Comparative Study of Nutritional Importance of Some Marine Macroalgae as a Novel Natural Source of Amino Acids 1

Article *in* Russian Journal of Marine Biology · March 2021

DOI: 10.1134/S1063074021010119

CITATIONS
0

READS
7

2 authors, including:

Fatma Ward
Damietta University
18 PUBLICATIONS **45** CITATIONS

SEE PROFILE

ISSN 1063-0740, Russian Journal of Marine Biology, 2021, Vol. 47, No. 1, pp. 39–46. © Pleiades Publishing, Ltd., 2021.

ORIGINAL PAPERS

Comparative Study of Nutritional Importance of Some Marine Macroalgae as a Novel Natural Source of Amino Acids[1]

F. M. Ward[a], * and M. A. Deyab[a]

[a] *Faculty of Science, Damietta University, New Damietta City, 34517 Egypt*

**e-mail: Fatma2028@yahoo.com*

Received March 12, 2020; revised August 27, 2020; accepted September 24, 2020

Abstract—This study aimed to investigate the amino acids contents of some brown (*Hormophysa cuneiformis*, *Sargassum muticum*, and *Padina minor*), red (*Digenea simplex*, *Amphiroa anceps*, and *Corallina mediterranea*), and green macroalgae (*Codium elongatum*, *Ulva fasciata*, and *Cladophora* sp.) collected from the Egypt coasts, using an Eppendorf/Biotronik LC 3000 amino acid analyzer. The results showed that the total amino acid content ranged from 11.84 ± 0.55 mg/g dry weight (DW) in *D. simplex* to 33.43 ± 1.29 mg/g DW in *U. fasciata*. Threonine and L-methionine were the major essential amino acids (EAAs) in red and brown macroalgae, respectively, whereas in green macroalgae, the major EAAs varied between macroalgae species as follows: L-lysine in *C. elongatum*, L-leucine in *U. fasciata*, and L-valine in *Cladophora* sp. L-aspartic and L-glutamic acids together represented a large portion of the amino acid content. The high content of EAAs in all the species under study makes them an important resource for nutritional applications.

Keywords: amino acid analyzer, amino acid profile, nutritional value, Phaeophyta, Chlorophyta, Rhodophyta

DOI: 10.1134/S1063074021010119

INTRODUCTION

Macroalgae are multicellular marine organisms playing important environmental, biological, and ecological roles in the coastal aquatic environment [7]. They are classified on the basis of their anatomy, pigmentation, morphology, and chemical composition as brown (Phaeophyta), red (Rhodophyta), and green macroalgae (Chlorophyta) [8]. Macroalgae perform many ecological roles including being a base for almost all aquatic food chains due to the high contents of nutrients such as vitamins, fibers, free amino acids, polyunsaturated fatty acids, and minerals [23]. The nutrient composition of macroalgae is generally known to be highly influenced by species, habitat, maturity, geographical location, and environmental conditions [9].

Amino acids are precursors for the synthesis of secondary metabolites such as alkaloids that provide algae with chemical defense. In general, the amino acid profile is important for evaluating the nutritional value of algal proteins [12]. The nutritional value of food protein is mainly determined by the type, amount, and proportion of essential amino acids (EAAs). A quantitative estimation of amino acid composition in different species of marine macroalgae has revealed considerable differences in amino acids between them [24].

About 150 macroalgal species are used as human food in the coastal areas [18]. In Japan, macroalgae, traditionally cooked as sushi wrappings, jams, soups, or salads, make up approximately 25% of all food consumed, and, thus, have become the main income source for fishermen [23]. According to FAO statistics, South Korea, China, and Japan have the highest daily consumption of macroalgae: 46, 22, and 4 g per capita, respectively [27].

The macroalgae used in the present study are widely available on the Egypt coasts almost throughout the year. Therefore, the present study aimed to characterize amino acid profiles of *Hormophysa cuneiformis*, *Sargassum muticum*, *Padina minor*, *Digenea simplex*, *Amphiroa anceps*, *Corallina mediterranea*, *Codium elongatum*, *Ulva fasciata*, and *Cladophora* sp. collected from Egypt during the autumn of 2016 to gain extensive information about their nutritional value.

MATERIALS AND METHODS

Sample Collection

Nine macroalgal species were collected from the Egypt coasts manually at low tides during the autumn of 2016. *Amphiroa anceps* and *Ulva fasciata* were col-

[1] The text was submitted by the authors in English.

lected from the Alexandria sea coast (Abu-Qir, 31°19′ N, 30°03′ E); *Corallina mediterranea* was collected from the Damietta sea coast (Ras-Elbar, 31°30′ N, 31°49′ E); *Hormophysa cuneiformis*, *Sargassum muticum*, *Padina minor*, *Digenea simplex*, *Codium elongatum*, and *Cladophora* sp. were collected from the Hurghada sea coast (Hurghada, 27°13′ N, 33°45′ E). Macroalgal species were taxonomically identified according to Braune and Guiry [5] and Jha et al. [15].

Preparation of Macroalgal Species

Macroalgae were washed with seawater followed by distilled water to remove salt and foreign particles. Then the macroalgae were spread on blotting paper to remove excess water. The clean macroalgae were shade dried and then kept in an oven at 60°C for 4 h. The dried algal material was ground to 2 mm or smaller particle size. The algal powder was used for analyses.

Analysis of Amino Acids Profile

The algal samples were hydrolyzed according to the method of Adebiyi et al. [1] before the determination of amino acids. The amino acid analysis was carried out on an Eppendorf/Biotronik LC 3000 amino acid analyzer (Maintal, Germany) with an H 125× column at the National Institute of Oceanography and Fisheries, Alexandria, Egypt. Amino acid content was as expressed as mg/g dry weight (DW).

Statistical Analysis

All determinations were carried out in triplicate and the results were expressed as mean ± standard deviation. Data were analyzed using the SPSS v. 22 software. A two-tailed Pearson's product-moment correlation test was performed to assess the relationship between amino acid contents. Mean separation was performed using the Duncan's multiple range test at $P < 0.05$.

RESULTS

The amino acid profiles of nine macroalgal species revealed the presence of 18 amino acids: L-lysine, L-methionine, tryptophan, threonine, L-phenylalanine, L-isoleucine, L-leucine, histidine, L-valine, L-aspartic acid, L-glutamic acid, arginine, glycine, alanine, serine, tyrosine, cysteine, and proline. The statistical analysis showed significant differences in amino acid content between all the macroalgae analyzed. The total amino acid content ranged from 11.84 ± 0.55 mg/g DW in *D. simplex* to 33.43 ± 1.29 mg/g DW in *U. fasciata* (Fig. 1). Table 1 shows that the macroalgal species contained nine EAAs in different proportions ranging from 42.3 ± 0.55% (in *P. minor*) to 53.9 ± 0.62% (in *D. simplex*) of the total amino acid content.

The EAAs to non-EAAs ratio ranged from 0.73 in *P. minor* to 1.17 in *D. simplex*. It can be seen that L-methionine is a major EAA in the Phaeophyta species, constituting 32.4–37.9% of total EAAs. Threonine is a major EAA in all the studied Rhodophyta species. However, in the Chlorophyta species, the major EAA varied as follows: L-lysine in *C. elongatum*,

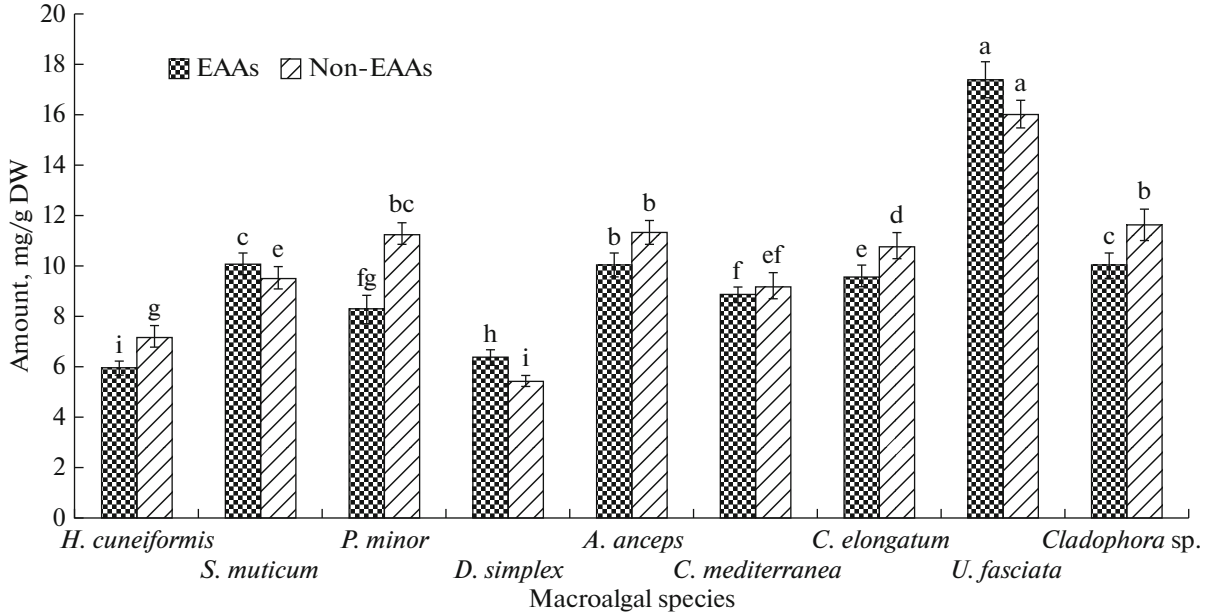

Fig. 1. Contents of EAAs and non-EAAs in some macroalgae collected from the Egypt coasts.

Table 1. Essential amino acid (EAAs) profiles of some macroalgae collected from the Egypt coasts

Groups and species	L-lysine	L-methionine	Tryptophan	Threonine	L-phenylalanine	L-isoleucine	L-leucine	Histidine	L-valine
Brown macroalgae									
H. cuneiformis	0.79 ± 0.03	1.94 ± 0.08	ND	0.49 ± 0.03	0.68 ± 0.01	0.64 ± 0.01	0.82 ± 0.06	0.41 ± 0.03	0.21 ± 0.01
S. muticum	1.23 ± 0.06	3.83 ± 0.14	0.29 ± 0.03	1.04 ± 0.03	0.89 ± 0.06	0.77 ± 0.06	0.63 ± 0.01	0.69 ± 0.02	0.74 ± 0.01
P. minor	0.52 ± 0.01	2.71 ± 0.14	ND	0.72 ± 0.06	1.06 ± 0.11	0.89 ± 0.09	1.44 ± 0.08	0.67 ± 0.06	0.27 ± 0.01
Red macroalgae									
D. simplex	0.69 ± 0.01	0.36 ± 0.03	0.18 ± 0.02	1.16 ± 0.07	1.09 ± 0.03	0.56 ± 0.07	0.91 ± 0.07	0.89 ± 0.01	0.54 ± 0.03
A. anceps	0.89 ± 0.09	0.41 ± 0.01	0.92 ± 0.03	2.06 ± 0.12	0.62 ± 0.00	1.32 ± 0.03	0.97 ± 0.03	1.72 ± 0.08	1.15 ± 0.09
C. mediterranea	1.15 ± 0.05	0.97 ± 0.04	ND	1.51 ± 0.03	1.22 ± 0.07	0.94 ± 0.03	1.43 ± 0.07	0.76 ± 0.01	0.89 ± 0.04
Green macroalgae									
C. elongatum	1.74 ± 0.07	0.89 ± 0.03	0.59 ± 0.00	1.45 ± 0.07	1.13 ± 0.09	0.70 ± 0.03	1.66 ± 0.06	0.63 ± 0.01	0.82 ± 0.09
U. fasciata	2.81 ± 0.12	1.95 ± 0.08	ND	3.02 ± 0.21	0.81 ± 0.03	2.21 ± 0.08	4.39 ± 0.10	0.78 ± 0.03	1.43 ± 0.08
Cladophora sp.	1.14 ± 0.10	0.73 ± 0.02	ND	1.08 ± 0.06	1.17 ± 0.10	1.52 ± 0.06	1.85 ± 0.09	0.34 ± 0.01	2.21 ± 0.09

EAA content is expressed as mg/g DW. Values are mean of three replicates ± standard deviation. ND, not detected.

Table 2. Non-essential amino acid (non-EAAs) profiles of some macroalgae collected from the Egypt coasts

Groups and species	L-aspartic acid	L-glutamic acid	Arginine	Glycine	Alanine	Serine	Tyrosine	Cysteine	Proline
Brown macroalgae									
H. cuneiformis	1.73 ± 0.14	2.15 ± 0.14	1.27 ± 0.08	0.18 ± 0.01	0.17 ± 0.01	0.45 ± 0.01	0.59 ± 0.01	0.32 ± 0.01	0.36 ± 0.01
S. muticum	1.76 ± 0.08	2.19 ± 0.08	1.84 ± 0.14	0.63 ± 0.02	0.71 ± 0.03	0.78 ± 0.03	0.68 ± 0.03	0.35 ± 0.01	0.57 ± 0.02
P. minor	2.32 ± 0.11	3.43 ± 0.14	1.91 ± 0.08	0.25 ± 0.01	0.29 ± 0.01	0.68 ± 0.03	1.18 ± 0.05	0.55 ± 0.01	0.68 ± 0.01
Red macroalgae									
D. simplex	1.73 ± 0.06	1.10 ± 0.03	0.09 ± 0.01	0.02 ± 0.01	0.43 ± 0.01	ND	0.06 ± 0.01	ND	2.03 ± 0.08
A. anceps	2.09 ± 0.08	1.74 ± 0.08	0.95 ± 0.03	1.18 ± 0.08	1.73 ± 0.08	1.49 ± 0.06	0.53 ± 0.00	ND	1.63 ± 0.08
C. mediterranea	2.26 ± 0.08	1.51 ± 0.14	0.32 ± 0.04	0.82 ± 0.03	1.43 ± 0.08	1.04 ± 0.03	0.47 ± 0.05	0.19 ± 0.01	1.16 ± 0.06
Green macroalgae									
C. elongatum	1.61 ± 0.06	3.15 ± 0.14	0.74 ± 0.03	1.07 ± 0.08	1.12 ± 0.06	1.41 ± 0.06	0.46 ± 0.03	ND	1.25 ± 0.06
U. fasciata	5.44 ± 0.14	6.19 ± 0.21	0.24 ± 0.04	0.78 ± 0.02	1.17 ± 0.06	0.92 ± 0.03	0.46 ± 0.03	0.14 ± 0.01	0.69 ± 0.03
Cladophora sp.	3.51 ± 0.14	2.83 ± 0.14	0.37 ± 0.04	1.15 ± 0.08	1.6 ± 0.13	0.97 ± 0.06	0.07 ± 0.01	ND	1.17 ± 0.02

Non-EAA content is expressed as mg/g DW. Values are mean of three replicates ± standard deviation. ND, not detected.

L-leucine in *U. fasciata*, and L-valine in *Cladophora* sp. Furthermore, it can be noted that tryptophan in *S. muticum*, *D. simplex*, *A. anceps*, and *C. elongatum* reached a much lower level compared to all EAAs and was completely absent in *H. cuneiformis*, *P. minor*, *C. mediterranea*, *U. fasciata*, and *Cladophora* sp. (Table 1).

The present results indicate also variations in non-EAAs content between macroalgal species and groups as shown in Table 2. Macroalgae contained nine non-EAAs: L-aspartic acid, L-glutamic acid, arginine, glycine, alanine, serine, tyrosine, cysteine, and proline. Non-EAAs contents ranged from 5.46 ± 0.21 mg/g DW in *D. simplex* to 16.03 ± 0.56 mg/g DW in *U. fasciata*. As shown in Table 3, all the studied species had a similar pattern in which L-glutamic and L-aspartic acids constituted together a large portion of the amino acid content (17.9–34.8% of total amino acids). L-glutamic and L-aspartic acids made up 20.1–29.4% of total amino acids in the brown algae, 17.9–23.9% of total amino acids in the red algae, and 23.3–34.8% of total amino acids in the green algae.

Pearson's correlations between different amino acids are shown in Table 4. L-lysine correlated positively with threonine, L-isoleucine, L-leucine,

Table 3. Amino acid profile of macroalgae as percentage of total amino acids

Amino acids	Brown macroalgae			Red macroalgae			Green macroalgae		
	H. cuneiformis	*S. muticum*	*P. minor*	*D. simplex*	*A. anceps*	*C. mediterranea*	*C. elongatum*	*U. fasciata*	*Cladophora* sp.
EAAs									
L-lysine	5.98	6.27	2.66	5.83	4.16	6.36	8.52	8.41	5.25
L-methionine	14.70	19.52	13.85	3.04	1.92	5.37	4.36	5.83	3.36
Tryptophan	0.00	1.48	0.00	1.52	4.30	0.00	2.89	0.00	0.00
Threonine	3.71	5.30	3.68	9.80	9.63	8.36	7.10	9.03	4.97
L-phenylalanine	5.15	4.54	5.42	9.21	2.90	6.75	5.53	2.42	5.39
L-isoleucine	4.85	3.92	4.55	4.73	6.17	5.20	3.43	6.61	7.00
L-leucine	6.21	3.21	7.36	7.69	4.53	7.91	8.13	13.13	8.52
Histidine	3.11	3.52	3.42	7.52	8.04	4.21	3.09	2.33	1.57
L-valine	1.59	3.77	1.38	4.56	5.37	4.93	4.02	4.28	10.18
Non-EAAs									
L-aspartic acid	13.11	8.97	11.85	14.61	9.77	12.51	7.88	16.27	16.17
L-glutamic acid	16.29	11.16	17.53	9.29	8.13	8.36	15.43	18.52	13.04
Arginine	9.62	9.38	9.76	0.76	4.44	1.77	3.62	0.72	1.70
Glycine	1.36	3.21	1.28	0.17	5.51	4.54	5.24	2.33	5.30
Alanine	1.29	3.62	1.48	3.63	8.08	7.91	5.48	3.50	7.37
Serine	3.41	3.98	3.47	0.00	6.96	5.76	6.90	2.75	4.47
Tyrosine	4.47	3.47	6.03	0.51	2.48	2.60	2.25	1.38	0.32
Cysteine	2.42	1.78	2.81	0.00	0.00	1.05	0.00	0.42	0.00
Proline	2.73	2.91	3.47	17.15	7.62	6.42	6.12	2.06	5.39

L-aspartic acid, and L-glutamic acid, and negatively with arginine. L-methionine showed significant positive correlations with arginine, tyrosine, and cysteine and a negative correlation with proline. A positive correlation existed between tryptophan and histidine ($r = 0.758$, $p < 0.05$). Threonine was found to correlate positively with L-isoleucine, L-leucine, and L-aspartic acid. L-isoleucine correlated positively with L-leucine, L-valine, L-aspartic acid, and L-glutamic acid. L-leucine was found to correlate positively with L-aspartic acid ($r = 0.933$, $p < 0.01$) and L-glutamic acid ($r = 0.908$, $p < 0.01$). Also, the analysis revealed a positive correlation of L-valine with glycine and alanine. A positive correlation was found between L-aspartic acid and L-glutamic acid ($r = 0.831$, $p < 0.01$). Arginine showed a positive correlation with both tyrosine and cysteine; glycine, a positive correlation with alanine and serine. Moreover, significant correlations were found between alanine and serine ($r = 0.775$, $p < 0.05$), tyrosine and cysteine ($r = 0.859$, $p < 0.01$), as well as cysteine and proline ($r = -0.742$, $p < 0.05$).

The total amino acid content in the Phaeophyta species ranged from 13.2 ± 0.68 mg/g DW in *H. cuneiformis* to 19.62 ± 0.86 mg/g DW in *S. muticum*. The ratios of EAAs to total amino acids were 0.45, 0.52, and 0.42 in *H. cuneiformis*, *S. muticum*, and *P. minor*, respectively. The results also indicate variations in the EAAs to non-EAAs ratio between the studied Phaeophyta species: 0.83 in *H. cuneiformis*, 1.06 in *S. muticum*, and 0.73 in *P. minor*. All the studied Phaeophyta species were rich in L-glutamic acid, L-methionine, L-aspartic acid, and arginine. *H. cuneiformis* and *P. minor* were poor in alanine, glycine, and L-valine, while *S. muticum* was poor in tryptophan, cysteine, and proline. No tryptophan was detected in *H. cuneiformis* and *P. minor*. As shown in Fig. 1, among the brown macroalgal species, *S. muticum* contained a higher level of EAAs (10.11 mg/g DW).

The total amino acid content in the Rhodophyta species ranged from 11.84 ± 0.55 mg/g DW in *D. simplex* to 21.40 ± 0.97 mg/g DW in *A. anceps*. The ratios of EAAs to total amino acids were 0.54, 0.47, and 0.49, and the EAAs to non-EAAs ratios were 1.17, 0.89, and

Table 4. Pearson's correlation matrix of amino acid concentrations of different macroalgae

	L-lysine	L-methionine	Tryptophan	Threonine	L-Phenylalanine	L-isoleucine	L-leucine	Histidine	L-valine	L-aspartic acid	L-glutamic acid	Arginine	Glycine	Alanine	Serine	Tyrosine	Cysteine	Proline
L-lysine	1																	
L-methionine	–0.353	1																
Tryptophan	–0.024	–0.308	1															
Threonine	0.793*	–0.226	0.250	1														
L-phenylalanine	–0.037	–0.200	–0.370	–0.235	1													
L-isoleucine	0.687*	–0.066	–0.106	0.791*	–0.213	1												
L-leucine	0.852**	–0.019	–0.294	0.771*	–0.002	0.853**	1											
Histidine	–0.014	–0.324	0.758*	0.481	–0.469	0.143	–0.109	1										
L-valine	0.488	–0.347	0.022	0.475	0.172	0.726*	0.477	–0.014	1									
L-aspartic acid	0.712*	0.022	–0.377	0.706*	–0.070	0.945**	0.933**	–0.102	0.628	1								
L-glutamic acid	0.670*	0.292	–0.262	0.588	–0.130	0.750*	0.908**	–0.209	0.309	0.831**	1							
Arginine	–0.676*	0.772*	0.088	–0.504	–0.314	–0.360	–0.438	–0.051	–0.515	–0.403	–0.054	1						
Glycine	0.429	–0.312	0.489	0.488	0.041	0.499	0.263	0.263	0.748*	0.273	0.185	–0.237	1					
Alanine	0.452	–0.498	0.411	0.590	0.091	0.565	0.288	0.399	0.802**	0.347	0.072	–0.473	0.925**	1				
Serine	0.347	–0.180	0.596	0.447	–0.085	0.366	0.196	0.370	0.440	0.123	0.208	0.012	0.912**	0.775*	1			
Tyrosine	–0.392	0.673*	–0.026	–0.205	–0.232	–0.143	–0.094	0.048	–0.564	–0.153	0.211	0.835**	–0.230	–0.400	0.120	1		
Cysteine	–0.519	0.822**	–0.455	–0.438	–0.102	–0.227	–0.148	–0.303	–0.585	–0.116	0.129	0.792*	–0.528	–0.639	–0.295	0.859**	1	
Proline	0.033	–0.800**	0.468	0.182	0.274	–0.126	–0.195	0.528	0.196	–0.219	–0.466	–0.595	0.151	0.368	0.016	–0.599	–0.742*	1

* Correlation is significant at a 0.05 level (2-tailed).
** Correlation is significant at a 0.01 level (2-tailed).

0.96 in *D. simplex*, *A. anceps*, and *C. mediterranea*, respectively. Cysteine and serine were not detected in *D. simplex*; cysteine and tryptophan were not detected in *A. anceps* and *C. mediterranea*, respectively. As shown in Fig. 1, among the Rhodophyta macroalgae, *A. anceps* contained a higher level of EAAs (10.06 ± 0.48 mg/g DW), especially aromatic amino acids such as threonine (2.06 ± 0.12 mg/g DW) and tryptophan (0.92 ± 0.03 mg/g DW).

The total amino acid content in the Chlorophyta species ranged from 20.42 ± 0.97 mg/g DW in *C. elongatum* to 33.43 ± 1.29 mg/g DW in *U. fasciata*. The ratios of EAAs to total amino acids were 0.47, 0.52, and 0.46 in *C. elongatum*, *U. fasciata*, and *Cladophora* sp., respectively. Tryptophan was detected neither in *U. fasciata*, nor in *Cladophora* sp., whereas cysteine was not detected in *C. elongatum* and *Cladophora* sp. Among the nine macroalgae, *U. fasciata* contained a higher level of EAAs (17.4 ± 0.73 mg/g DW), as shown in Fig. 1. Moreover, *U. fasciata* was rich in sulfur-containing amino acids such as leucine (4.39 ± 0.10 mg/g DW) and lysine (2.81 ± 0.12 mg/g DW).

DISCUSSION

Marine macroalgae possess substantial levels of protein, which, in some cases, can be higher than in various terrestrial plants. Al-Amoudi et al. [2] reported a higher total amino acid content (14.30 ± 0.24 mg/g DW) in *D. simplex* collected from the Jeddah Corniche. Variations in the content of amino acids may be proportional to their utilization by macroalgae during reproduction and growth.

In the present study, the EAA content in various macroalgae was higher than that in other macroalgae analyzed in earlier works: 37–42% in *Ulva lactuca* and *Gelidium amansii* and 36.5 % in *U. rigida* and *U. rotundata* [10, 22]. Dawczynski et al. [8] also reported that EAAs make up more than 30% of total amino acids in various macroalgae. The high level of L-methionine in the Phaeophyta species agreed with data obtained by Lourenço et al. [19] who reported high contents of methionine in brown macroalgae. This study showed low levels of tryptophan in some macroalgae and its absence in others. Tryptophan was not detected also in different algal species in previous studies [3, 25, 26]. It may be due to the destruction of tryptophan during the hydrolysis process.

In all the macroalgae analyzed in the present study, L-glutamic and L-aspartic acids constituted together a large percentage of the amino acid content (17.9–34.8% of total amino acids). Similar results were also obtained in previous studies by Wong and Cheung [29], Zubia et al. [30], and Gressler [13]. Biancarosa et al. [4] reported that L-glutamic and L-aspartic acids constituted together up to 30, 23, and 28% of total amino acids in the Phaeophyta, Rhodophyta, and Chlorophyta species, respectively. In the present study, the level of these two amino acids in *U. fasciata* amounted to 34.8 % of total amino acids, which was higher than those reported for *U. rigida* (26%) and *U. rotundata* (32%) by Fleurence et al. [9]. The high levels of aspartic and glutamic acids were responsible for the specific smell and taste of the macroalgae.

L-lysine and arginine are polar amino acids with a charge at typical biological pH values. The positive correlation between L-lysine and L-aspartic acid ($r = 0.712$, $p < 0.05$) may be due to the synthesis of L-lysine from L-aspartic acid by the diaminopimelate pathway [17]. Both threonine and L-aspartic acid belong to the oxaloacetate/aspartate family of amino acids [17]. The L-isoleucine, L-leucine, and L-valine amino acids are characterized by branched aliphatic side chains [28]. L-isoleucine and L-valine amino acids give a specific complex taste to macroalgae [21]. The glycine and serine are characterized by their small size. The correlation between L-valine and alanine may be explained by the pyruvate which is the precursor of both L-valine and alanine [17].

The present work revealed a high ratio of EAAs to total amino acids in Chlorophyta. Ismail [14] reported a lower ratio of EAAs to total amino acids for *Sargassum linifolium* (0.37). The dominance of aspartic acid, glutamic acid, glycine, alanine, and serine in the Rhodophyta species agrees with data obtained by Impellizzeri et al. [11]. Lourenço et al. [19] reported significant variations in the threonine, glycine, methionine, and arginine content of *Codium decorticatum*, *C. spongiosum*, and *C. taylorii*. In other studies, tryptophan was not detected in different members of Rhodophyta and in *Ulva* species [19, 23]. In the present study, 17 amino acids were detected in *U. fasciata* collected from the Alexandria coast, Egypt. However, *U. fasciata* collected from the coasts of India and southeastern Brazil was reported to have only 16 amino acids [19, 25]. *U. lactuca*, collected from the Tunisian and Egypt coasts, was also found to contain 17 and 16 amino acids, respectively [16]. Only 15 amino acids were found in *U. reticulate* collected from the Thailand coast. These variations in amino acids content may be due to the differences in algal species and environmental conditions such as water salinity, water temperature, and pH [6, 20].

Therefore, the considerable levels of all EAAs in the studied macroalgae indicate that they contain high-quality proteins and that the macroalgal proteins have a higher nutritional value than the terrestrial plant proteins, which makes the macroalgae a valuable nutritious item of human food.

CONCLUSIONS

It can be concluded that the nutritional composition of macroalgae is highly influenced by their group and species. All the macroalgae species analyzed in this study represent natural resources with a potential economic value to be used in human and animal diet due to the high content of essential amino acids in them. Further studies with more species involved are required to determine their biochemical composition.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

REFERENCES

1. Adebiyi, A.P., Jin, D., Ogawa, T., and Muramoto, K., Acid hydrolysis of protein in a microcapillary tube for the recovery of tryptophan, *Biosci., Biotechnol., Biochem.*, 2005, vol. 69, pp. 255–257.
2. Al-Amoudi, O.A., Mutawie, H.H., Patel, A.V., and Blunden, G., Chemical composition and antioxidant activities of Jeddah corniche algae, Saudi Arabia, *Saudi J. Biol. Sci.*, 2009, vol. 16, pp. 23–29.
3. Benjama, O. and Masniyom, P., Nutritional composition and physicochemical properties of two green seaweeds (*Ulva pertusa* and *U. intestinalis*) from the Pattani Bay in Southern Thailand, *Songklanakarin J. Sci. Technol.*, 2011, vol. 33, pp. 575–583.
4. Biancarosa, I., Espe, M., Bruckner, C.G., et al., Amino acid composition, protein content, and nitrogen-to-protein conversion factors of 21 seaweed species from Norwegian waters, *J. Appl. Phycol.*, 2017, vol. 29, pp. 1001–1009.
5. Braune, W. and Guiry, M.D., *Seaweeds: A Colour Guide to Common Benthic Green, Brown and Red Algae of the World's Oceans*, Gatner, A.R.G., Ed., Königstein, Germany: Koeltz Scientific Books, 2011.
6. Brown, M.R., The amino-acid and sugar composition of 16 species of microalgae used in mariculture, *J. Exp. Mar. Biol. Ecol.*, 1991, vol. 145, pp. 79–99.
7. Carneiro, J.G., Rodrigues, J.A.G, Teles, F.B., et al., Analysis of some chemical nutrients in four Brazilian tropical seaweeds, *Acta Sci., Biol. Sci.*, 2014, vol. 36, pp. 137–145.
8. Dawczynski, C., Schubert, R., and Jahreis, G., Amino acids, fatty acids, and dietary fibre in edible seaweed products, *Food Chem.*, 2007, vol. 103, pp. 891–899.
9. Fleurence, J., Seaweed proteins: biochemical nutritional aspects and potential uses, *Trends Food Sci. Technol.*, 1999, vol. 10, pp. 25–28.
10. Fleurence, J., Le Coeur, C., Mabeau, S., et al., Comparison of different extractive procedures for proteins from the edible seaweeds *Ulva rigida* and *Ulva rotundata, J. Appl. Phycol.*, 1995, vol. 7, pp. 577–582.
11. Impellizzeri, G., Mangiafico, S., Piattelli, M., et al., Amino-acid profiles in red algae, *Biochem. Syst. Ecol.*, 1977, vol. 5, pp. 77–80.
12. Górska-Warsewicz, H., Laskowski, W., Kulykovets, O., et al., Food products as sources of protein and amino acids—The case of Poland, *Nutrients*, 2018, vol. 10, no. 12, art. ID 1977. https://doi.org/10.3390/nu10121977
13. Gressler, V., Yokoya, N.S., Fujii, M.T., et al., Lipid, fatty acid, protein, amino acid and ash contents in four Brazilian red algae species, *Food Chem.*, 2010, vol. 120, pp. 585–590.
14. Ismail, G.A., Biochemical composition of some Egyptian seaweeds with potent nutritive and antioxidant properties, *Food Sci. Technol.*, 2017, vol. 37, pp. 294–302.
15. Jha, B., Reddy, C.R.K., Thakur, M.C., et al., *Seaweeds of India: The Diversity and Distribution of Seaweeds of Gujarat Coast*, Borowitzka, M., Ed., Dordrecht: Springer-Verlag, 2009.
16. Khairy, H.M. and El-Shafay, S.M., Seasonal variations in the biochemical composition of some common seaweed species from the coast of Abu Qir Bay, Alexandria, Egypt, *Oceanologia*, 2013, vol. 55, pp. 435–452.
17. Kumar, V., Sharma, A., Thukral, A.K., and Renu, B., Amino acid profiling of the leaves of plants in the vicinity of river Beas, India, *J. Chem. Pharm. Res.*, 2015, vol. 7, pp. 504–510.
18. Kumari, P., Kumar, M., Gupta, V., et al., Tropical marine macroalgae as potential sources of nutritionally important PUFAs, *Food Chem.*, 2010, vol. 120, pp. 749–757.
19. Lourenço, S.O., Barbarino, E., De-Paula, J.C., et al., Amino acid composition, protein content and calculation of nitrogen-to-protein conversion factors for 19 tropical seaweeds, *Phycol. Res.*, 2002, vol. 50, pp. 233–241.
20. Marinho-Soriano, E., Fonseca, P.C., Carneiro, M.A.A., and Moreira, W.S.C., Seasonal variation in the chemical composition of two tropical seaweeds, *Bioresour. Technol.*, 2006, vol. 97, pp. 2402–2406.
21. Mouritsen, O.G., Umami flavour as a means of regulating food intake and improving nutrition and health, *Nutr. Health*, 2012, vol. 21, pp. 56–75.
22. Ochiai, Y., Katsuragi, T., and Hashimoto, K., Proteins in three seaweeds, "Aosa" *Ulva lactuca*, "Arame" *Eisenia bicyclis*, and "Makusa" *Gelidium amansii, Nippon Suisan Gakkaishi*, 1987, vol. 53, pp. 1051–1055.
23. Ortiz, J., Romero, N., Robert, P., et al., Dietary fiber, amino acid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea antarctica, Food Chem.*, 2006, vol. 99, pp. 98–104.
24. Qasim, R., Amino acid composition of some common seaweeds, *Pak. J. Pharm. Sci.*, 1991, vol. 4, pp. 49–54.
25. Rameshkumar, S., Ramakritinan, C.M., and Yokeshbabu, M., Proximate composition of some selected seaweeds from Palk bay and Gulf of Mannar, Tamilnadu, India, *Asian J. Biomed. Pharm. Sci.*, 2012, vol. 3, pp. 1–5.

26. Ratana-arporn, P. and Chirapart, A., Nutritional evaluation of tropical green seaweeds *Caulerpa lentillifera* and *Ulva reticulate, Kasetsart J.: Nat. Sci.*, 2006, vol. 40 (suppl.), pp. 75–83.

27. Robledo, D., Fraga, J., and Gasca-Leyva, E., Social and economic dimensions of carrageenan seaweed farming in Mexico, in *Social and Economic Dimensions of Carrageenan Seaweed Farming*, Fisheries and Aquaculture Technical Paper, no. 580, Valderrama, D., et al., Eds., Rome: FAO, 2013, pp. 182–199.

28. Wolfe, R.R., Branched-chain amino acids and muscle protein synthesis in humans: myth or reality?, *J. Int. Soc. Sports Nutr.*, 2017, vol. 14, art. ID 30. https://doi.org/10.1186/s12970-017-0184-9

29. Wong, K.H. and Cheung, P.C.K., Nutritional evaluation of some subtropical red and green seaweeds: Part I — proximate composition, amino acid profiles and some physico-chemical properties, *Food Chem.*, 2000, vol. 71, pp. 475–482.

30. Zubia, M., Payri, C.E., Deslandes, E., and Guezennec, J., Chemical composition of attached and drift specimens of *Sargassum mangarevense* and *Turbinaria ornata* (Phaeophyta: Fucales) from Tahiti, French Polynesia, *Bot. Mar.*, 2003, vol. 46, pp. 562–571.