histidine	51.25 $\pm$ 1.74 ^b	41.86 $\pm$ 0.90 ^c	55.50 $\pm$ 3.25 ^{ab}	55.07 $\pm$ 3.91 ^{ab}	62.21 $\pm$ 7.60 ^a
Arginine	6.69 $\pm$ 0.14 ^a	3.88 $\pm$ 0.37 ^c	4.37 $\pm$ 0.49 ^c	5.78 $\pm$ 0.20 ^b	4.31 $\pm$ 0.36 ^c
Threonine	5.07 $\pm$ 0.11 ^a	2.94 $\pm$ 0.28 ^c	3.10 $\pm$ 0.02 ^c	4.38 $\pm$ 0.15 ^b	3.26 $\pm$ 0.27 ^c
Alanine	2.31 $\pm$ 0.23 ^a	1.65 $\pm$ 0.04 ^b	2.40 $\pm$ 0.24 ^a	2.31 $\pm$ 0.11 ^a	ND
Proline	5.23 $\pm$ 0.04 ^b	3.15 $\pm$ 0.35 ^d	4.95 $\pm$ 0.25 ^{bc}	4.55 $\pm$ 0.40 ^c	6.87 $\pm$ 0.53 ^a
Tyrosine	6.22 $\pm$ 0.58 ^a	4.19 $\pm$ 0.38 ^b	5.25 $\pm$ 0.22 ^{ab}	5.46 $\pm$ 0.45 ^a	5.98 $\pm$ 0.99 ^a
Valine	12.86 $\pm$ 0.57 ^a	8.30 $\pm$ 0.69 ^d	10.43 $\pm$ 0.38 ^b	9.51 $\pm$ 0.01 ^c	10.30 $\pm$ 0.15 ^{bc}
Methionine	ND	ND	ND	ND	ND
Cysteine	ND	ND	ND	ND	ND
Isoleucine	11.46 $\pm$ 0.38 ^a	7.55 $\pm$ 0.26 ^b	11.02 $\pm$ 0.81 ^a	8.15 $\pm$ 1.30 ^b	12.48 $\pm$ 1.35 ^a
Leucine	11.26 $\pm$ 0.94 ^a	7.19 $\pm$ 0.90 ^b	11.45 $\pm$ 0.52 ^a	8.18 $\pm$ 0.99 ^b	11.65 $\pm$ 0.43 ^a
Phenylalanine	9.89 $\pm$ 0.78 ^a	7.22 $\pm$ 0.06 ^c	9.57 $\pm$ 0.47 ^a	8.69 $\pm$ 0.10 ^b	ND
Lysine	ND	ND	ND	ND	ND

Different letters in the same row indicate significant differences ($p < 0.05$) according to multiple range test (MRT). Standard deviation was calculated on three replicates. Nd: Not determined.

Table 5. Effect of different drying methods on fatty acid composition of *Durvillaea Antarctica*. FD: freeze drying; VD: vacuum drying; SD: solar drying; CD: convective drying; IRD: infrared drying. Values are expressed as mean $\pm$ standard deviation.

Fatty acid (g 100 g ⁻¹ of sample)	Drying methods				
	FD	VD	SD	CD	IRD
Butyric acid C4:0	0.51 $\pm$ 0.05 ^d	1.16 $\pm$ 0.02 ^a	0.97 $\pm$ 0.10 ^b	0.90 $\pm$ 0.08 ^b	0.72 $\pm$ 0.11 ^c
Myristic acid C14:0	8.56 $\pm$ 0.33 ^a	7.20 $\pm$ 0.63 ^{bc}	6.87 $\pm$ 0.39 ^c	7.97 $\pm$ 0.42 ^{ab}	8.31 $\pm$ 0.28 ^a
Palmitic acid C16:0	20.21 $\pm$ 0.99 ^a	20.89 $\pm$ 0.30 ^a	21.52 $\pm$ 0.21 ^a	16.49 $\pm$ 1.34 ^b	21.46 $\pm$ 2.28 ^a
Palmitoleic acid C16:1	1.55 $\pm$ 0.02 ^b	1.45 $\pm$ 0.05 ^c	ND	1.51 $\pm$ 0.01 ^b	1.66 $\pm$ 0.03 ^a
Margaric acid C17:0	ND	ND	ND	ND	ND
Stearic acid C18:0	1.32 $\pm$ 0.15 ^d	2.06 $\pm$ 0.19 ^b	2.50 $\pm$ 0.08 ^a	1.66 $\pm$ 0.33 ^{cd}	1.87 $\pm$ 0.20 ^{bc}
Oleic acid C18:1 ω 9	13.09 $\pm$ 0.17 ^c	16.10 $\pm$ 0.80 ^a	12.09 $\pm$ 1.06 ^c	16.81 $\pm$ 0.57 ^a	14.89 $\pm$ 0.25 ^b
Linoleic acid C18:2 ω 6	5.58 $\pm$ 0.23 ^c	6.62 $\pm$ 0.58 ^{ab}	5.96 $\pm$ 0.48 ^{bc}	7.52 $\pm$ 0.43 ^a	6.18 $\pm$ 0.83 ^{bc}
Arachidic acid C20:0	ND	ND	ND	ND	ND
Gamma-linolenic acid C18:3n6	ND	ND	ND	ND	ND
Alpha-linolenic acid C18:3 ω 3	9.34 $\pm$ 0.19 ^a	8.33 $\pm$ 0.73 ^b	8.23 $\pm$ 0.32 ^b	8.59 $\pm$ 0.60 ^{ab}	7.71 $\pm$ 0.58 ^b
Docosanoic acid C22:0	ND	ND	ND	ND	ND
Dihomo-gamma-linolenic acid C20:3 ω 6	ND	ND	ND	ND	ND
Arachidonic acid C20:4 ω 6	17.38 $\pm$ 0.51 ^b	17.64 $\pm$ 0.18 ^b	21.15 $\pm$ 0.39 ^a	16.28 $\pm$ 0.34 ^c	17.52 $\pm$ 0.54 ^b
Eicosapentaenoic acid C20:5 ω 3	9.64 $\pm$ 0.49 ^{bc}	9.04 $\pm$ 1.09 ^c	10.84 $\pm$ 0.38 ^a	9.36 $\pm$ 0.11 ^c	10.41 $\pm$ 0.16 ^{ab}
SFA¹	30.60 $\pm$ 1.17^a	31.31 $\pm$ 0.88^a	31.86 $\pm$ 0.55^a	27.02 $\pm$ 1.32^b	32.36 $\pm$ 2.50^a
MUFA²	14.64 $\pm$ 0.17^c	17.55 $\pm$ 0.76^{ab}	12.09 $\pm$ 1.06^d	18.32 $\pm$ 0.57^a	16.55 $\pm$ 0.25^b
PUFA³	41.94 $\pm$ 1.14^b	41.63 $\pm$ 1.05^b	46.18 $\pm$ 1.14^a	41.75 $\pm$ 0.65^b	41.83 $\pm$ 1.69^b
ω3/ω6	0.83 $\pm$ 0.01^b	0.72 $\pm$ 0.09^c	0.70 $\pm$ 0.03^c	1.10 $\pm$ 0.02^a	0.77 $\pm$ 0.02^{bc}

Different letters in the same row indicate significant differences ($p < 0.05$) according to multiple range test (MRT). Standard deviation was calculated on three replicates.

¹Saturated fatty acids: C4:0, C14:0, C16:0, C17:0, C18:0, C20:0 and C22:0.

²Monounsaturated fatty acids: C16:1 and C18:1 ω 9.

³Polyunsaturated fatty acids: C18:2 ω 6, C18:3 ω 6, C18:3 ω 3, C20:3 ω 6, C20:4 ω 6 and C20:5 ω 3.