Int Aquat Res (2022) 14:117-125
https://doi.org/10.22034/IAR.2022.1949245.1226

ORIGINAL RESEARCH

The determination of the molecular weight profiles and biochemical compositions eight macroalgae species from Turkey

Eyup Ilker Saygili . Mehmet Naz . Emine Sukran Okudan . Zafer Cetin . Necla Benlier . Eda Ogut . Meltem Gungor . Seda Busra Bakir . Pinar Gunel Karadeniz . Salih Veziroglu . Aydın Gulses . Tolga Depci . Oral Cenk Aktas . Selin Sayin

Received: 07 January 2022 / Accepted: 17 May 2022 / Published online: 24 May 2022

Abstract Algae biomass could be one of the most important economic values in near future. For this reason, we determined the biochemical compositions and molecular weight profiles (MWPs) of eight macroalgae; Green Algae (*Codium fragile*, *Ulva intestinalis, Chaetomorpha linum,* and *Codium bursa*), Red Algae (*Ellisolandia elongata, Jania rubens,* and *Amphiroa rigida),* Brown Algae (*Padina pavonica*) collected from different regions in Turkey. The differences measured between biochemical compositions such as ash, lipid, and protein of macroalgae species were statistically significant ($P<0.05$). The lowest and highest ash, lipid, and protein values of eight macroalgae tested were 30.599 ± 2.739 % (*Ulva intestinalis*)- 81.231 ± 0.527 % (*Amphiroa rigida*), 0.190 ± 0.063 % (*Ellisolandia elongata*)- 1.764 ± 0.090 % (*Chaetomorpha linum*), and 2.057 ± 0.093 (*Amphiroa rigida*)- 15.280 ± 0.621 (*Chaetomorpha linum*). The highest levels of MWP of macroalgae tested were determined in 2532 Da ≥. The lowest levels of MWP belonging to the macroalgae was observed in 2532-13000 Da except for *Ulva intestinalis* and *Padina pavonica* belonging to 67000 Da ≤. The values observed 2532 Da ≥ were similar to each other except

Eyup Ilker Saygili (✉) . Eda Ogut . Meltem Gungor
Department of Medical Biochemistry, School of Medicine, SANKO University, 27090, Gaziantep, Turkey
e-mail: isaygili@sanko.edu.tr

Mehmet Naz
Department of Aquaculture, Faculty of Marine Sciences and Technology, Iskenderun Technical University, Iskenderun, Hatay, Turkey

Emine Sukran Okudan
Faculty of Fisheries, Akdeniz University, Dumlupınar Bulvarı, 07058, Antalya, Turkey

Zafer Cetin
Department of Medical Biology, School of Medicine, SANKO University, 27090, Gaziantep, Turkey

Necla Benlier
Department of Medical Pharmacology, SANKO University School of Medicine, 27090, Gaziantep, Turkey

Seda Busra Bakir
Department of Mechanical Engineering, Gaziantep University Osmangazi, University Boul., 27410 Şehitkamil/Gaziantep, Turkey

Pinar Gunel Karadeniz
Department of Biostatistics, SANKO University Faculty of Medicine, 27090, Gaziantep, Turkey

Salih Veziroglu . Oral Cenk Aktas
Chair for Multicomponent Materials, Institute of Materials Science, Faculty of Engineering, Kiel University, Kaiserstr. 2, 24143 Kiel, Germany

Aydın Gulses
Department of Oral and Maxillofacial Surgery, Christian Albrechts University, Universitätsklinikum Schleswig Holstein, Kiel, Germany

Tolga Depci
Department of Petrol and Natural Gases Engineering, Faculty of Engineering and Natural Sciences, Iskenderun Technical University, Iskenderun, Hatay, Turkey

Selin Sayin
Department of Marine Technologies, Faculty of Marine Sciences and Technology, Iskenderun Technical University, Iskenderun, Hatay, Turkey

for *Ulva intestinalis.* The 13700 – 67000 Da and 2532-13000 Da levels belonging to *Ulva intestinalis* were higher than those of other tested macroalgae. However, level of *Ulva intestinalis* (67000 Da ≤) was lower than those of tested macroalgae species, followed by *Padina pavonica.* In conclusion, biochemical compositions of tested macroalgae can make important contributions to feed formulations and functional foods. In addition, based on our biochemical composition analysis the specific macroalgae species are the most promising algal content for use in different industrial areas such as cosmetics, drugs, and functional foods.

Keywords Macroalgae . Biochemical composition . Blue bioeconomy . Circular economy . Marine science . Aquaculture

Introduction

Algae are an important autotrophic group of organisms that have unicellular or multicellular structure (Pooja 2014). Algae can be classified into two categories according to several features, which is carried out in the form of macroalgae and microalgae. Macroalgae, also known as moss, are macroscopic and multicellular living creatures. They have contain different photosynthetic pigments and flagella. According to these characteristics, they are divided into Chlorophyta (green algae), Rhodophyta (red algae), Phaeophyta (brown algae), Chrysophyta (Diatoms), and Flagelleta (Flagellates) (El Gamal 2014).

Algae are used in industrial fields such as food, agriculture, feed, cosmetics, medicine, and pharmacy. Also, algae have high biological activity and high levels of fatty acids, protein, and mineral substances (Durmaz et al. 2008). The biochemical content of macroalgae varies depending on the type, light, and temperature conditions (Durmaz et al. 2008).

About 70% of our world is covered by the sea (Visbeck 2018). The marine ecosystem and particularly marine algae draw attention as an important opportunity area in the use of biological innovations as a source of raw materials (Rotter et al. 2021). Biochemical compositons (ash, lipid, and protein) and molecular weight profiles (MWPs) of soluble proteins of macroalgae are important to determine for industrial potentials. There is no knowledge about combining analysis of proximate compositions and the MWPs of soluble protein of macroalgae. Therefore, we aimed to determine the biochemical compositions (ash, lipid, and protein) and MWPs of soluble protein of eight macroalgae; Green Algae (*Codium fragile*, *Ulva intestinalis*, *Chaetomorpha linum,* and *Codium bursa*), Red Algae (*Ellisolandia elongata* , *Jania rubens,* and *Amphiroa rigida),* Brown Algae (*Padina pavonica*) collected from different regions in Turkey.

Recently, macro-algae have attracted the attention of the food industry due to their low calorie content for weight loss, high content of vitamins, minerals, and dietary fiber (Fatma et al. 2015; Taskin et al. 2020). Macroalgae consumed in Asian countries for centuries are considered promising sustainable alternatives to traditional terrestrial animal resources (Bleakley and Hayes 2017; Øverland et al. 2019; Yang et al. 2017). So, the abundance of algae in Turkey can also contribute to its economy. However, it is necessary to understand the chemical composition of these algae in order to find an effective use in the target industry. The current study aims to determine the biochemical characterization i.e (molecular weight, ash, lipid, and protein) content of eight different algal types (*Codium fragile, Ulva intestinalis, Chaetomorpha linum, Codium bursa, Ellisolandia elongata, Jania rubens, Amphiroa rigida,* and *Padina pavonica* species) which are commonly found on the coasts of the Mediterranean and Aegean Sea.

As a result of decreasing available land and water resources and increasing population, increasing demand for protein sources has led to increased interest in macroalgae as alternative protein sources.

Materials and methods

Macroalgae were collected from the coasts of Çanakkale, Muğla, and Antalya (Fig.1). Sampling studies were carried out in the form of vertical and horizontal scans, with SCUBA diving and free diving between 0-40 m depths underwater. The sampling area has been reached by boat when necessary. Macroalgae were photographed underwater with the "Olympus OM-DE-M5" camera during the sampling (Fig. 2). Some of the collected materials have been determined in jars in 4-6% neutralized formaldehyde solution

Fig. 1 Map of study area and location of sampling stations. Çanakkale; *Codium fragile,* Muğla; *Codium bursa,* Antalya; *Amphiroa rigida, Chaetomorpha linum, Ellisolandia elongata, Jania rubens, Padina pavonica, Ulva intestinalis.*

prepared with seawater, for later determination and definition in the laboratory. The identification studies of macroalgae were carried out with Olympus brand SZX16 model stereo zoom and BX51 model binocular light microscopes.

Macroalgae have been gathered in shirred bags which are made of plankton cloth underwater (70x50cm). The collected materials were cleaned with fresh water in order to remove the epiphytes, rocks, sand, and mud that may be present in them. The extracted materials have been dried in a shaded area in the laboratory for later analysis without being exposed to direct sunlight.

Biochemical compositions

Biochemical compositions, such as ash, lipid, and protein of eight macroalgae collected from the coasts of Çanakkale, Muğla, and Antalya were determined according to the AOAC (2000) and also, lipid analyses were performed according to the chloroform–methanol extraction method described by Bligh and Dyer (1959).

Molecular weight profiles

The MWPs of eight macroalgae were performed according to Boza et al. (1994). In the analysis, TSK–Gel 2000 SWXL column was used in the HPLC device and molecular weights were calculated according to the bovine albumin (67.000 Da), ribonuclease A (13.700 Da), insulin chain A (2532 Da), tyr–tyr–tyr (508 Da), tryptophan (204 Da), tyrosine (181 Da), and p–aminobenzoic acid (137 Da) standards. Retention order of the standards used in HPLC gel filtration chromatography method were bovine albumin (67.000 Da), ribonuclease A (13.700 Da), insulin chain A (2.532 Da), L–tyrosine (181 Da), 4-aminobenzoic acid (137 Da), Tyr– Tyr–Tyr (508 Da), and D–tryptophan (204 Da). The molecular weight classes of macroalgae were evaluated in 4 different sections depending on their retention times: 67.000 Da ≤, 67.000-13.700 Da, 13.700-2.532 Da, and 2.532 Da ≥. Calculating the total areas of the molecular weight classes and considering the areas of 67.000 ≤ Da, and 2.532 Da ≥, the areas of 67.000 Da ≤, 67.000– 13.700 Da, 13.700 –2.532 Da were determined as protein / polypeptide and areas of 2.532 Da ≥ were determined as free amino acid / di+tri+oligopeptide.

Statistical analysis

Results were submitted as mean ± standard error (SE). Statistical comparisons were were made by OneWay Analysis (ANOVA) using SPSS 12. Differences were considered statistically significant when $P<0.05$ (Zar et al. 1999).

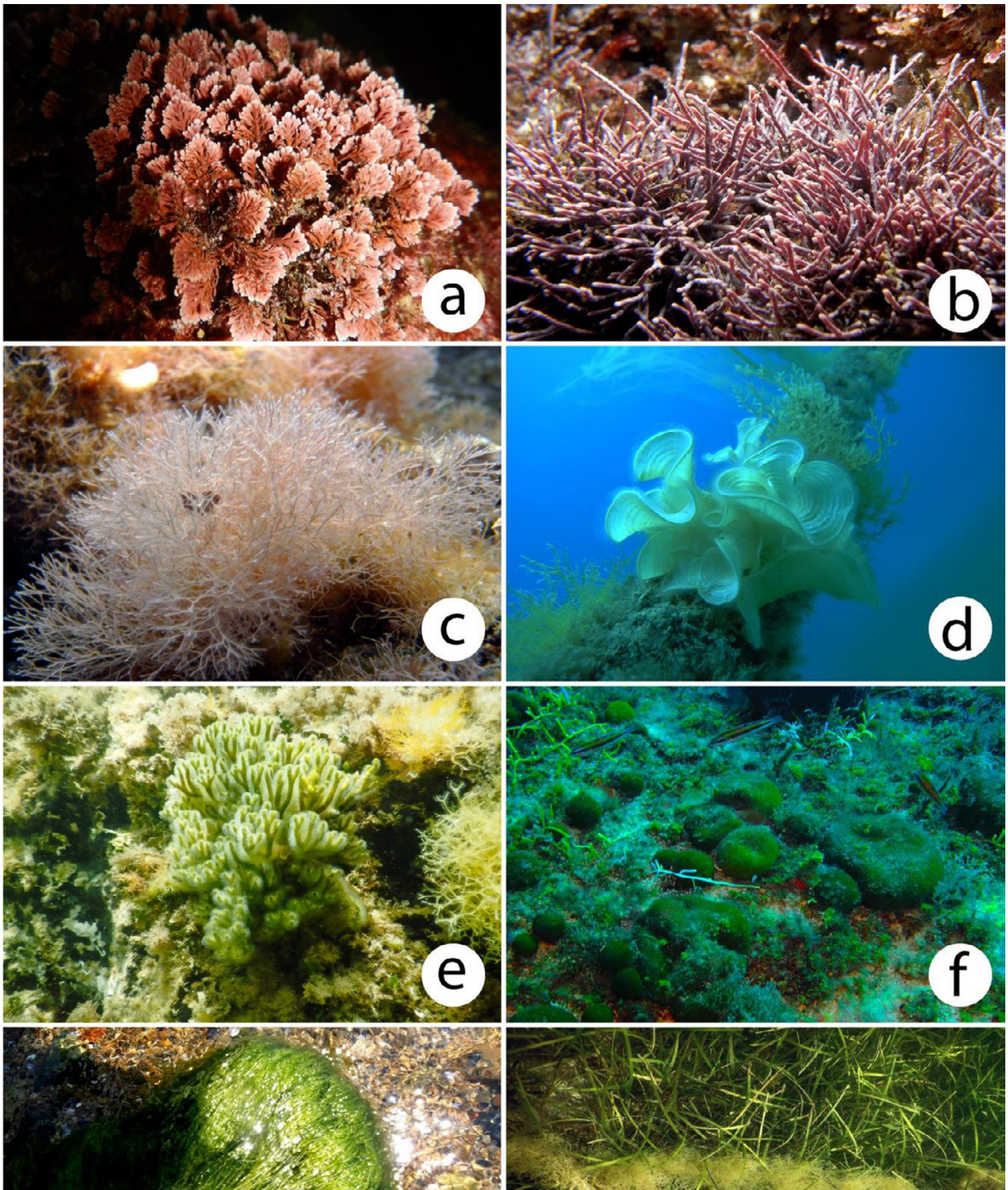

Fig. 2 a; *Ellisolandia elongata,* b; *Amphiroa rigida,* c; *Jania rubens,* d; *Padina pavonica,* e; *Codium fragile,* f; *Codium* bursa, g; Ulva intestinalis, h; Chaetomorpha linum (Photography by Emine Şükran Okudan).

Results and discussion

It is important to determine the relationship between algae biochemical composition differences and environmental conditions on Turkey's coasts. By using these biochemical ingredients, we think that consider algae is a special ecosystem. With these raw materials, could be obtained products with high

Table 1 The stations where the macroalgae are collected in Turkey's coasts

Species Name	City	Coordinate	Depth	Date
Codium fragile (Suringar) Hariot 1889	Çanakkale	40° 1'35.90"K 26°19'49.49"D	0-1 m	9.07.2015
Ulva intestinalis Linnaeus 1753	Antalya	36°13'42.30"K 29°56'23.31"D	0-1m	7.08.2015
Chaetomorpha linum (O.F.Müller) Kützing 1845	Antalya	36°13'42.30"K 29°56'23.31"D	0-1m	7.08.2015
Codium bursa (Olivi) C.Agardh 1817	Muğla	36°47'21.46"K 28°15'18.69"D	5-25m	10.10.2015
Ellisolandia elongata (J.Ellis & Solander) K.R.Hind & G.W.Saunders 2013	Antalya	36°53'30.95"K 30°42'50.25"D	0-1 m	22.07.2015
Jania rubens (Linnaeus) J.V.Lamouroux 1816	Antalya	36°32'70.28"K 30°33'28.94"D	0,2m	29.07.2015
Amphiroa rigida J.V.Lamouroux 1816	Antalya	36°16'41.17"K 30° 8'28.51"D	1-3m	7.08.2015
Padina pavonica (Linnaeus) Thivy in W.R.Taylor 1960	Antalya	36°49'59.84"K 31° 7'28.67"D	1-2m	13.08.2015

Table 2 Proximate compositions of macroalgae (mean±SD)

	Proximate Compositions		
Green Algae	Ash (%)	Lipid (%)	Protein (%)
Codium fragile	53.818 ± 1.750^{c}	1.536 ± 0.061^{e}	8.497 ± 0.044^{d}
Ulva intestinalis	30.599 ± 2.739^{a}	0.642 ± 0.060^{c}	13.100 ± 0.447^{e}
Chaetomorpha linum	45.382 ± 0.997^{b}	1.764 ± 0.090^{f}	15.280 ± 0.621^{f}
Codium bursa	69.728 ± 2.365^{e}	0.897 ± 0.030^{d}	2.488 ± 0.316^{a}
Red Algae			
Ellisolandia elongata	76.442 ± 0.094^{f}	0.190 ± 0.063^{a}	5.218 ± 0.082^{c}
Jania rubens	76.495 ± 0.813^{f}	0.329 ± 0.048^{b}	4.416 ± 0.169^{b}
Amphiroa rigida	81.231 ± 0.527^{g}	0.242 ± 0.033^{ab}	2.057 ± 0.093^{a}
Brown Algae			
Padina pavonica	61.993 ± 0.621^{d}	0.674 ± 0.110^{c}	4.299 ± 0.138^{b}

added value to ensure sustainable development efficiency. The application of algal bioactive contents in the pharmaceutical and nutraceutical industries will be important in the near future (Gomes-Dias et al. 2022; Mandalka et al. 2022).

The aim of this study was to determine the biochemical compositions (ash, lipid, and protein), and MWPs of soluble protein of eight macroalgae; Green Algae (*Codium fragile*, *Ulva intestinalis*, *Chaetomorpha linum,* and *Codium bursa*), Red Algae (*Ellisolandia elongata, Jania rubens,* and *Amphiroa rigida),* Brown Algae (*Padina pavonica*) collected from stations mentioned in Table 1. The biochemical compositions, and MWPs (HPLC-Gel filtration chromatography) of eight macroalgae are summarized in Table 2, and Fig. 3, respectively.

The differences observed in the ash, lipid and protein values of the eight macroalgae tested were statistically significant ($P<0.05$). The protein contents of the eight macroalge ranged from 2.057 ± 0.093% (*Amphiroa rigida*) to 15.280 ± 0.621% (*Chaetomorpha linum*). The highest protein levels were determined in green algae except for *Codium bursa* (2.488 ± 0.316%). Protein values of red and brown algae were similar to each other except for *Amphiroa rigida* (2.057 ± 0.093%).

It has been reported that the protein content is generally between 10-30% in red and green algae, and between 5-15% in brown algae (Burtin 2003). Dawczynski et al. (2007) revealed that protein levels of red algae were higher than those of brown algae. However, Aycan and Sayın (2020) showed that the protein ratio of *Ellisolandia elongata*, which is the only red algae species, is similar to *Sargassum vulgare* and lower than *Dictyota dichotoma* from brown algae. According to the results of our study, protein levels of green

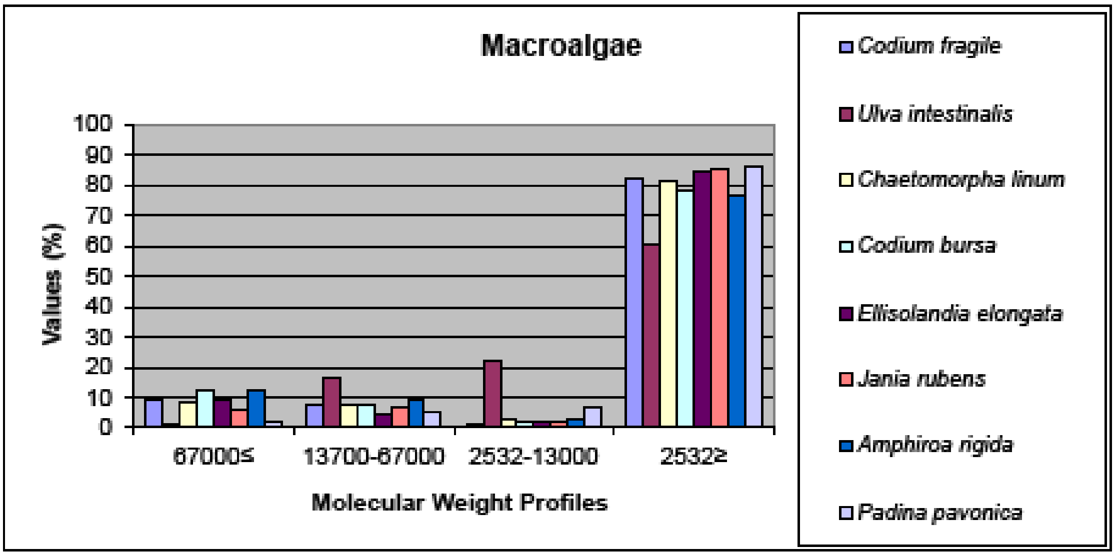

Fig. 3 Molecular weight profiles of macroalgae; Green Algae (*Codium fragile*, *Ulva intestinalis*, *Chaetomorpha linum,* and *Codium bursa*), Red Algae (*Ellisolandia elongata, Jania rubens,* and *Amphiroa rigida),* Brown Algae (*Padina pavonica*).

and red algae except for *Codium bursa* and *Amphiroa rigida* were higher than those of *Padina pavonica* from brown algae as mentioned by Burtin (2003) and Dawczynski et al. (2007). Olsson et al. (2020) were indicated that the protein content of seaweeds on the Swedish west coast which was most abundant in the red seaweeds but was generally low in all species (59–201 g kg−1 dw). Besides, It were stated that the green macroalgae species Ulva fasciata was found to have the highest protein (20.66 ± 0.04%), nitrogen contents (3.31 ± 0.01%), and Cladophora laetevirens had the highest lipid contents (Haroon et al. 2018).

Wahbeh (1997) showed that the protein content of the macroalgae *Padina pavonica* collected at the beach in Aqaba, Jordan was 17.4%. Tabarsa et al. (2012) found a protein content of 11.83% in *Padina pavonica*, which they collected in April in southern Iran (Persian Gulf). Ozgun et al. (2015) showed that the protein levels of eight brown macroalgae collected from Iskenderun Bay was varied from 2.897±0.373% to 6.519±0.432%. The protein level of *Padina pavonica* tested in the study were lower than those of protein levels revealed by Wahbeh et al. (1997) and Tabarsa et al. (2012) but not Ozgun et al. (2015). Mazlum et al. (2021) revealed that the protein level of *Jania rubens* from red macroalgae was 5.99. The protein level of *Jania rubens* tested was similar to the level determined by Mazlum et al. (2021). Studies have shown that seasonal changes have caused changes in the biochemical compositions of macroalgae.

The protein content of macroalgae varies within seasonal cycles. A recent review lists the protein content of macroalgae species from different geographical regions (Koyande et al. 2019; Pimentel et al. 2019). Gordalina et al. (2021) studied on protein isolation and characterization using SDS-PAGE methods in different seaweed species.

Unlike microalgae, macroalgae have been used in human nutrition for many years, meaning that most of them do not need new approval for human consumption (Banach et al. 2020). It is known that, the amount of EFSA-approved macroalgae species is significantly higher than microalgae. Andreeva et al. (2021) showed that protein concentrates obtained from tested algae species in the study can be used as a protein source for both food products and feed additives.

The lowest and highest lipid amounts of eight macroalgae were found in *Ellisolandia elongata* (0.190 ± 0.063%) and *Chaetomorpha linum* (1.764 ± 0.090%), respectively. The highest lipid levels were observed in green macroalgae, followed by *Padina pavonica* which belongs to brown macroalgae. The lipid level of *Ulva intestinalis* belonging to green macroalgae was similar to *Padina pavonica*. The lipid levels of red macroalgae were lower than those of other macroalgae species.

Wahbeh et al. (1997) revealed that the lipid content of the macroalgae *Padina pavonica* collected at the beach in Aqaba, Jordan was 4.4%. McDermid and Stuercke (2003) reported that lipid content of macroalgae was less than 4%. Polat and Ozogul (2008) showed that lipid contents of red and brown algae were between 1.10-11.53%. Lipid contents are generally low in macroalgae, at between 1-5% (Singh and Singh 2015).

Gosch et al. (2012) showed that the lipid content of brown seaweeds *(Phaeophyceae*) typically had the highest total lipid content, followed by green *(Chlorophyta)* and red seaweeds *(Rhodophyta)*.

Ahmad et al. (2012) stated that brown algae species have higher lipid content than red and green algae species. The results of our study were supported by Ahmad et al. (2012) but not green macroalgae. In our study, lipid contents except for *Codium fragile* and *Chaetomorpha linum* were lower than those of 1-5% contents stated by Singh and Singh (2015). Chakraborty and Bhattacharya (2012) mentioned that lipid contents of macroalgae may vary depending on the type and amount of nutritive elements in the environment. Also, Singh et al. (2015) indicated that lipid contents of macroalgae depends on light intensity, salinity, and temperature conditions. Mazlum et al. (2021) revealed that lipid content of *Jania rubens* from red macroalgae was 0.39±0.103. Lipid content of *Jania rubens* tested was similar to the content determined by Mazlum et al. (2021).

Algal ash content is an important food, feed, and feedstock for biofuel production Algae can contain as much as 70% dry matter ash in different locations. Algae ash content not only reduces the amount of ash-free matter, the valuable part of algae biomass but also leads to a concern for heavy metal toxicity and decreases inclusion levels for algae used in food and agriculture (Liu 2017; de Souza et al. 2019). The highest and lowest ash values were found in *Amphiroa rigida* (81.231 ± 0.527%) and *Ulva intestinalis* (30.599 ± 2.739%), respectively. The highest ash values were found in red macroalgae. *Padina pavonica* belonging to brown macroalgae was higher than those of green macroalgae species except for *Codium bursa.* Tabarsa et al. (2012) emphasized that the ash content of macroalgae varies between 8-40% of their dry weight. Polat and Ozogul (2008) determined that the ash contents varies between 2.28-51.63%. On the other hand, Liu (2017) reveal that algae can contain as high as 70% dry matter ash in different locations. Wahbeh (1997) indicated that the ash content of the macroalgae *Padina pavonica* collected at the beach in Aqaba, Jordan was 23.1%. Ozgun and Turan (2015) showed that the ash contents of eight brown macroalgae collected from Iskenderun Bay was varied from 1.66±0.29% to 18.19±2.66%. Uslu et al. (2021) determined that the ash amount of the macroalgae *Padina pavonica* collected from Antalya, Turkey was 22±0.2 %. The results of Tabarsa et al. (2012) Polat and Ozogul (2013) and Ozgun and Turan (2015) were lower than those of the results of our study except for *Ulva intestinalis* and *Chaetomorpha linum*. *Padina pavonica* ash contents revealed by Wahbeh (1997) and Uslu et al. (2021) were lower than those of *Padina pavonica* tested in our study. Ash content results of macroalgae tested were supported by Liu (2017). Factors such as geographical location and season might be important factors in change the ash content of macroalgae (Renaud et al. 2006; Mohamed et al. 2012; Cabrita et al. 2016). Mazlum et al. (2020) revealed that ash content of *Jania rubens* from red macroalgae was 78.740 ± 0.066. Ash content of *Jania rubens* tested was similar to the content determined by Mazlum et al. (2020).

MWPs of eight macroalgae Green Algae (*Codium fragile*, *Ulva intestinalis*, *Chaetomorpha linum* and *Codium bursa*), Red Algae (*Ellisolandia elongata, Jania rubens* and *Amphiroa rigida),* Brown Algae (*Padina pavonica*) collected from Turkey were given in Fig. 4. The highest MWPs in macroalgae tested in the present study were determined in 2532 Da ≥. The lowest contents were found in 2532-13000 Da except for *Ulva intestinalis* and *Padina pavonica*. The highest MWPs belongs to 67000 ≤ Da, 13700-67000 Da and 2532-13000 Da were observed in *Amphiroa rigida* (12.535±0.57%), *Ulva intestinalis* (16.16±0.73%), and *Ulva intestinalis* (21.94±0.29%). The MWPs belongs to 67000≤Da of *Codium bursa* (12.44±1.08%) and *Amphiroa rigida* (12.535±0.57%) were similar to each other. On the other hand, the MWPs belongs to 67000 ≤ Da and 2532 Da ≥ of *Ulva intestinalis* were lower than those of other tested macroalgae species. The MWPs belong to 67000 ≤ Da, 13700-67000 Da, and 2532-13000 Da of macroalgae species were lower than 20% except for *Ulva intestinalis* (21.94±0.29%). Kolkovski (2004) and Kolkovski (2008) reported that in general, molecular weight classes between 1,000 and 10,000 daltons were positive effect on nutrition.

Diken et al. (2018) observed that the molecular weight profiles of animal and vegetable (except for soy protein concentrate–SPC) feed ingredients were high in the 2.532 Da ≥ group. Also, the molecular weight profiles of Ulva sp. and Sargassum sp. tested in this study were the highest in the group of 2.532 Da ≥. The above-mentioned differences might be attributed to environmental conditions and algal species differences.

It has been known that protein forms used in feeds have an important role in the development of the larval digestive system (Cahu and Infante 1995; Zambonino Infante et al. 1997). Ronnestad et al. (1999) and Holt (2000) indicated that the identification of the protein forms may contribute towards the more appropriate feed formulation for critical larval stages. MWPs showed that macroalgae tested had an exogenous supply

of free aminoacids. On the other hand, the use of macroalgae in feed formulations may cause the high leaching ratios due to the high contents of 2532 ≥ Da MWPs of eight macroalgae.

It is well known that biochemical compositions of algae species could be linked to cultivating conditions, algal developmental stages, species specificity, genetic differences, or differences in environmental conditions (Araujo et al. 2021; De Vicose et al. 2012; Degeorges and Masquelet 2002; Khan et al. 2018).

Conclusion

In conclusion, all tested macroalgae can make important contributions to feed formulations and be the basis for the development of functional foods. Considering these MWPs data results, it is cautioned that the use of macroalgae in feed formulations may cause the high leaching ratios containing 2532 ≥ Da MWP. In addition, based upon our research on biochemical composition in the macroalgae species, green, brown, and red macroalgae are the most promising algal species for use in different industrial applications such as cosmetics, drugs, and functional foods with great benefits for the human health and our society.

Authors contribution EIS & TD & SS and MG: Design and conceptualization of the study; EIS & ZC: finalization of the draft; MN & ESO: Collection of the sample; EIS & SS & MN: laboratory analysis of the sample and drafting the manuscript; PGK and SBB: Statistical analysis, and revision of the draft; Wet lab analysis: SS & EIS and MN; NB and EO: Data acquisition and interpretation; OCA & SV and AG: Material composition analysis and manuscript language editing; EIS: Coordination of the study and finalization of the manuscript.

Conflicts of interest The authors declare that they have no conflict of interest.

References

Ahmad F, Sulaiman MR, Saimon W, Yee CF, Matanjun P (2016) Proximate compositions and total phenolic contents of selected edible seaweed from Semporna, Sabah, Malaysia. Borneo Sci 31:85-96

Andreeva A, Budenkova E, Babich O, Sukhikh S, Ulrikh E, Ivanova S, Dolganyuk V (2021) Production, purification, and study of the amino acid composition of microalgae proteins. Molecules 26(9):2767

Araújo R, Vázquez Calderón F, Sánchez López J, Azevedo IC, Bruhn A, Fluch S, Laurans M (2021) Current status of the algae production industry in Europe: an emerging sector of the Blue Bioeconomy. Fron Mar Sci 7:1247

Aycan A, Sayin S (2020) Geleceğin fonksiyonel ürünleri için bazı denizel makroalglerin potansiyellerinin belirlenmesi. Med Fish Aqua Res 3(1):20-33

Banach J, Hoek-van den Hil E, van der Fels-Klerx H (2020) Food safety hazards in the European seaweed chain. Comp Rev Food Sci Food Saf 19(2):332-364

Bleakley S, Hayes M (2017) Algal proteins: extraction application, and challenges concerning production. Food 6(5):33

Bligh EG, Dyer W J (1959) A rapid method of total lipid extraction and purification. Can J Biochem Physiol 37(8):911-917

Boza JJ, Jiménez J, Martínez O, Suárez MD, Gil A (1994) Nutritional value and antigenicity of two milk protein hydrolysates in rats and guinea pigs. The Nutr J 124(10):1978-1986

Burtin P (2003) Nutritional value of seaweeds. Elec J Env Agricult Food Chem 2(4):498-503

Cabrita ARJ, Maia MRG, Oliveira HM, Sousa-Pinto I, Almeida AA, Pinto E, Fonseca AJM (2016) Tracing seaweeds as mineral sources for farm-animals. J Appl Psychol 28(5):3135-3150. doi:10.1007/s10811-016-0839-y

Cahu C, Infante J (1995) Effect of the molecular form of dietary nitrogen supply in sea bass larvae: response of pancreatic enzymes and intestinal peptidases. Fish Physiol Biochem 14(3):209-214

Chakraborty S, Bhattacharya T (2012) Nutrient composition of marine benthic algae found in the Gulf of Kutch coastline, Gujarat, India. J Algal Biomass Util 3(1):32-38

Dawczynski C, Schubert R, Jahreis G (2007) Amino acids, fatty acids, and dietary fibre in edible seaweed products. Food Chem 103(3):891-899

De Viçose GC, Viera MP, Huchette S, Izquierdo MS (2012) Larval settlement, early growth and survival of Haliotis *tuberculata* coccinea using several algal cues. J Shellfish Res 31(4):1189-1198

de Souza MP, Hoeltz M, Gressler PD. Benitez LB, Schneider RCS (2019) Potential of microalgal bioproducts: general perspectives and main challenges. Waste Biomass Valoriz 10:2139–2156. https://doi.org/10.1007/s12649-018-0253-6

Degeorges R, Masquelet AC (2002) The cubital tunnel: anatomical study of its distal part. Surg Radiol Anat 24(3-4):169-176. doi:10.1007/s00276-002-0032-7

Diken G, Demir O, Naz M (2018) The inhibitory effects of different diets on the protease activities of *Argyrosomus regius* (Pisces, Scianidae) larvae as a potential candidate species. J Appl Anim Res 46(1):94-99

Durmaz Y, Duyar HA, Gökpınar Ş, Öğretmen YÖ, Bandarra NM (2008) Ulva spp. (Sinop, Karadeniz) türünün yağ asitleri, a tokoferol ve toplam pigment miktarının araştırılması. J Fish Sci 2(4):350-356

El Gamal AA (2010) Biological importance of marine algae. SPJ 18(1):1-25

Fatma C, Yilmaz Ö, Durucan F, Özdemir NŞ (2015) Biochemical components of three marine macroalgae (*Padina pavonica*, *Ulva lactuca* and *Taonia atomaria*) from the levantine sea coast of antalya, Turkey. J Biol Environ Sci 6:401-411

Gomes-Dias JS, Teixeira JA, Rocha CM (2022) Recent advances in the valorization of algae Polysaccharides for food and nutraceutical applications: a review on the role of green processing technologies. Food Bioproc Technol, https://doi.org/10.1007/s11947-022-02812-5

Gordalina M, Pinheiro HM, Mateus M, da Fonseca MMR, Cesário MT (2021) Macroalgae as protein sources—a review on protein bioactivity, extraction, purification and characterization. Appl Sci 11(17):7969
Gosch BJ, Magnusson M, Paul NA, De Nys R (2012) Total lipid and fatty acid composition of seaweeds for the selection of species for oil-based biofuel and bioproducts. Gcb Bioenergy 4(6):919-930
Haroon AM, Hussian AEM, El-Sayed SM (2018) Deviations in the biochemical structure of some macroalgal species and their relation to the environmental conditions in Qarun Lake, Egypt. Egypt J Aquat Res 44(1):15-20
Holt GJ (2000) Symposium on recent advances in larval fish nutrition. In (Vol. 6, pp. 141-141) Blackwell Science Ltd Osney Mead, Oxford Ox2 One, Oxon England
Khan MI, Shin JH, Kim JD (2018) The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. Microbial cell factories 17(1):1-21
Kolkovski S (2004) Marine fish larvae diets–current status and future directions. Inscripción N 165.283 Editorial UC TEMUCO Manuel Montt 056, Temuco Fono
Kolkovski S (2008) Advances in marine fish larvae diets. Avances en Nutrición Acuicola
Koyande AK, Chew KW, Rambabu K, Tao Y, Chu DT, Show PL (2019) Microalgae: A potential alternative to health supplementation for humans. Food Sci Human Well 8(1):16-24
Liu K (2017) Characterization of ash in algae and other materials by determination of wet acid indigestible ash and microscopic examination. Algal Res 25:307-321
Mandalka A, Cavalcanti MILG, Harb TB, Toyota Fujii M, Eisner P, Schweiggert-Weisz U, Chow F (2022) Nutritional composition of beach-cast marine algae from the Brazilian coast: added value for algal biomass considered as waste. Foods 11:1201. https://doi.org/10.3390/foods11091201
Mazlum Y, Yazici M, Sayin S, Habiboğlu O, Sinem U (2020) Effects of two different macroalgae (*Ulva lactuca* and *Jania rubens*) species on growth and survival of red swamp crayfish (*Procambarus clarkii*) as feed additive. Mar Sci Technol Bull 10(2):154-162
McDermid KJ, Stuercke B (2003) Nutritional composition of edible Hawaiian seaweeds. J Appl Phycol 15(6):513-524
Mohamed S, Hashim SN, Rahman HA (2012) Seaweeds: a sustainable functional food for complementary and alternative therapy. Trend Food Sci Technol. 23(2):83–96
Olsson J, Toth GB, Albers E (2020) Biochemical composition of red, green and brown seaweeds on the Swedish west coast. J Appl Phycol 32(5):3305-3317
Øverland M, Mydland LT, Skrede A (2019) Marine macroalgae as sources of protein and bioactive compounds in feed for monogastric animals. J Sci Food Agric 99(1):13-24
Ozgun S, Turan F, Çinar M, Bakir K, Öztürk B, Katağan T, Bakır B (2015) Biochemical composition of some brown algae from Iskenderun Bay, the northeastern Mediterranean coast of Turkey. J Black Sea/Mediterr Environ 21(2):125-134
Pimentel FB, Alves RC, Harnedy PA, FitzGerald RJ, Oliveira MBP (2019) Macroalgal-derived protein hydrolysates and bioactive peptides: Enzymatic release and potential health enhancing properties. Trend Food Sci Tech 93:106-124
Polat S, Ozogul Y (2013) Seasonal proximate and fatty acid variations of some seaweeds from the northeastern Mediterranean coast. Oceanologia 55(2):375-391
Pooja S (2014) Algae used as medicine and food-a short review. J Pharm Sci 6(1):33
Renaud SM, Luong-Van JT (2006) Seasonal variation in the chemical composition of tropical Australian marine macroalgae. Paper presented at the Eighteenth International Seaweed Symposium
Rønnestad I, Thorsen A, Finn RN (1999) Fish larval nutrition: a review of recent advances in the roles of amino acids. Aquaculture 177(1-4):201-216
Rotter A, Barbier M, Bertoni F, Bones AM, Cancela ML, Carlsson J, Conk Dalay M (2021) The essentials of marine biotechnology. Front Mar Sci 8:158
Singh S, Singh P (2015) Effect of temperature and light on the growth of algae species: a review. Ren Sust Energy Rev 50:431-444
Tabarsa M, Rezaei M, Ramezanpour Z, Robert Waaland J, Rabiei R (2012) Fatty acids, amino acids, mineral contents, and proximate composition of some brown seaweeds 1. J Phycol 48(2):285-292
Taşkın E, Tan İ, Minareci E, Minareci O, Çakır M, Polat-Beken Ç (2020) Ecological quality status of the Turkish coastal waters by using marine macrophytes (macroalgae and angiosperms). Ecol Indicators 112:106107
Uslu L, Sayin S, Naz M, Taskin E, Soyler O, Saygili I, Cetin Z, Dinler ZM, Isik O (2021) Proximate analysis and fatty acid profile of some brown macroalgae collected from the northeasthern mediterranean coast. Fres Environ Bull 30(7A):9433-9437
Visbeck M (2018) Ocean science research is key for a sustainable future. Nature communications 9(1):1-4
Wahbeh MI (1997) Amino acid and fatty acid profiles of four species of macroalgae from Aqaba and their suitability for use in fish diets. Aquaculture 159(1-2):101-109
Yang LE, Lu QQ, Brodie J (2017) A review of the bladed Bangiales (Rhodophyta) in China: history, culture and taxonomy. Eur J Phycol 52(3):251-263
Zambonino Infante JL, Cahu CL, Peres A (1997) Partial substitution of di-and tripeptides for native proteins in sea bass diet improves *Dicentrarchus labrax* larval development. J Nutri 127(4):608-614
Zar JH (1999) Biostatistical analysis. Prentice Hall, princeton

Publisher's Note