Chemical composition and nutritional value of different seaweeds from the west Algerian coast

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Keywords: West Algerian seaweeds; proximate composition; lipids and minerals; nutrition support; human diet

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ABSTRACT

Analysis of proximate composition, lipid fraction (fatty acids, lipid classes), macroelements and trace elements was carried out on brown (*Cystoseira stricta*; *Cystoseira compressa*), red (*Corallina elongata*) and green (*Enteromorpha compressa*; *Ulva lactuca*) seaweeds collected from the west Algerian coast, to assess their nutritional value. Protein, lipid, carbohydrate and ash content (g kg^{-1} dry alga) was in the ranges 58.5–141.4, 6.4–27.1, 134.0–461.1 and 246.1–764.2, respectively. The lowest caloric value was obtained for *C. elongata* ($827.6 \text{ kcal kg}^{-1}$ dry alga), the remaining values being in the range 2,106–2,479 kcal kg^{-1} dry alga. *C. elongata* and *C. stricta* provided the highest PUFA content, while a valuable $n-6/n-3$ ratio of between 0.95 and 4.20 was obtained for all species. α -Tocopherol was present in all seaweeds, the highest level being obtained in *U. lactuca*. Macroelements K and Na were predominant in *C. compressa* and *C. stricta*, Mg and Ca being most abundant in *E. compressa* and *C. elongata*, respectively. In all cases, a healthy Na/K value < 0.7 was observed, while a profitable ion quotient ratio was observed in all cases, except for *C. elongata*. Estimated daily intake of most minerals from the algae studied is lower than the corresponding recommended daily intake.

Keywords: West Algerian seaweeds; proximate composition; lipids and minerals; nutrition support; human diet

Running head: Nutritional value of west Algerian seaweeds.

INTRODUCTION

Seaweeds, the popular term for marine macroalgae, are classified based on anatomy, pigmentation, morphology, chemical composition and other characteristics as green (chlorophyte), brown (phaeophyte) and red (rhodophyte) algae (Dawczynski et al., 2007). In general, marine algae can produce a great variety of secondary metabolites with biological activity, being rich in vitamins such as A, B₁, B₁₂, C, D and E and in minerals such as Ca, P and K (Gupta and Abu-Ghannam, 2011). Most seaweeds contain a high ash (84–436 g kg⁻¹ dry alga) and fibre (53–523 g kg⁻¹ dry alga) content, low protein levels (49–378 g kg⁻¹ dry alga) and small amounts of fat (9.2–52 g kg⁻¹ dry alga) (Hamid et al., 2015). Furthermore, red and green species have been shown to be rich in carbohydrates, whereas iodine and soluble fibre are reported to be abundant in brown algae. Interestingly, different authors have shown that the chemical composition of seaweeds can vary with species, maturity, habitat and environmental conditions (Burtin, 2003; Ortiz et al., 2006).

As a result of this high nutritional value, seaweeds have been harvested for a variety of uses and exploitation such as phycocolloid and iodine extraction, biofuel and fertiliser production, aquaculture feed and human consumption (Fleurence, 1999). Macroalgae are known to be a good source of healthy constituents that can inhibit the oxidation of low-density lipoproteins and play an important role in the arachidonic acid chain by inhibiting the formation of prostaglandins and thromboxane (Vazhiyil, 2008). The lipid composition of marine algae has also raised considerable interest due to the high content of polyunsaturated fatty acids (PUFA), especially C18:3 n -3, C18:4 n -3, C20:4 n -6, C20:5 n -3 and C22:6 n -3 acids. These fatty acids have been shown to play an important role in the prevention of cardiovascular diseases, osteoarthritis and diabetes, and have been reported to possess antimicrobial, antiviral, anti-inflammatory and

antitumoural properties (Dawczynski et al., 2007). Interestingly, great variability in lipid class content and fatty acid profiles has been observed according to species, geographical location, season, temperature, salinity, light intensity, nutrient availability and physiological stage (Yaich et al., 2011). Furthermore, the majority of the macroelements and trace elements needed for human nutrition and development can be found in macroalgae (El-Said and El-Sikaily, 2013; Bonanno and Orlando-Bonaca, 2018); such elements are considered essential for biological processes, including growth, reproduction, hormone metabolism and antioxidant defence.

Previous studies related to seaweeds from the Algerian coast can be considered scarce. Chemical and biological evaluation of the nutritive value of *Ulva lactuca* has been done (Zitouni et al., 2014), while the antioxidant properties of *Asparagopsis taxiformis* (Mellouk et al., 2017) and the antimicrobial behaviour of a combined ethanol-aqueous extract of *Cystoseira compressa* have been demonstrated (Oucif et al., 2018). Knowledge of the chemical composition and nutritional value is necessary so that utilisation of algae from such a North African coast can be increased and they can be widely exploited commercially.

Consequently, the present study explored the proximate composition (moisture, ash, proteins, lipids and carbohydrates), lipid composition (fatty acid profile and content of phospholipids, sterols, free fatty acids and tocopherol compounds) and mineral composition (macroelements and trace elements, essential and toxic) of five abundant seaweed species from the west Algerian coast (*Cystoseira stricta*, *Cystoseira compressa*, *Corallina elongata*, *Enteromorpha compressa* and *Ulva lactuca*). The primary objective of the current research was to provide information about their possible nutritional benefits for the human diet.

MATERIALS AND METHODS

Sampling and processing

Fresh *C. stricta*, *C. compressa*, *C. elongata*, *E. compressa* and *U. lactuca* were collected in May 2016 on the Oran coast, Western Algeria (35° 44' 29.72" N and 0° 50' 14.21" W). A total weight of 1 kg was taken for each alga that was split into three independent groups that were analysed separately ($n = 3$). Species identification was made in the Laboratory of Aquaculture and Bioremediation by employing the Algabase site (www.algabase.com). Upon arrival to the laboratory, alga samples were washed thoroughly with running water to remove salts, sand and epiphytes. Biomass was then washed with distilled water and dried at room temperature (23 ± 2 °C) for 72 h in the dark. Then, the dried material was milled, powdered and stored at -20 °C until further analysis.

Proximate analysis

Moisture was determined in fresh algae by drying to constant weight at 105 ± 2 °C for 4 h, according to official method 950.46B (AOAC, 1990); results were calculated as g kg^{-1} wet weight.

Protein content ($N \times 6.25$) was determined by the Kjeldahl method, in agreement with procedure 928.08 (alternative II; AOAC, 1990). The lipid fraction was extracted and quantified gravimetrically according to the method of Sánchez-Machado et al. (2002). Ash was determined at 550 °C by official method 920.153 (AOAC, 1990). Carbohydrates were estimated by difference. The content of proteins, lipids, carbohydrates and ash was calculated as g kg^{-1} dry alga.

The caloric value (kcal kg^{-1} dry alga) was calculated by multiplying protein, carbohydrate and lipid values by a factor of 4, 4 and 9, respectively (FAO, 2003).

Lipid class analysis

The phospholipid (PL) content in the lipid extract was measured according to the method of Raheja et al. (1973), which is based on formation of a complex with ammonium molybdate. Results were calculated as g PL kg⁻¹ lipids.

The sterol (ST) content in the lipid extract was assessed by the method of Huang et al. (1961), based on the Liebermann–Buchardt reaction. Results were calculated as g ST kg⁻¹ lipids.

The free fatty acid (FFA) content in the lipid extract was determined following the method of Lowry and Tinsley (1976), which is based on the formation of a complex with cupric acetate-pyridine. Results were calculated as g FFA kg⁻¹ lipids.

The profile of tocopherol compounds was analysed according to the method of Cabrini et al. (1992). For this, dry algae were extracted with hexane which was eliminated under nitrogen flux. The resulting alga extracts were then dissolved in isopropanol and injected into an HPLC system (ODS column, 15 cm × 0.46 cm i.d.); detection was achieved at 280 nm. The presence of different tocopherol compounds (α , β , γ and δ) was checked, their content being calculated with calibration curves prepared from the corresponding commercial tocopherols. For each tocopherol compound, results were expressed as mg kg⁻¹ dry alga.

Analysis of the fatty acid profile

Lipid extracts were converted into fatty acid methyl esters (FAME) by using acetyl chloride, being then analysed by gas–liquid chromatography (Perkin Elmer 8700 chromatograph, Madrid, Spain) (Álvarez et al., 2009). Peaks corresponding to FAME were identified by comparison of their retention times with those of standard mixtures

(Qualmix Fish, Larodan, Malmo, Sweden; FAME Mix, Supelco, Inc.). Peak areas were automatically integrated; C19:0 fatty acid was used as an internal standard for quantitative purposes. The content of each fatty acid (FA) was expressed as g 100 g⁻¹ of total FA.

Results concerning FA groups (saturated, SFA; monounsaturated, MUFA; PUFA; *n*-3 PUFA; *n*-6 PUFA) and *n*-6/*n*-3 ratio were also calculated.

Mineral analysis

The content of 22 minerals was analysed according to the following procedure based on EPA 3050B (US-EPA, 1996). About 1 g of ground sample was put into a digestion flask with 9 mL of hyperpure 69% nitric acid (TMA), 3 mL of H₂O₂ (for ultratrace analysis) and 3 mL of Milli-Q water. The sample was then digested in a microwave oven (Mars-Xpress CEM Corp., Matthews, NC, USA). After digestion treatment, samples were analysed for Hg using a flow injection mercury system (FIMS; 400 Perkin Elmer; emission lamp: 253.7 nm) and for the other elements using inductively coupled plasma optical emission spectrometry (ICP-OES; Perkin Elmer Optima 4300 DV) for which the following working conditions were employed: 1,300 W (power), 15 L min⁻¹ (plasma gas flow rate), 0.2 L min⁻¹ (auxiliary gas flow rate) and 0.6 L min⁻¹ (carrier gas flow rate). Accuracy of the analytical procedures was ensured using certified reference material (duck weed aquatic plant; BCR-670) prepared by the Institute for Reference Materials and Measurements (Table 1). Results obtained were calculated as g kg⁻¹ dry alga for macroelements and as mg kg⁻¹ dry alga for trace elements.

Statistical analysis

Data ($n = 3$) obtained from the different chemical analyses were subjected to one-way ANOVA ($p < 0.05$) to investigate differences among the five different alga species (Statistica version 6.0, 2001; Statsoft Inc.). Comparison of means was performed using a least-squares difference (LSD) method.

RESULTS AND DISCUSSION

Proximate composition

Analysis of moisture content revealed great differences among the different algae under study (Table 2); values (g kg^{-1} fresh alga) varied between 840.0 for *C. compressa* and 470.5 for *C. elongata*, so that the following increasing sequence was obtained for alga groups: red < green < brown. The present results are in agreement with previous data on related species such as the brown alga *Cystoseira abies-marina* (838.0 g kg^{-1} fresh alga) (Patarra et al., 2011) and red alga *Jania rubens* (445.5 g kg^{-1} fresh alga) (Polat and Özogul, 2009).

Regarding protein content, the red seaweed *Corallina elongata* showed the lowest ($p < 0.05$) level (Table 2), thus providing similar values to the red alga *C. officinalis* (59.1 g kg^{-1} dry alga) (Ismail, 2017). Meanwhile, the highest average protein values were found in *C. stricta*, followed by *E. compressa* and *U. lactuca*. Opposite results have been obtained previously for protein content when comparing brown, red and green seaweeds. Fleurence (1999) reported that brown seaweeds contained lower levels of protein ($30\text{--}150 \text{ g kg}^{-1}$ dry alga) than green seaweeds ($90\text{--}260 \text{ g kg}^{-1}$ dry alga), while Anitha et al. (2008) reported that phaeophytes generally have higher protein content than other kinds of seaweed. Interestingly, lower protein levels (28.9 g kg^{-1} dry alga) than in the current study were obtained by Ozgun and Turan (2015) for *C.*

compressa collected from the north-eastern Mediterranean coast of Turkey, and for *U. lactuca* obtained in the north-east of Hong Kong (70.6 g kg⁻¹ dry alga; Wong and Cheung, 2000) and from the Tunisian coast (84.6 g kg⁻¹ dry alga; Yaich et al., 2011). Meanwhile, a higher protein level than in the current study was determined in *E. compressa* (266.2 g kg⁻¹ dry alga) collected from the Azorean coast by Patarra et al. (2011).

Seaweeds are known to have a relatively low lipid content (10–50 g kg⁻¹ dry alga), with strong differences among species (Burtin, 2003). In agreement with Gosch et al. (2012), the brown seaweeds investigated in the current study showed the highest lipid content ($p < 0.05$), followed by green and red seaweeds (Table 2). Thus, the values obtained in the current study can be considered to be in the range reported by Dawczynski et al. (2007) for brown seaweeds (10–45 g kg⁻¹ dry alga). Furthermore, similar lipid contents to those obtained in the present study for *U. lactuca* and *E. compressa* were recorded by Zitouni et al. (2014) and Kasimala et al. (2017) when collected from the Algerian and Eritrean coasts, respectively. In agreement with the low content determined in the current study for *C. elongata*, previous research has also shown low fat levels for the Corallinaceae family (1–23 g kg⁻¹ dry alga) (Wielgosz-Collin et al., 2016).

Carbohydrates are an abundant biochemical constituent in algae and represent the main energy source for the development of the different metabolic routes. Except for *C. elongata*, this constituent was the most abundant after moisture (Table 2). Thus, the green algae *E. compressa* and *U. lactuca* showed the highest content ($p < 0.05$), followed by both brown algae studied; interestingly, *C. elongata* had a markedly lower value ($p < 0.05$). The results of the current study are in agreement with those of Kasimala et al. (2017), who indicated the following decreasing sequence for

carbohydrate content in seaweed groups: green > brown > red. As an explanation, chlorophytes are reported to grow in very shallow waters, so that the resulting high exposure to sunlight makes them synthesise more carbohydrates by photosynthesis (Kasimala et al., 2017). In agreement with the present values, previous research on chlorophyte species has reported a carbohydrate content in the 434–602 g kg⁻¹ dry alga range, while *E. compressa* collected from the Indian coast showed a value of 482 g kg⁻¹ dry alga (Mamatha et al., 2007).

Ash was the most abundant ($p < 0.05$) constituent in *C. elongata* (Table 2); a high content has also been reported in other Corallinaceae algae such as *C. officinalis* (778 g kg⁻¹ dry alga) (Marsham et al., 2007) and *J. rubens* (807.3 g kg⁻¹ dry alga) (Polat and Özogul, 2009). In the current study, ash values for brown and green seaweeds ranged from 246.1 to 320.4 g kg⁻¹ dry alga, values similar to those found in previous research for *E. flexuosa* and *U. fasciata* collected in coastal areas of Hawaii (232 and 322 g kg⁻¹ dry alga, respectively; McDermid et al., 2007) and for *Cystoseira corniculata* from north-eastern Mediterranean coasts (290 g kg⁻¹ dry alga; Polat and Özogul, 2009).

The lowest caloric value was obtained for *C. elongata* (827.6 kcal kg⁻¹ dry alga), while levels corresponding to green and brown seaweeds were in the range 2,106–2,479 kcal kg⁻¹ dry alga (i.e., 8.81–10.37 kJ g⁻¹ dry alga). The energy values obtained in the current study are in agreement with those obtained for the Hawaiian brown seaweeds *Sargassum echinocarpum* and *Dictyota acutiloba* (8.85 and 10.14 kJ g⁻¹ dry alga, respectively) and green seaweeds *U. fasciata* and *E. flexuosa* (9.95 and 11.07 kJ g⁻¹ dry alga, respectively) (McDermid et al., 2007).

Lipid class analysis

Assessment of PL showed great differences among the alga species under study (Table 3). Values for the PL content ranged from 54.4 (*U. lactuca*) to 191.6 g kg⁻¹ lipids (*C. stricta*), so that the following increasing sequence for seaweeds groups was attained: green < red < brown, in agreement with a previous comparative study on different kinds of algae (Kumari et al., 2013). In contrast, lower PL values have been pointed out for brown seaweeds in other previous reports. Le Tutour et al. (1998) recorded 47 g kg⁻¹ lipids in *Fucus vesiculosus* and *Ascophyllum nodosum*, while 27 g kg⁻¹ lipids was recorded for *F. serratus*. Meanwhile, an average value of 220 g kg⁻¹ lipids was signalled for the red alga *Grateloupia turuturu*.

ST content ranged from 100.8 (*U. lactuca*) to 161.9 g kg⁻¹ lipids (*E. compressa*) (Table 3). Comparison among the different seaweed groups did not lead to a definite trend. However, previous studies signalled that algae from the genus *Cystoseira* were very rich in bioactive terpenes and ST (Shalaby, 2011). Among macroalgae, cholesterol has been shown to be the most abundant ST in all rhodophyte species, fucosterol being the most abundant in phaeophytes, and isofucosterol among chlorophytes (Kendel et al., 2015). Interestingly, phytosterols have been reported to provide beneficial effects, including inhibition of cholesterol absorption, as well as anticancer, antioxidant, antidiabetic, anti-inflammatory, antibacterial, antifungal and antiulcerative actions (Balboa et al., 2013).

The highest FFA content ($p < 0.05$) was recorded in *C. elongata* (198.7 g kg⁻¹ lipids), while values obtained for green and brown algae were in the range 103.9–139.8 g kg⁻¹ lipids (Table 3). FFA are important intermediate compounds during metabolism changes in living bodies. To our knowledge, no previous description of the FFA content in alga species has been provided up to now.

Results concerning the tocopherol assessment are depicted in Table 3. Qualitative analysis showed that β -tocopherol was not detected in any of the algae under study. Furthermore, *C. compressa* and *U. lactuca* contained α -, γ -, and δ -tocopherol compounds, while *E. compressa* showed the presence of α - and δ -tocopherol, and *C. stricta* and *C. elongata* contained only α -tocopherol. Higher levels of vitamin E (i.e., α -tocopherol) have previously been reported in brown seaweeds, especially for the genera *Fucus* and *Ascophyllum* (Burtin, 2003). In the current study, the highest amount of α -tocopherol was found in *E. compressa*, while δ -tocopherol was found to be especially abundant in *U. lactuca*. Great interest has been focused on vitamin E content in food and food products in agreement with its preservative effect in the antioxidant defence system. The data from the current study indicate a very high amount of α -tocopherol in all seaweeds when compared to those reported for *U. lactuca* collected from the northern coast of Chile (9.3 mg kg⁻¹ dry alga; Ortiz et al., 2006) and for other seaweeds obtained from the Galician coast (north-western Spain) (*Laminaria ochroleuca*, 8.9 mg kg⁻¹ dry alga; *Himanthalia elongata*, 12.0–33.3 mg kg⁻¹ dry alga) (Sánchez-Machado et al., 2002).

Fatty acid analysis

Concerning the FA composition, the major SFA in all kinds of algae was C16:0 (Table 4). Other SFA present in all samples were C14:0 and C18:0. Comparison among seaweeds showed that *E. compressa* had the highest C16:0 average level, but the lowest for C14:0 and C18:0. In contrast, *C. stricta* had the highest average values for C14:0 and C18:0, but the lowest for C16:0. The presence and content of such a main FA are in agreement with the results obtained by Polat and Özogul (2009) for brown (*Cystoseira corniculata* and *Padina pavonica*) and red (*Laurencia papillosa* and *Jania rubens*)

seaweeds collected from the north-eastern Mediterranean coast and with those focused on algae of the genus *Cystoseira* (*C. compressa*, *C. humilis*, *C. tamariscifolia*, *C. nodicaulis* and *C. baccata*) obtained from the Algarve coast (Portugal) (Vicetto-Duarte et al., 2015).

In the seaweeds in the current study, the most abundant MUFA were C16:1*n*-9, C18:1*n*-9 and C18:1*n*-7 (Table 4). As for SFA, the content of individual MUFA varied among the alga species under study. Thus, C18:1*n*-7 was the most abundant in green seaweeds, whereas in brown and red seaweeds C18:1*n*-9 was most abundant. Vizetto-Duarte et al. (2015) also reported C18:1*n*-9 acid as the main MUFA in brown seaweeds, accounting for 9% and 17% in *C. tamariscifolia* and *C. compressa* collected from the south Portuguese coast, respectively.

There were remarkable differences in PUFA composition among the algae in the current study (Table 4). In agreement with previous studies on different kinds of marine algae from the Pacific coast of North California (Khotimchenko et al., 2002), the major PUFA in brown algae was C20:4*n*-6. For the green alga *E. compressa*, C18:2*n*-6 was the most abundant. It is interesting that a relatively high C22:5*n*-3 content (5.39%) was detected in *U. lactuca* since this FA has often been described as being present at trace levels (< 1%) in most algae species (Tabarsa et al., 2012). Beneficial effects such as inhibition of platelet aggregation and strong endothelial cell migration ability have been described by Kaur et al. (2011) for this acid. On the other hand, the present data show that the red seaweed *C. elongata* could be an interesting source of C20:5*n*-3 (15.82%). Gosch et al. (2012) also reported that C20:5*n*-3 was the most abundant essential PUFA in red seaweeds, especially in *Champia parvula*. Interestingly, *n*-3 PUFA have been shown to compete with the conversion of linoleic acid to arachidonic acid, thus regulating the relative amounts of *n*-3 and *n*-6 PUFA (Calder, 2012); among *n*-3 PUFA,

C20:5 n -3 has proven potential beneficial application for different kinds of illnesses. A low presence of the essential C22:6 n -3 was found in the current study for all alga species, the highest content being found in brown seaweeds. This acid is generally absent or has been reported to be present at low levels in different phaeophytes, according to previous research on *Cystoseira nodicaulis*, *C. tamariscifolia* and *C. usneoides* (Silva et al., 2013).

Concerning the analysis of FA groups (Fig. 1), the SFA group was the most abundant in all seaweeds, with values from 44.64% in *C. stricta* to 59.40% in *C. compressa*. Meanwhile, the MUFA content ranged from 18.03% in *C. elongata* to 37.49% in *U. lactuca*. However, comparison among the alga groups currently under study did not lead to a general distribution trend for both FA groups. Concerning PUFA, their content varied between 14.02% in *U. lactuca* and 32.34% in *C. elongata*. Interestingly, the following decreasing sequence for PUFA average content was implied for the seaweed groups under study: red > brown > green. Differences in FA group distribution led to great differences in the PUFA/SFA ratio, so that a value of 0.28 was obtained for *U. lactuca*, while *C. elongata* reached a markedly higher score (0.65).

Distribution of PUFA between n -6 and n -3 series is depicted in Fig. 2. Thus, the highest proportion of n -3 PUFA was found in *C. elongata* (16.62%) and the lowest in *E. compressa* (3.37%). On the other side, the highest n -6 PUFA values were obtained for *C. stricta* (17.72%), while the lowest scores were found for *U. lactuca* (6.89%). Concerning both PUFA series (i.e., n -3 and n -6), great attention has recently been accorded to the n -6/ n -3 ratio. In order to prevent inflammatory, cardiovascular and neurological disorders, the World Health Organization (WHO) currently recommends that this ratio should not exceed 10 in the human diet (Kumari et al., 2013); additionally, the European Nutritional Society reported that a human diet with an

$n-6/n-3$ ratio of 5:1 or lower would have health benefits (Simopoulos, 2002). In the current study, the $n-6/n-3$ ratio ranged from 0.95 (*C. elongata*) to 4.20 (*E. compressa*) (Fig. 2). Consequently, and in agreement with recommended values, the lipid composition of all alga species under study can be considered as profitable and highly valuable from a health point of view.

Mineral content

Macroelement results (Table 5) indicate that brown seaweeds have a higher ($p < 0.05$) K and Na content than the green and red algae of the present study. Similarly, El-Said and El-Sikaily (2013) observed that green seaweeds showed smaller average Na and K values than brown seaweeds from the Egyptian Mediterranean Sea coast. Furthermore, in a comparative study of seaweeds from the Persian Gulf, Rohani-Ghadikolaie et al. (2012) also found higher K contents in brown seaweeds. Concerning Mg, the current study showed that this element was the most abundant ($p < 0.05$) in the green and red algae tested. High values (38.9 g kg^{-1} dry alga) were also obtained by Yaich et al. (2011) when analysing *U. lactuca* collected from the Tunisian coast. In this study, Ca was the most abundant element in the red seaweed *C. elongata*; a similar result was reported by Polat and Özogul (2009) in other red algae such as *L. papillosa* and *J. rubens* when compared to brown algae (*Cystoseira corniculata* and *P. pavonica*). Such a high Ca amount in the current research can be explained on the basis that *C. elongata* is a calcareous alga, this implying a marked Ca presence.

Great attention is being accorded nowadays to the Na/K ratio in the human diet. Yang et al. (2011) found a reduced risk of cardiovascular diseases if a Na/K ratio < 1.0 is present. Interestingly, a Na/K ratio below 0.7 was found in all the seaweeds in the current study (Table 5).

Highly profitable dietary and healthy information is provided by the ion quotient ratio. This value can be calculated in agreement with the following formula, concentrations being given in moles (Kiss et al., 2004):

$$\text{Ion quotient} = ([\text{Ca}^{+2}] + [\text{Na}^{+}]) / ([\text{Mg}^{+2}] + [\text{K}^{+}])$$

Low molar ratios (0.41, 0.43, 0.55 and 0.77) were determined for *C. compressa*, *E. compressa*, *U. lactuca* and *C. stricta*, respectively (Table 5). Thus, the employment of such seaweed species in foods could lead to a decrease of the ion quotient range in the human body (2.5–4.0) and reduce the development of related diseases such as hypertension, preeclampsia and heart disease (El-Said and El-Sikaily, 2013; Ismail et al., 2017). However, *C. elongata* showed a markedly higher value (4.54), so this alga would not be recommended for use in food (Table 5).

Marked differences in trace element content were found among the five alga species, although Sr, Fe and B were in general the most abundant (Table 5). The highest presence of Sr was observed in *C. elongata*. Furthermore, a definite trend among alga groups was observed for Sr content according to the following increasing sequence: red < brown < green. Interestingly, Sr is known to be necessary to stimulate the growth of coral, being fixed in its skeleton at the same time as Ca. Concerning Fe and B content, the highest average values were found in *E. compressa* and *C. compressa*, respectively.

The highest ($p < 0.05$) concentrations of As, Ba, Cd and Rb were recorded in brown seaweeds (Table 5). The predominant trace elements in green seaweeds were Cr, Cu and V, while *C. elongata* showed the highest average levels for Li, Mn, Zn, Pb and Sr. Co was found in low concentrations in all algae in the current study, in accordance with the results of Krishnaiah et al. (2008). Polat and Özogul (2009) also found that the

Mn and Zn content was higher in red (*L. papillosa* and *J. rubens*) algae than in brown (*C. corniculata* and *P. pavonica*) ones when comparing algae from the north-eastern Mediterranean coast. Furthermore, similar levels of As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn were recorded by Bonanno and Orlando-Bonaca (2018) in different kinds of brown, red and green seaweeds collected from the Mediterranean coasts when compared to those obtained in the current study. Meanwhile, all seaweeds under study showed the presence of Se; this element has recently been reported to be a health-promoting ingredient in foods as it is related to an endogenous antioxidant system (Fairweather-Tait et al., 2011).

The levels of total As varied over a wide range (4.4–141.0 mg kg⁻¹ dry alga) in the algae in the current study, in agreement with the data provided by Almela et al. (2002) for 18 alga-derived commercial products related to brown, red and green seaweeds (2.0–172 mg kg⁻¹ dry alga range). Remarkably, brown algae provided the highest ($p < 0.05$) levels of the element in the current study, thus showing a greater capacity for its accumulation. It is worth pointing out that As has been reported to exist both in inorganic (toxic) and organic (non-toxic) forms, the less toxic form being more abundant as is the case for arsenic–sugar compounds. It is important to point out that the brown alga *Hizikia fusiforme* provides a high inorganic As content (60–72% of the total As) (Almela et al., 2002). In the present research, both forms of As have been measured altogether, so that differentiation between toxic and non-toxic As cannot be carried out.

The estimated daily intake in adults for trace elements related to non-cancerous health content was calculated using the following equation (Herbicide Risk Assessment for the Aquatic Plant Management Final Supplemental Environmental Impact Statement, 2001; Health Consultation, Land Crab Evaluation, National Oceanographic Atmospheric Administration Data, 2006) (Table 6):

$$\text{Estimated daily intake (mg kg}^{-1}\text{ day}^{-1}) = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

where C is the average concentration (mg kg⁻¹) of the contaminant element, IR is ingestion rate (0.227 kg day⁻¹, 8 oz meal, for adults), EF is exposure frequency or number of exposure events per year of exposure (365 days year⁻¹), ED is exposure time (70 years), BW is body weight (70 kg) and AT is average time (non-cancer/lifetime = ED × 365 days year⁻¹).

Among all the seaweeds in the current study, the brown species *C. compressa* and *C. stricta* showed the highest estimated daily intake values for Cd (1.32E-02 and 9.72E-03 mg kg⁻¹ day⁻¹, respectively). Taking into account the maximum Cd level of 4.1 mg kg⁻¹ dry alga, consumption of less than 73 g of this alga per day would mean ingestion of a lower percentage of Cd than the one established by the WHO (2006) (0.001 mg of Cd day⁻¹ for a body weight of 70 kg). Table 6 also shows that in all seaweeds tested, the daily intakes of Ca, Mg, K, Na, Cr, Fe, B, Mn, V, Hg, Pb, Zn, Cu, Se, Ni and Li were lower than the recommended daily intakes for such elements (WHO, 1993; Trumbo et al., 2001; Institute of Medicine, 2005; WHO, 2006, 2011).

CONCLUSIONS

Information about the chemical composition, caloric value, lipid fraction (FA and lipid classes), macroelements and trace elements shows that the seaweeds studied can be considered as promising candidates for nutritional support to the human diet. Thus, the presence of α-tocopherol and healthy n-6/n-3 and Na/K ratios were observed in all seaweeds. A profitable ion quotient ratio was obtained for all seaweeds, except for *C. elongata*. Furthermore, estimated daily intakes of most macroelements and trace

elements are lower than the corresponding recommended daily intake. Knowledge of this chemical composition would be profitable for identifying strains suitable for pharmaceutical, feed or fertiliser applications. Interestingly, the five macroalgae studied could be an alternative source of antioxidants, healthy FA and essential minerals to meet the recommended daily intake of vitamin E, *n*-3 FA and trace elements. However, before being used as a food component, the current data show that attention must be paid to their heavy metal content by monitoring their levels to ensure chemical safety.

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FIGURE LEGENDS

Figure 1

Fatty acid (FA) group (saturated, SFA; monounsaturated, MUFA; polyunsaturated, PUFA) content* in different seaweeds from the west Algerian coast.

* Data expressed as average values of three replicates ($n = 3$); standard deviations are indicated by bars. For each FA group, average values accompanied by different letters (a–d) indicate significant differences ($p < 0.05$).

Figure 2

Content* of n -3 and n -6 polyunsaturated fatty acids (PUFA) in total fatty acids (TFA) and n -6/ n -3 ratio in different seaweeds from the west Algerian coast.

* Data expressed as average values of three replicates ($n = 3$); standard deviations are indicated by bars. For each parameter, average values accompanied by different letters (a–e) indicate significant differences ($p < 0.05$).

TABLE 1

**Accuracy control of the analytical procedures for the
determination* of macroelements and trace elements (average $\pm$
SD)****

Element	Certified	Measured	Unit
MACROELEMENTS			
Ca	nd**	28.0 ± 1.1	g kg^{-1}
Mg	nd	4.91 ± 0.19	mg kg^{-1}
K	nd	24.44 ± 0.93	g kg^{-1}
Na	nd	7.80 ± 0.29	g kg^{-1}
TRACE ELEMENTS			
As	1.98 ± 0.19	2.01 ± 0.01	mg kg^{-1}
B	nd	1480 ± 40	mg kg^{-1}
Ba	56.5 ± 0.3	54.9 ± 1.1	mg kg^{-1}
Cd	0.0755 ± 0.0025	0.0752 ± 0.0004	mg kg^{-1}
Co	1.25 ± 0.22	1.25 ± 0.01	mg kg^{-1}
Cr	2.05 ± 0.10	2.01 ± 0.01	mg kg^{-1}
Cu	1.82 ± 0.30	1.75 ± 0.02	mg kg^{-1}
Fe	1.01 ± 0.01	0.98 ± 0.03	g kg^{-1}
Pb	2.06 ± 0.12	2.01 ± 0.02	mg kg^{-1}
Li	1.48 ± 0.03	1.37 ± 0.08	mg kg^{-1}
Mn	1.53 ± 0.02	1.50 ± 0.03	g kg^{-1}
Hg	nd	8.1 ± 1.6	$\mu\text{g kg}^{-1}$
Ni	2.45 ± 0.27	2.51 ± 0.02	mg kg^{-1}
Rb	7.96 ± 0.09	8.02 ± 0.05	mg kg^{-1}
Se	0.183 ± 0.040	0.175 ± 0.040	mg kg^{-1}
Sr	180 ± 1	182 ± 4	mg kg^{-1}
V	3.48 ± 0.18	3.51 ± 0.02	mg kg^{-1}
Zn	24.0 ± 2.1	22.7 ± 0.5	mg kg^{-1}

* Data expressed as average values $\pm$ standard deviation ($n=3$; three replicates); nd: no data.

** Certified reference material was Aquatic Plant BCR-CRM670 (GeoReM).

TABLE 2

Proximate composition and caloric value* of different brown, red and green seaweeds collected from the west Algerian coast**

Composition and caloric value	Brown seaweed		Red seaweed	Green seaweed	
	<i>C. compressa</i>	<i>C. stricta</i>	<i>C. elongata</i>	<i>E. compressa</i>	<i>U. lactuca</i>
Moisture	840.0 ± 0.0 a	802.5 ± 0.1 b	470.5 ± 0.2 e	719.1 ± 1.5 d	749.4 ± 5.2 c
Proteins	89.1 ± 8.4 b	141.4 ± 0.3 a	58.5 ± 0.6 c	136.1 ± 6.7 a	125.4 ± 0.7 a
Lipids	18.3 ± 1.8 b	27.1 ± 0.1 a	6.4 ± 0.3 d	10.0 ± 0.2 c	9.8 ± 0.1 c
Carbohydrates	396.2 ± 0.7 c	354.5 ± 0.4 d	134.0 ± 1.1 e	461.1 ± 10.8 a	428.1 ± 2.8 b
Ash	320.4 ± 4.2 b	246.1 ± 1.7 d	764.2 ± 2.2 a	263.6 ± 2.8 c	271.3 ± 3.5 c
Caloric value	2,106 ± 1 d	2,227 ± 0 c	827.6 ± 0.0 e	2,479 ± 2 a	2,303 ± 1 b

* Data are expressed as average values of three replicates ($n = 3$) ± standard deviations. For each row, average values followed by different letters (a-e) indicate significant ($p < 0.05$) differences.

** Chemical data calculated as g kg⁻¹ dry alga, except for moisture (g kg⁻¹ fresh alga). Caloric value is expressed as kcal kg⁻¹ dry alga.

TABLE 3

Content* on phospholipids, sterols, free fatty acids and tocopherols of different brown, red and green seaweeds collected from the west Algerian coast

	Brown seaweed		Red seaweed	Green seaweed	
	<i>C. compressa</i>	<i>C. stricta</i>	<i>C. elongata</i>	<i>E. compressa</i>	<i>U. lactuca</i>
Phospholipids	140.7 ± 1.0 b	191.6 ± 5.5 a	83.7 ± 3.9 c	82.9 ± 12.0 c	54.4 ± 0.5 d
Sterols	135.9 ± 7.2 b	136.2 ± 0.4 b	104.3 ± 5.5 c	161.9 ± 4.3 a	100.8 ± 1.7 c
Free fatty acids	103.9 ± 9.7 c	138.6 ± 11.0 b	198.7 ± 6.8 a	139.8 ± 6.6 b	107.6 ± 6.9 c
α -Tocopherol	266.3 ± 34.1 a	113.9 ± 5.0 b	259.2 ± 9.0 a	410.6 ± 107.2 a	291.0 ± 0.1 a
β -Tocopherol	nd**	nd	nd	nd	nd
γ -Tocopherol	13.6 ± 19.2 a	nd	nd	nd	26.4 ± 37.3 a
δ -Tocopherol	267.6 ± 101.2 b	nd	nd	278.4 ± 24.2 b	1,916.2 ± 200.5 a

* Data expressed as average values of three replicates ($n = 3$) ± standard deviations. In each row, average values followed by different letters (a-d) indicate significant ($p < 0.05$) differences. Content on phospholipids, sterols and free fatty acids are expressed as g kg⁻¹ lipids. Content on tocopherol compounds is expressed as mg kg⁻¹ dry alga.

**nd: not detected.

TABLE 4

Fatty acids composition of different brown, red and green seaweeds collected from the west Algerian coast*

Fatty acid	Brown seaweed		Red seaweed	Green seaweed	
	<i>C. compressa</i>	<i>C. stricta</i>	<i>C. elongata</i>	<i>E. compressa</i>	<i>U. lactuca</i>
Myristicacid (C14:0)	6.11 ± 0.62 b	7.49 ± 0.02 a	4.70 ± 0.09 c	1.01 ± 0.05 d	1.07 ± 0.02 d
Pentadecylicacid (C15:0)	1.10 ± 0.17 bc	1.38 ± 0.01 ab	1.68 ± 0.02 a	1.10 ± 0.02 bc	0.79 ± 0.04 c
Palmiticacid (C16:0)	48.34 ± 0.67 b	28.70 ± 0.74 e	40.17 ± 0.16 d	50.48 ± 0.42 a	44.93 ± 0.07 c
Margaricacid (C17:0)	1.33 ± 0.08 a	1.57 ± 0.05 a	0.88 ± 0.08 b	0.42 ± 0.15 c	0.32 ± 0.02 c
Stearicacid (C18:0)	2.53 ± 0.00 b	5.52 ± 0.11 a	2.21 ± 0.08 b	1.19 ± 0.13 c	1.37 ± 0.02 c
Palmitoleicacid (C16:1 <i>n</i> -7)	6.66 ± 0.11 b	8.26 ± 0.23 a	3.05 ± 0.07 c	2.14 ± 0.01 d	3.08 ± 0.07 c
Vaccenicacid (C18:1 <i>n</i> -7)	5.59 ± 0.03 d	6.26 ± 0.14 c	3.45 ± 0.06 e	23.05 ± 0.08 b	29.02 ± 0.16 a
Oleicacid (C18:1 <i>n</i> -9)	7.69 ± 0.25 b	9.39 ± 0.12 a	7.40 ± 0.12 b	2.08 ± 0.10 d	4.79 ± 0.01 c
Eicosenoic acid (C20:1 <i>n</i> -9)	0.18 ± 0.25 c	0.98 ± 0.06 ab	1.26 ± 0.13 a	0.25 ± 0.00 bc	0.22 ± 0.31 c
Cetoleicacid (C22:1 <i>n</i> -11)	0.69 ± 0.65 a	1.18 ± 0.42 a	2.11 ± 0.64 a	0.51 ± 0.55 a	nd**
Nervonicacid (C24:1 <i>n</i> -9)	0.15 ± 0.22 b	3.25 ± 0.02 a	0.78 ± 0.06 b	0.28 ± 0.39 b	0.38 ± 0.41 b
Linoleicacid (C18:2 <i>n</i> -6)	4.66 ± 0.15 b	3.47 ± 0.18 c	2.35 ± 0.09 d	8.69 ± 0.01 a	5.12 ± 0.10 b
Eicosadienoicacid (C20:2 <i>n</i> -6)	0.60 ± 0.21 ab	1.12 ± 0.32 a	1.09 ± 0.04 a	0.10 ± 0.15 b	nd
Arachidonic acid (C20:4 <i>n</i> -6)	8.72 ± 0.65 b	12.60 ± 0.00 a	11.95 ± 0.14 a	3.58 ± 0.02 c	1.35 ± 0.10 d
Eicosapentaenoic acid (C20:5 <i>n</i> -3)	3.62 ± 0.04 c	6.37 ± 0.03 b	15.82 ± 0.16 a	1.63 ± 0.15 d	1.59 ± 0.12 d
Docosatetraenoicacid (C22:4 <i>n</i> -6)	0.86 ± 0.33 b	0.51 ± 0.24 b	0.33 ± 0.10 b	1.76 ± 0.08 a	0.41 ± 0.01 b
Docosapentaenoic acid (C22:5 <i>n</i> -3)	0.17 ± 0.23 c	0.62 ± 0.28 bc	0.19 ± 0.26 c	1.36 ± 0.05 b	5.39 ± 0.22 a
Docosahexaenoicacid (C22:6 <i>n</i> -3)	0.99 ± 0.02 ab	1.33 ± 0.01 a	0.60 ± 0.10 bc	0.37 ± 0.01 cd	0.15 ± 0.21 d

* Data expressed as average values of three replicates ($n = 3$) ± standard deviations. In each row, average values followed by different letters (a-e) indicate significant ($p < 0.05$) differences. Fatty acids content is expressed g/100 g total fatty acids.

**nd: not detected.

TABLE 5

Contents* on macroelements and trace elements of different brown, red and green seaweeds collected from the west Algerian coast

	Brown seaweed		Red seaweed	Green seaweed	
	<i>C. compressa</i>	<i>C. stricta</i>	<i>C. elongata</i>	<i>E. compressa</i>	<i>U. lactuca</i>
MACROELEMENTS					
Ca	12.5 ± 0.3 c	12.0 ± 0.0 c	254.6 ± 5.0 a	27.2 ± 0.9 b	14.0 ± 0.3 c
Mg	16.1 ± 0.4 c	6.5 ± 0.0 d	30.5 ± 0.7 b	40.3 ± 1.2 a	30.5 ± 0.2 b
K	79.4 ± 2.0 a	47.1 ± 0.1 b	6.1 ± 0.1 e	10.8 ± 0.4 d	22.5 ± 0.1 c
Na	18.4 ± 0.4 b	19.5 ± 0.0 a	2.6 ± 0.0 c	3.7 ± 0.0 d	15.6 ± 0.1 c
Na/K ratio	0.23 ± 0.03 d	0.41 ± 0.01 b	0.42 ± 0.01 b	0.34 ± 0.02 c	0.69 ± 0.01 a
Ion quotient ratio	0.41 ± 0.03 d	0.77 ± 0.04 b	4.54 ± 0.09 a	0.43 ± 0.03 d	0.55 ± 0.05 c
TRACE ELEMENTS					
As	141.0 ± 1.0 a	136.0 ± 1.0 b	7.4 ± 0.7 c	4.4 ± 0.6 c	6.2 ± 0.1 c
B	132.0 ± 2.0 a	100.0 ± 1.0 c	60.5 ± 0.2 d	47.8 ± 1.8 e	104.0 ± 1.0 b
Ba	9.8 ± 0.1 a	10.0 ± 0.0 a	5.7 ± 0.0 c	6.1 ± 0.0 b	2.8 ± 0.0 d
Cd	4.1 ± 0.0 a	3.0 ± 0.0 b	< 0.3 c	< 0.3 c	< 0.3 c
Co	0.2 ± 0.0 b	< 0.2 b	0.3 ± 0.0 a	< 0.2 b	< 0.2 b
Cr	< 0.4 e	0.6 ± 0.0 d	1.4 ± 0.0 c	2.0 ± 0.0 b	3.0 ± 0.1 a
Cu	0.5 ± 0.0 d	0.8 ± 0.0 c	< 0.3 e	2.6 ± 0.1 b	2.0 ± 0.0 a
Fe	65.1 ± 0.6 d	133.0 ± 1.0 c	228.0 ± 1.0 a	230.0 ± 10.0 a	189.0 ± 1.0 b
Pb	0.4 ± 0.0 b	0.5 ± 0.1 b	1.2 ± 0.1 a	< 0.4 b	< 0.4 b
Li	0.3 ± 0.0 d	0.3 ± 0.0 c	1.4 ± 0.0 a	0.4 ± 0.0 b	0.4 ± 0.0 b
Mn	3.6 ± 0.0 e	8.1 ± 0.1 a	12.5 ± 0.0 b	8.1 ± 0.3 d	8.6 ± 0.0 c
Hg	0.02 ± 0.00 a	0.01 ± 0.00 b	0.01 ± 0.00 b	0.009 ± 0.00 c	0.01 ± 0.00 b
Ni	2.3 ± 0.0 b	1.4 ± 0.0 d	1.2 ± 0.0 e	2.0 ± 0.0 c	2.7 ± 0.0 a
Rb	49.0 ± 0.7 a	32.9 ± 0.3 b	< 1.6 e	6.6 ± 0.1 d	10.7 ± 0.4 c
Se	< 0.04 a	< 0.04 a	< 0.04 a	< 0.04 a	< 0.04 a
Sr	1102.0 ± 26.0 b	1076.0 ± 3.0 b	1455.0 ± 34.0 a	272.0 ± 6.0 c	133.0 ± 3.0 d
V	< 0.7 d	< 0.7 d	2.1 ± 0.0 c	18.0 ± 0.9 a	7.6 ± 0.1 b
Zn	10.5 ± 0.0 b	10.2 ± 0.0 c	21.6 ± 0.1 a	5.5 ± 0.0 e	7.8 ± 0.0 d

* Data expressed as average values of three replicates ($n = 3$) ± standard deviations. In each row, average values followed by different letters (a-e) indicate significant ($p < 0.05$) differences. Macroelements values are expressed as g kg⁻¹ dry alga; trace elements values are expressed as mg kg⁻¹ dry alga.

TABLE 6

Estimated and acceptable daily intakes* of macroelements and trace elements of seaweeds collected from the west Algerian coast

Element	Brown seaweed		Red seaweed	Green seaweed		Reference values
	<i>C. compressa</i>	<i>C. stricta</i>	<i>C. elongata</i>	<i>E. compressa</i>	<i>U. lactuca</i>	
Macro-elements						
Ca	40.53	38.91	825.63	88.20	45.40	1,000
Mg	52.21	21.07	98.90	130.68	98.90	320-420
K	257.48	152.73	19.78	35.02	72.96	4,700
Na	59.66	63.23	8.43	11.99	50.58	1,500
Trace elements						
As	4.57E-01	4.41E-01	2.39E-02	1.42E-02	2.01E-02	nd**
B	4.28E-01	3.24E-01	1.96E-01	1.55E-01	3.37E-01	20
Ba	3.17E-02	3.24E-02	1.84E-02	1.97E-02	9.08E-03	nd**
Cd	1.32E-02	9.72E-03	< 9.72E-04	< 9.72E-04	< 9.72E-04	1.00E-03
Co	6.48E-04	< 6.48E-04	9.72E-04	< 6.48E-04	< 6.48E-04	nd**
Cr	1.29E-03	1.94E-03	4.54E-03	6.48E-03	9.72E-03	(2.5-3.5)E-02
Cu	1.62E-03	2.59E-03	9.72E-04	8.43E-03	6.48E-03	0.9
Fe	2.11E-01	4.31E-01	7.39E-01	7.45E-01	6.12E-01	8-18
Pb	1.29E-03	1.62E-03	3.89E-03	< 1.29E-03	< 1.29E-03	3.57E-03
Li	9.72E-04	9.72E-04	4.54E-03	1.29E-03	1.29E-03	0.65-3.10
Mn	1.16E-02	2.62E-02	4.05E-02	2.62E-02	2.78E-02	1.8-2.3
Hg	6.48E-05	3.24E-05	3.24E-05	2.91E-05	3.24E-05	5.71E-04
Ni	7.45E-03	4.54E-03	3.89E-03	6.48E-03	8.75E-03	1
Rb	1.58E-01	1.06E-01	< 5.18E-03	2.14E-02	3.46E-02	nd**
Se	< 1.29E-04	< 1.29E-04	< 1.29E-04	< 1.29E-04	< 1.29E-04	5.5E-02
Sr	3.57	3.48	4.71	8.82E-01	4.31E-01	nd**
V	< 2.27E-03	< 2.27E-03	6.81E-03	5.83E-02	2.46E-02	1.8
Zn	3.40E-02	3.30E-02	7.00E-02	1.78E-02	2.52E-02	8-11

* Estimated daily intakes and reference values are expressed as mg dry alga kg⁻¹ day⁻¹ for adult female and male (19-70 years, body weight 70 kg).

** nd: Not determined.

n-3 and *n*-6 PUFA contents (g/100 g TFA)