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Seasonal variations in the biochemical composition of some common seaweed species from the coast of Abu Qir Bay, Alexandria, Egypt

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Abstract

Variations in protein, carbohydrate, lipid, ash, moisture, fatty acid and amino acid contents of the seaweeds *Ulva lactuca* Linnaeus (Chlorophyta), *Jania rubens* (Linnaeus) J.V. Lamouroux and *Pterocladia capillacea* (S.G. Gmelin) Bornet (Rhodophyta) were studied seasonally from spring to autumn 2010. The seaweeds were collected from a rocky site near Boughaz El-Maadya on the coast of Abu Qir Bay east of Alexandria, Egypt. Remarkable seasonal variations were recorded in the levels of the studied parameters in the three species. *Pterocladia capillacea* was characterized by the highest protein and carbohydrate content throughout the different seasons, whereas *Ulva lactuca* contained more lipids ($4.09 \pm 0.2\%$) than *J. rubens* and *P. capillacea*. The highest total fatty acids were recorded in *J. rubens* during the three seasons, while saturated fatty acids were predominant in *P. capillacea* during spring. This is due mainly to the presence of palmitic acid (C16:0), which made up 74.3% of the saturated fatty acids. The highest level of polyunsaturated fatty acids (PUFA) in these algae was measured in *J. rubens*; DHA

(22:6ω_3) was the main acid, making up 26.4% of the total fatty acids especially during summer. Proline was the major component of the amino acids in the three algal species, with maximum amounts in *U. lactuca*.

1. Introduction

A wide variety of seaweeds grow along the Egyptian Mediterranean coast, especially at Alexandria. The green alga *Ulva lactuca* and the red algae *Jania rubens* and *Pterocladia capillacea* are among the most abundant macroalgae on the Alexandria coast, particularly from spring to autumn (Aleem 1993).

Seaweeds are a commercially important, renewable marine resource. Variability in chemical constituents and growth of algae may be interspecific, intra-annual or inter-annual. Certain seaweeds contain significant quantities of proteins, lipids, minerals and vitamins (Norziah & Ching 2002, Sánchez-Machado et al. 2004, Van Ginneken et al. 2011), while nutrient contents can vary with species (Fujiwara-Arasaki et al. 1984, Nisizawa et al. 1987), geographical location, season and temperature (Kaehler & Kennish 1996, Haroon 2000). Temperature was shown to affect the growth rate and chemical content of the rhodophytes *Palmaria palmata* (Mishra et al. 1993), *Laminaria japonica* (Honya et al. 1994), *Macrocystis pyrifera* (McKee et al. 1992, Castro-Gonzalez et al. 1994) and *Nereocystis luetkeana* (Rosell & Srivastava 1985).

Seaweeds are nutritionally valuable as fresh or dried vegetables, or as ingredients in a wide variety of prepared foods (Robledo & Pelegrín 1997). Seasonal variations in the chemical composition and nutritive value have been reported in common marine seaweeds from the Gulf of Gdańsk coast on the southern Baltic Sea (Haroon 2000), from Hong Kong (Kaehler & Kennish 1996) and from Ireland (Mercer et al. 1993). The seasonal variation of fatty acids in seaweeds has also been studied (Floreto et al. 1993, Nelson et al. 2002).

Proteins, carbohydrates and lipids are the most important biochemical components of algae. Lipids are widely distributed in several resistance stages of algae (Miller 1962). A few studies were done on the fatty acids of microalgae and seaweeds (Takagi et al. 1985, Wood 1988, Liekenjie 1989). The macroalgal biomass can store large amounts of oil, which can be exploited for the production of biodiesel (John & Anisha 2011).

Seaweeds belonging to the Rhodophyta possess high levels of proteins (10–30% DW) (Darcy-Vrillon 1993). The protein contents of some red seaweeds, such as *Palmaria* and *Porphyra tenera*, are 35 and 47% DW respectively (Morgan et al. 1980). These levels are even comparable to that of soybeans (35% DW).

There is evidence to suggest that the fatty acid (FA) and sterol composition may be useful for taxonomic purposes (Herbreteau et al. 1997). Rhodophyta are characterized by a high content of C-20 polyunsaturated fatty acids (PUFAs), mainly arachidonic and eicosapentaenoic acids. Other abundant FAs in this class are palmitic and oleic acids. Lipids are major sources of metabolic energy during the embryonic and pre-feeding fish larval stages (Evans et al. 2000). The studies by Estevez et al. (1999) showed that essential FAs such as docosahexaenoic acid (DHA, 22:6ω_3), eicosapentaenoic acid (EPA, 20:5ω_3) and arachidonic acid (ARA, 20:4ω_6) are important in larval fish nutrition.

The amino acid composition in free or bound form has been studied in several species of marine algae (Dave & Parekh 1978, Smith & Gayler 1979, Qasim 1991); pronounced differences were observed in proteins and amino acids between different algal groups.

The present study discusses the seasonal variability in the biochemical composition of three macro-algal species, widely distributed along Alexandria Coast, namely *U. lactuca*, *J. rubens* and *P. capillacea*.

2. Material and methods

2.1. Study area

Abu Qir Bay (AQ) is a shallow semi-closed basin lying about 20 km east of Alexandria city, between longitudes 30°03′ and 30°22′E and latitudes 31°16′ and 31°28′N (Figure 1). It is bordered on the north-east by the Rosetta mouth of the Nile and on the south-west by the Abu Qir headland, which was recently extended further seawards by the construction of Abu Qir Harbour. The bay, one of the main Egyptian fishery grounds, receives industrial, domestic and agricultural wastes through the El-Tabia Pumping station (TPS). In addition, the bay receives agricultural drainage water from the adjacent Lake Edku through Boughaz El-Maadya.

2.2. Sampling

Three marine algal species were collected during April, August and October 2010, representing spring, summer and autumn respectively. The species collected were the chlorophyte *Ulva lactuca* Linnaeus, and the rhodophytes *Jania rubens* Linnaeus J.V. Lamouroux *Pterocladia capillacea* S.G. Gmelin Bornet. The algae were collected from submerged rocks on the coast of Abu Qir Bay near Boughaz El-Maadya (Figure 1) where they are usually abundant during the relevant collecting periods. All the samples were brought to the laboratory in plastic bags containing seawater to prevent the seaweeds from drying out. Epiphytes and extraneous matter were

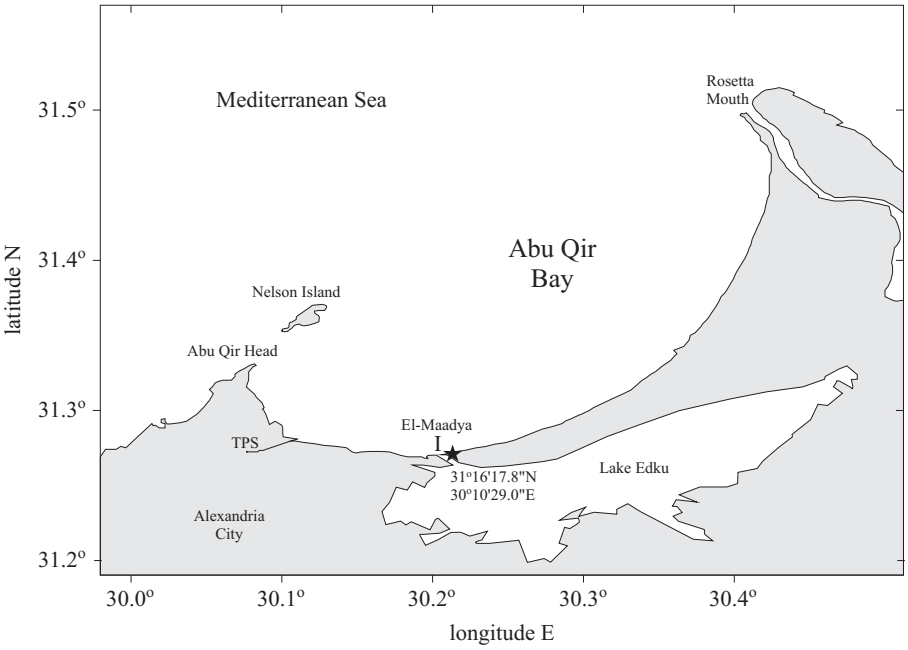

Figure 1. Map showing the rocky sampling site (I) on the eastern side of Boughaz El-Maadya on the coast of Abu Qir Bay, Alexandria, Egypt

removed by washing the seaweeds first with seawater and then with distilled water. The samples were air-dried at room temperature and kept in plastic bags for biochemical analysis. The algae were identified following Aleem (1993).

2.3. Protein estimation

The protein fraction (% of DW) was calculated from the elemental N determination using the nitrogen-protein conversion factor of 6.25 according to AOAC (1995).

2.4. Carbohydrate estimation

The total carbohydrate was estimated by following the phenol-sulphuric acid method of Dubois et al. (1956), using glucose as standard.

2.5. Lipid estimation

Lipids were extracted with a chloroform-methanol mixture (2:1 v/v). The lipids in chloroform were dried over anhydrous sodium sulphate, after which the solvent was removed by heating at 80°C under vacuum (AOAC 2000).

2.6. Fatty acid methyl esters

The lipids in chloroform were dried over anhydrous sodium sulphate, and the solvent was removed by heating at 60°C under vacuum. Fatty acid methyl esters (FAMEs) were prepared according to Vogel (1956). The analysis was performed in a gas liquid chromatograph (Pye Unicam Series 304 Gas Chromatograph) equipped with dual flame ionization detector and dual channel recorder. FAMEs were separated through a coiled glass column (1.5×4 mm) packed with Diatomite (100–120 mesh) and coated with 10% polyethylene glycol adipate (PEGA). The column oven temperature was programmed at 8°C min^{-1} from 70°C to 190°C, then isothermally at 190°C for 25 min with nitrogen at 30 ml min^{-1}. FAMEs were identified by comparing the retention times of experimental samples to those of known standards. The FA analysis was performed at the Central Laboratory of the Faculty of Agriculture, Cairo University.

2.7. Ash content

The ash content was estimated by ashing the ground dried samples overnight in a muffle furnace at 525°C.

2.8. Estimation of amino acids

A 3 g algal sample was prepared for hydrolysis according to Blackburn (1978) and Walker (1996) prior to the determination of amino acids. Amino acid analyses were carried out using an LC 3000 Eppendorf/Biotronik amino acid analyser using an H $125 \times$ type column at the Regional Centre for Mycology and Biotechnology, Al-Azhar University, Cairo, Egypt.

3. Statistical analysis

The levels of the biochemical components (proteins, carbohydrates, lipids, ash and moisture) were obtained as the mean of three replicates $\pm$ SD (standard deviation). In addition, the mean values of each biochemical component were subjected to one-way ANOVA followed by Duncan's multiple range test at $p < 0.05$ using the SPSS Inc. program version 15 (2006) to detect significant differences among the target species in different seasons.

4. Results and discussion

The biochemical contents of the three algal species are listed in Table 1. The results show that the protein content in the different species during spring was somewhat higher than in summer and autumn. In comparison

Table 1. The mean (± SD) contents of lipid, protein, carbohydrate, ash and moisture in the algal species collected at Abu Qir Bay from spring to autumn 2010

Parameter (% DW)		Protein	Carbohydrate	Lipid	Ash	Moisture
	spring	20.12 ± 0.23^{a}	44.81 ± 0.62^{a}	4.09 ± 0.2^{a}	22.08 ± 0.26^{a}	$8.9\text{b} \pm 0.08^{a}$
U. lactuca	summer	17.88 ± 0.10^{b}	46.42 ± 0.19^{b}	3.57 ± 0.1^{b}	17.56 ± 0.18^{b}	14.57 ± 0.5^{b}
	autumn	16.78 ± 0.04^{c}	42.09 ± 0.2^{c}	3.14 ± 0.0^{c}	23.19 ± 0.16^{c}	14.8 ± 0.75^{b}
	spring	12.93 ± 0.23^{d}	42.18 ± 0.15^{c}	2.39 ± 0.09^{d}	39.25 ± 0.84^{d}	3.25 ± 0.2^{c}
J. rubens	summer	11.14 ± 0.03^{e}	39.20 ± 0.11^{d}	2.30 ± 0.08^{d}	42.3 ± 0.21^{e}	5.1 ± 0.10^{d}
	autumn	9.76 ± 0.03^{f}	34.57 ± 0.29^{e}	1.47 ± 0.11^{e}	50.54 ± 0.29^{f}	3.66 ± 0.31^{c}
	spring	23.72 ± 0.03^{g}	50.49 ± 0.2^{f}	2.71 ± 0.05^{f}	13.02 ± 0.23^{g}	10.06 ± 0.18^{e}
P. capillacea	summer	20.95 ± 0.03^{h}	50.96 ± 0.11^{f}	2.09 ± 0.11^{g}	15.81 ± 0.29^{h}	10.19 ± 0.43^{e}
	autumn	17.35 ± 0.03^{i}	47.98 ± 0.12^{g}	1.76 ± 0.12^{h}	23.68 ± 0.32^{c}	$9.23 \pm 0.2^{a}e$
F-value		99999.99	3010.76	563.97	13987.34	1288.28
p-value		0.0001	0.0001	0.0001	0.0001	0.0001

Values with the same letter in each separate parameter are insignificant (one-way ANOVA).

with the other algal species, *Jania rubens* attained the highest protein level over the year. The protein content showed significant seasonal differences (one-way ANOVA, $p < 0.05$) between the different species as well as within each species. The protein content of seaweeds can vary according to species, seasonal period and geographic area (Fleurence 1999, Haroon 2000, Ratana-arporn & Chirapart 2006). Wong & Cheung (2000) recorded similar values in *P. capillacea* (26.95% during spring) and the red alga *Palmaria* sp. (13.87%), as well as conspicuously lower values in the green alga *U. lactuca* (7.06%), and in the brown algae *Himanthalia elongata* (7.49%) and *Laminaria ochroleuca* (7.49%). Haroon (2000) found a range of 9.42 ± 4.62–20.60 ± 5.0% of DW in *Enteromorpha* spp., while the protein content in *U. reticulata* was three times that in *U. lactuca* and slightly less than that in *Porphyra* sp. (Sánchez-Machado et al. 2004).

Carbohydrate is the most important component for metabolism as it supplies the energy needed for respiration and other metabolic processes. Changes in carbohydrate content in the different seasons were observed during the present study (Table 1). The highest carbohydrate content was found in *U. lactuca* and *P. capillacea* (46.42 and 50.96% of DW respectively) during summer, and in *J. rubens* (42.18% of DW) during spring. Significant seasonal differences (one-way ANOVA, $p < 0.05$) were observed in carbohydrate content in *U. lactuca*, but insignificant differences in *P. capillacea*. On the other hand, the differences between the carbohydrate content in *U. lactuca* during autumn and in *J. rubens* during spring were insignificant. Similar values were found in *U. reticulata* (50.24% of DW) (Shanmugam & Palpandi 2008), *Gracilaria* spp. (48.4% of DW) (Reeta & Kulandaivelu 1999) and *Enteromorpha* spp. (54.71% of DW – during July) (Haroon 2000). Furthermore, Sasikumar (2000) recorded respective carbohydrate contents of 20.4 and 54.6% in the green algae *Enteromorpha intestinalis* and *Codium linum*, but Hossain et al. (2003) found 19.93% in the brown alga *Sargassum horneri*. John & Anisha (2011) showed that the fermentation of carbohydrates obtained from macroalgal biomass can be used for the production of bioethanol.

The total lipid contents in the three seaweed species were relatively low (Table 1), the highest value being in *U. lactuca* during spring (4.09% of DW). The seasonal differences between the lipid content were significant (one-way ANOVA, $p < 0.05$) in two of the three algal species, the exception being *J. rubens*. These differences may be due to environmental factors affecting the growth of the seaweed. Sánchez-Machado et al. (2004) recorded that, as the temperature increased, the lipid level decreased and remained almost stable until the end of the growing season, so the results of the present study showed a decrease in lipid contents from spring till autumn.

Typically, seaweeds are not considered a good source of lipids (Ratana-arporn & Chirapart 2006), and the total lipid content has always been found to be $< 4\%$ (Herbreteau et al. 1997), but their PUFA content can be as high as that of land plants (Darcy-Vrillon 1993, Sánchez-Machado et al. 2004). The present results are supported by the findings of Reeta (1993) in *Sargassum wightii* (0.16–1.55%), Reeta & Kulandaivelu (1999) in *Gracilaria* spp. (0.78–3.97%), Sasikumar (2000) in *Enteromorpha intestinalis* (1.2%) and Shanmugam & Palpandi (2008) in *U. reticulata* (1.7%).

Ash contents were quite high, the highest level being in *J. rubens* (Table 1). This, in turn, was much higher than that recorded by Sánchez-Machado et al. (2004) in *Caulerpa lentillifera* (24.21%) and *U. reticulata* (17.58%). Meanwhile, the latter authors recorded comparable amounts of ash in *Himanthalia elongata* (26.78%), *Laminaria ochroleuca* (29.47%) and *Porphyra* sp. (19.07%). The statistical analyses showed significant seasonal differences (one-way ANOVA, $p < 0.05$) in ash content between all three algal species, except for an insignificant difference in autumn between *P. capillacea* and *U. lactuca* in autumn.

As shown in Table 2, the maximum total FAs were produced by *J. rubens* during autumn. Saturated FAs were predominant in *P. capillacea* during spring. This was due mainly to the presence of palmitic acid (C16:0), which made up 74.3% of the saturated FAs. A similar amount (70.01% of the total FAs) was found by Shanmugam & Palpandi (2008), with the dominance of C16:0 and C14:0 (50.76% and 11.77% respectively). Palmitic acid was also the major FA (85.36%) in *Gellidum micropterum* (Venkatesalu et al. 2004), in *Porphyra* spp. (63.19%) (Sánchez-Machado et al. 2004) and in other algal species like *Ergrezia menziesii*, *Chondracanthus canaliculatus* and *Ulva lobata* (Nelson et al. 2002) as well as in *Sargassum* species (Hamdy & Dawes 1998). This can be attributed to the influence of environmental factors and/or characteristic features of the individual genera (Khotimchenko 1991).

The results presented in Table 2 show that monounsaturated FAs attained the highest seasonal values in the three algae during autumn. They were the next most common FAs in *P. capillacea* (Shanmugam & Palpandi 2008), and oleic acid was present in a high concentration in *Porphyra* spp. (Dawczynski et al. 2007). In the present study *J. rubens* was characterized by the highest amount of PUFAs among the studied algae, and DHA (22:6ω_3) was the predominant component in autumn. In *U. rigida* and *U. fasciata* El-Shoubaky et al. (2008) found the same FAs except C20:4 (ω_6). Although fish oil is the major source of ω_3 and ω_6 long-chain PUFAs (arachidonic acid, EPA and DHA) (Ackman 1982), their original source is marine algae and phytoplankton, which are a major dietary

Table 2. Fatty acid content in algal species collected at Abu Qir Bay from spring to autumn 2010 (Sp. – Spring, Su. – Summer, Au. – Autumn)

Fatty acids (FA)	*U. lactuca*			*J. rubens*			*P. capillacea*		
	Sp.	Su.	Au.	Sp.	Su.	Au.	Sp.	Su.	Au.
Saturates (SFA)									
C 6:0	1.20	0.00	0.59	1.52	1.50	2.22	0.22	0.52	0.75
C 8:0	0.27	0.48	0.80	5.10	1.96	11.89	0.35	1.45	0.96
C 10:0	1.07	0.09	0.32	0.00	0.00	0.00	0.29	0.00	0.39
C 11:0	1.56	0.00	0.47	0.00	0.00	0.00	0.44	0.32	1.13
C 12:0	8.39	1.47	3.09	44.45	17.34	87.40	2.26	4.39	7.50
C 13:0	38.41	8.93	14.72	242.53	101.82	8.87	13.79	20.76	34.47
C 14:0	6.17	2.53	8.01	123.52	13.00	61.92	16.92	32.84	23.77
C 15:0	4.52	1.39	9.37	147.56	5.61	263.9	2.27	10.63	18.79
C 16:0	280.64	75.47	218.26	175.21	89.24	262.25	140.18	196.96	235.29
C 17:0	1.10	1.57	5.20	25.33	5.46	20.28	1.82	2.49	2.18
C 18:0	6.39	7.46	22.61	59.23	11.37	48.03	5.20	10.64	29.32
C 20:0	10.24	2.84	4.37	19.96	11.49	21.05	4.97	2.03	4.47
C 21:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15
C 24:0	0.00	0.00	4.94	0.00	0.00	0.00	0.00	0.00	0.00
Sum	359.96	102.23	292.75	844.41	258.79	787.81	188.71	283.03	360.17
% to T. FA	75.00	70.70	71.10	50.50	41.30	35.70	76.20	74.00	70.00
Monounsaturates (MUFA)									
C 14:1	22.03	5.66	5.78	33.00	66.04	293.47	9.53	12.35	47.75
C 15:1	24.61	6.99	4.54	184.08	74.65	333.29	9.73	2.82	4.02
C 16:1	10.14	2.42	5.27	74.48	36.95	139.52	4.56	6.36	10.80

Table 2. (*continued*)

Fatty acids (FA)	*U. lactuca*			*J. rubens*			*P. capillacea*		
	Sp.	Su.	Au.	Sp.	Su.	Au.	Sp.	Su.	Au.
Monounsaturates (MUFA)									
C 17:1	0.68	0.53	6.35	7.65	1.40	5.72	1.69	0.94	0.78
C 18:1	1.57	0.00	47.32	0.00	5.32	11.27	3.21	16.72	11.66
C 20:1	0.84	0.14	1.44	0.00	0.40	0.00	0.00	0.83	1.03
C 22:1	6.05	1.94	13.74	4.93	1.45	0.00	0.33	0.67	0.81
Sum	65.92	17.68	84.44	304.14	186.21	783.27	29.05	40.69	76.85
% to T. FA	13.80	12.20	20.50	18.20	29.80	35.50	11.70	10.60	14.90
Polyunsaturates (PUFA)									
C 18:2 ω_6	0.83	2.22	4.33	104.56	1.68	8.24	0.65	23.82	23.27
C 18:3 ω_3	0.00	0.85	6.47	44.69	0.00	0.00	1.04	0.34	0.71
C 20:2 ω_6	3.16	0.35	1.29		3.23	7.75	5.61	0.00	1.92
C 20:3 ω_6	0.00	0.00	0.31	8.01	9.79	26.57	0.46	3.12	2.03
C 20:4 ω_6	0.25	1.48	0.00	21.84	1.85	0.00	0.00	0.00	0.85
C 20:5 ω_3	0.17	0.00	0.00	3.52	1.92	7.90	1.29	4.42	1.87
C 22:2	3.65	1.38	1.63	0.00	5.91	15.23	0.00	1.14	4.52
C 22:6 ω3	45.80	18.48	19.98	340.00	156.56	566.91	20.94	26.10	42.59
Sum	53.86	24.76	34.01	522.62	180.94	632.60	29.99	58.94	77.76
% to T. FA	11.20	17.10	8.40	31.30	28.90	28.80	12.10	15.40	15.10
T. FA [μg g^{-1}]	479.74	144.67	411.20	1671.17	625.94	2203.68	247.75	382.66	514.78

Table 3. Amino acid content in algal species collected at Abu Qir Bay from spring to autumn 2010 (Sp. – Spring, Su. – Summer, Au. – Autumn)

Amino acids	*U. lactuca*			*J. rubens*			*P. capillacea*		
	Sp.	Su.	Au.	Sp.	Su.	Au.	Sp.	Su.	Au.
Essential amino acids									
threonine	142.03	92.30	178.59	1.49	1.76	10.16	127.63	166.99	159.10
valine	222.08	128.96	246.04	3.07	3.81	12.67	204.45	235.09	227.61
methionine	22.91	14.45	35.82	1.98	2.24	4.54	24.80	33.09	34.41
isoleucine	79.76	54.76	140.28	0.96	0.64	3.49	91.05	127.5	134.10
leucine	153.82	113.96	188.23	1.57	1.39	10.74	141.25	168.39	173.76
phenylalanine	147.39	87.81	265.27	1.99	0.60	6.77	116.94	196.23	191.39
histidine	261.52	134.12	193.72	13.99	16.92	41.01	247.38	255.78	245.03
lysine	113.71	77.77	182.96	3.20	1.99	9.76	182.82	261.39	248.14
Total	1143.20	704.13	1430.90	28.25	29.35	99.14	1136.3	1444.5	1413.50
% to Total Amino acids	34.60	35.80	32.30	32.00	32.10	37.00	40.10	36.80	36.60
Non-essential amino acids									
aspartic	189.24	149.78	233.78	8.21	15.31	32.87	171.50	223.27	215.86
serine	134.56	101.78	158.29	2.24	2.69	16.44	130.36	157.12	149.56
glutamine	169.30	124.13	191.94	2.51	2.77	19.93	151.36	196.18	178.22
proline	1150.10	459.43	1668.40	27.11	25.96	40.04	822.58	1259.70	1302.30
glycine	176.94	141.91	211.64	3.05	4.38	24.02	147.02	198.44	187.42
alanine	187.31	167.37	214.00	2.77	3.75	19.11	155.90	188.04	187.73
cystine	0.00	0.00	0.00	6.28	0.00	0.00	0.00	0.00	0.00

Table 3. (*continued*)

Amino acids	*U. lactuca*			*J. rubens*			*P. capillacea*		
	Sp.	Su.	Au.	Sp.	Su.	Au.	Sp.	Su.	Au.
Non-essential amino acids									
arginine	91.21	75.62	221.69	2.11	1.72	10.43	77.29	157.21	137.87
tyrosine	60.58	45.42	101.44	5.89	5.54	5.87	44.12	99.85	86.17
Total	2159.30	1265.4	3001.20	60.17	62.12	168.71	1700.10	2479.80	2445.10
% to Total Amino acids	65.40	64.20	67.70	68.00	67.90	63.00	59.90	63.20	63.40
Total Amino acids [μg g^{-1}]	3302.00	1970.00	4432.00	88.42	91.47	267.90	2836.00	3924.00	3859.00

source for fish (Nordøy 1989). PUFAs may be very responsive to environmental changes, as they play important roles in algal physiology (Nichols et al. 1998). A change in temperature from one season to another has a major effect on the FA composition of cell membranes (Phleger 1991).

The seasonal profiles of amino acids in the three seaweed species are presented in Table 3. Proline was the major amino acid in *U. lactuca*, accounting for 34.8, 23.3 and 37.6% of the total amino acids during spring, summer and autumn respectively. Proline is known to accumulate in large quantities in higher plants in response to environmental stresses (Ashraf & Foolad 2007), and many plants accumulate proline as a nontoxic and protective osmolyte under saline conditions (Khatkar & Kuhad 2000). The amounts of amino acids seem to be vary in different algal species. Examining different seaweeds, Christine et al. (2007) found that essential amino acids made up over 30% of the total amino acids in different seaweeds. Other studies recorded $37 \pm 38\%$ in *Porphyra tenera*, *Grateloupia turuturu*, *Ulva pertusa* and *Codium fragile* (Fujiwara-Arasaki et al. 1984), 37–42% in *U. lactuca* and *Gelidium amansii* (Ochiai et al. 1987), $36.5 \pm 38.6\%$ in *U. rigida* and *U. rotundata* (Fleurence et al. 1995) and 45–49% in *Kappaphycus alvarezii* and *Hypnea musciformis* (Kumar & Kaladharan 2007). During the present study *U. lactuca* and *P. capillacea* contained distinctly higher concentrations of valine than *J. rubens*, especially during spring. These results coincide with the findings of Ratana-arporn & Chirapart (2006), who reported that essential amino acids made up almost 40% of the total amino acids in *Caulerpa lentillifera* and *U. reticulata*. Comparison of the amino acid compositions of seaweeds with the FAO reference pattern (FAO 1981) and those of other food proteins (Orr & Watt 1968) indicate the high nutritional value of seaweed proteins, which are able to make an active contribution to the total required amount of essential amino acids in food.

5. Conclusion

The present study revealed pronounced seasonal variations in the biochemical composition of three algal species. *Pterocladia capillacea* was characterized by the highest protein and carbohydrate contents, while *Ulva lactuca* contained more lipids than the other two species. *J. rubens* demonstrated distinctly higher levels of total fatty acids than the other two algal species, but saturated fatty acids were comparatively high in *P. capillacea* during spring compared to the other species, mainly because of the presence of palmitic acid (C16:0). Polyunsaturated fatty acids (PUFA) were the highest in *J. rubens*, with the dominance of DHA ($22{:}6\omega_3$ especially during summer. Proline was the major amino acid in the three algal species, reaching maximum amounts in *U. lactuca*.

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