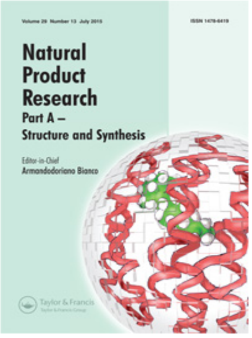

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Fatty acid profile of different species of algae of the *Cystoseira* genus: a nutraceutical perspective

Catarina Vizetto-Duarte[a], Hugo Pereira[a], Carolina Bruno de Sousa[a], Amélia Pilar Rauter[b], Fernando Albericio[cdef1], Luísa Custódio[a], Luísa Barreira[a] and João Varela[a]*

[a]*Centre of Marine Sciences, University of Algarve, Campus of Gambelas, 8005-139 Faro, Portugal;* [b]*Department of Chemistry and Biochemistry, Center of Chemistry and Biochemistry, Faculty of Sciences University of Lisbon, Campo Grande, Ed. C8, Piso 5, 1749-016 Lisbon, Portugal;* [c]*Institute for Research in Biomedicine, Barcelona Science Park, Baldiri Reixac 10, 08028 Barcelona, Spain;* [d]*CIBER-BBN, Networking Centre on Bioengineering, Biomaterials and Nanomedicine, Barcelona Science Park, Baldiri Reixac 10, 08028 Barcelona, Spain;* [e]*Department of Organic Chemistry, University of Barcelona, Martí i Franqués 1–11, 08028 Barcelona, Spain;* [f]*School of Chemistry, University of KwaZulu-Natal, 4001 Durban, South Africa*

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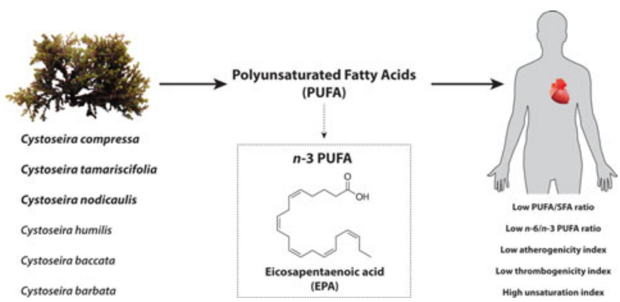

The fatty acid (FA) composition of six macroalgae from the *Cystoseira* genus, namely *Cystoseira compressa*, *Cystoseira humilis*, *Cystoseira tamariscifolia, Cystoseira nodicaulis, Cystoseira baccata* and *Cystoseira barbata*, was determined. Polyunsaturated fatty acids (PUFA) corresponded to 29–46% of the total FA detected. *C. compressa*, *C. tamariscifolia* and *C. nodicaulis* stood out for their low PUFA/saturated fatty acid, low n-6 PUFA/n-3 PUFA ratios as well as favourable unsaturation, atherogenicity and thrombogenicity indices, suggesting a high nutritional value with potential applications in the nutraceutical industry.

Keywords: brown algae; *Cystoseira*; fatty acids; nutrition; PUFA

1. Introduction

Marine macroalgae are being increasingly exploited as sources of polyunsaturated fatty acids (PUFA) for nutritional purposes (Pereira et al. 2012). The main dietary source of n-3 PUFA in humans is seafood, through the direct consumption of oily fish (e.g. salmon and mackerel). However, the sustainability of fish sources for the exploitation of PUFA is rather uncertain due to declining fish stocks and increasing market demand (FAO 2010). Hence, there is a need to find sustainable alternative sources of PUFA for food and feed applications. Ochrophyta (e.g.

*Corresponding author. Email: jvarela@ualg.pt

Cystoseira) is one of the most promising phyla of algae due to increased amounts of PUFA commonly detected in several species when compared to other algal phyla (Colombo et al. 2006; Silva et al. 2013).

In this sense, the objectives of this work are to report the fatty acid (FA) profile of six species of brown macroalgae belonging to the *Cystoseira* genus, namely *Cystoseira humilis*, *Cystoseira compressa*, *Cystoseira tamariscifolia*, *Cystoseira nodicaulis*, *Cystoseira baccata* and *Cystoseira barbata*, as well as consider and discuss the use of these seaweeds as sources of nutraceuticals. To the best of the authors' knowledge, this is the first report on the FA profile of *C. compressa*, *C. humilis*, *C. baccata* and *C. barbata*.

2. Results and discussion

2.1. *Total fatty acid methyl esters (FAME) concentration*

Total FAME concentration ranged from 6.7 in *C. humilis* to 9.4 mg/g of dry weight in *C. nodicaulis* (Figure 1). These data are in accordance with the values obtained for other ochrophytes (Pereira et al. 2012). However, the total FAME concentration obtained for *C. nodicaulis* and *C. tamariscifolia* in this work (9.4 and 8.4, respectively) was higher than the ones reported by Silva et al. 2013 (1.9 and 0.8, respectively).

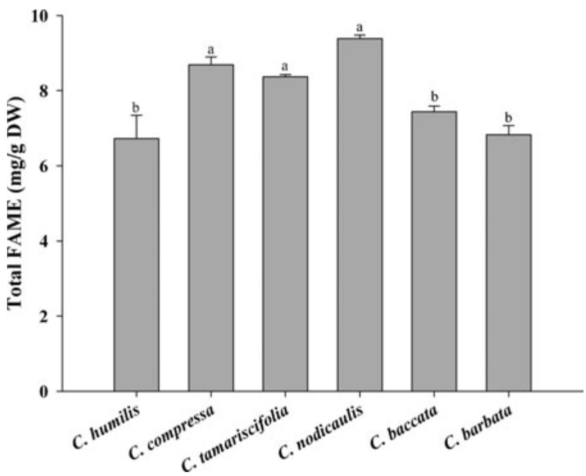

Figure 1. Total FAME concentration of different macroalgae from *Cystoseira* genus. Bars represent means ± SD ($n = 4$). Different letters (a–b) indicate significant differences by Tukey HSD test at $p < 0.05$.

2.2. *FA profiles*

Saturated fatty acid (SFA) varied from 34% in *C. compressa* to 54% in *C. barbata*. Palmitic acid (C16:0) was the most abundant SFA in all studied species, ranging from 26% in *C. compressa* and *C. nodicaulis* to 35% of total fatty acids (TFA) in *C. barbata* (Table 1). Our results are in accordance with the ones obtained in different *Cystoseira* species, namely *C. nodicaulis, C. tamariscifolia, C. usneoides, C. abies-marina, C. crinita* and *C. osmundacea* from other locations (Khotimchenko et al. 2002; Frikha et al. 2011; Ivanova et al. 2013; Patarra et al. 2013; Silva et al. 2013). It is known that a high intake of palmitic acid has a cholesterol-raising effect (Clandinin et al. 2000); however, this effect can be counterbalanced by high levels of linoleic acid (LA) (Clandinin et al. 2000; French et al. 2002). Monounsaturated fatty acids (MUFA)

Table 1. Fatty acid methyl esters (FAME) profile of different *Cystoseira* species (*C. humilis*, *C. compressa*, *C. tamariscifolia*, *C. nodicaulis* and *C. baccata*).

Fatty acid (%)	Common name	*C. humilis*	*C. compressa*	*C. tamariscifolia*	*C. nodicaulis*	*C. baccata*	*C. barbata*
C12:0	Lauric acid	0.33 ± 0.04	nd	nd	nd	nd	nd
C14:0	Myristic acid	15.25 ± 1.06	4.34 ± 0.05	7.83 ± 0.05	7.15 ± 0.20	9.69 ± 0.31	8.59 ± 0.10
C15:0	Pentadecanoic acid	0.42 ± 0.01	0.32 ± 0.01	0.50 ± 0.01	0.48 ± 0.02	0.75 ± 0.10	1.11 ± 0.08
C16:0	Palmitic acid	33.86 ± 0.44	26.47 ± 0.08	27.47 ± 0.11	26.81 ± 0.12	28.09 ± 0.18	35.15 ± 0.61
C17:0	Margaric acid	nd	nd	0.17 ± 0.01	0.19 ± 0.01	1.14 ± 0.37	1.47 ± 0.02
C18:0	Stearic acid	1.08 ± 0.06	0.76 ± 0.01	1.22 ± 0.03	1.17 ± 0.11	1.48 ± 0.19	2.14 ± 0.15
C20:0	Arachidic acid	nd	0.72 ± 0.03	0.71 ± 0.01	0.98 ± 0.01	1.45 ± 0.05	1.78 ± 0.19
C22:0	Behenic acid	nd	0.93 ± 0.03	0.78 ± 0.01	0.67 ± 0.12	2.01 ± 0.09	2.17 ± 0.39
C24:0	Lignoceric acid	nd	0.74 ± 0.03	0.54 ± 0.02	nd	1.72 ± 0.07	1.98 ± 0.23
∑ SFA		50.94 ± 1.15[b]	34.28 ± 0.11[f]	39.22 ± 0.13[d]	37.45 ± 0.28[e]	46.33 ± 0.57[c]	54.39 ± 0.81[a]
C16:1	Palmitoleic acid	3.84 ± 0.12	2.74 ± 0.01	7.50 ± 0.08	2.31 ± 0.03	13.15 ± 0.35	4.87 ± 0.21
C18:1	Oleic acid	9.24 ± 0.22	17.07 ± 0.06	8.73 ± 0.16	16.44 ± 0.15	10.00 ± 0.21	11.68 ± 0.12
C20:1	Eicosenoic acid	nd	nd	0.21 ± 0.01	0.15 ± 0.01	nd	nd
∑vMUFA		13.08 ± 0.20[d]	19.81 ± 0.06[b]	16.44 ± 0.09[c]	18.90 ± 0.15[b]	23.15 ± 0.41[a]	16.55 ± 0.24[c]
C18:2 (n-6)	Linoleic acid	17.08 ± 0.41	10.45 ± 0.04	7.05 ± 0.06	8.93 ± 0.03	3.48 ± 0.23	5.31 ± 0.18
C20:2 (n-6)	Eicosadienoic acid	0.57 ± 0.01	0.60 ± 0.01	0.40 ± 0.01	0.62 ± 0.01	0.89 ± 0.02	1.26 ± 0.11
C16:3 (n-3)	Hexadecatrienoic acid	nd	nd	0.34 ± 0.01	nd	nd	nd
C18:3 (n-6)	γ-Linolenic acid	nd	2.28 ± 0.01	1.76 ± 0.02	nd	nd	nd
C20:3 (n-6)	Eicosatrienoic acid	1.04 ± 0.09	2.35 ± 0.01	2.13 ± 0.03	2.53 ± 0.05	0.99 ± 0.03	1.20 ± 0.12
C20:4 (n-6)	Arachidonic acid	11.71 ± 1.22	20.11 ± 0.05	22.82 ± 0.16	26.51 ± 0.20	19.93 ± 0.44	19.08 ± 0.82
C20:5 (n-3)	Eicosapentaenoic acid	5.58 ± 0.56	10.12 ± 0.05	9.84 ± 0.13	5.06 ± 0.02	5.23 ± 0.33	2.21 ± 0.21
∑ PUFA		35.98 ± 0.40[b]	45.91 ± 0.09[a]	44.34 ± 0.22[a]	43.65 ± 0.21[a]	30.52 ± 0.60[c]	29.06 ± 0.88[d]

Notes: Results are expressed as means ± SD (% of total FAME). [a–f]Different letters in the same row indicate significant differences between species ($p < 0.05$). nd, not detected.

Table 2. Nutritional indices calculated for different *Cystoseira* species (*C. humilis, C. compressa, C. tamariscifolia, C. nodicaulis* and *C. baccata*).

	C. humilis	*C. compressa*	*C. tamariscifolia*	*C. nodicaulis*	*C. baccata*	*C. barbata*
PUFA/SFA	0.71^{a}	1.34^{a}	1.13^{a}	1.17^{a}	0.66^{a}	0.53^{a}
$\sum$ n-3	5.58 ± 0.56^{b}	10.12 ± 0.05^{a}	10.18 ± 0.13^{a}	5.06 ± 0.02^{b}	5.23 ± 0.33^{b}	2.21 ± 0.21^{b}
$\sum$ n-6	30.40 ± 1.29^{c}	$35.79 \pm 0.07^{a,b}$	$34.16 \pm 0.18^{b,c}$	38.59 ± 0.21^{a}	25.29 ± 0.50^{d}	26.85 ± 0.86^{d}
$\sum$ n-6/$\sum$ n-3	$5.45^{b,c}$	$3.54^{b,c}$	3.36^{c}	7.63^{b}	$4.84^{b,c}$	12.15^{a}
UI	126.17^{d}	186.83^{a}	184.52^{a}	176.95^{b}	140.72^{c}	120.67^{e}
AI	1.94^{a}	0.67^{e}	0.97^{d}	0.89^{d}	1.25^{c}	1.52^{b}
TI	1.30^{b}	0.54^{e}	0.65^{e}	0.80^{d}	0.98^{c}	1.61^{a}

Notes: $^{a-e}$Different letters in the same row indicate significant differences between species by Tukey HSD test at $p < 0.05$. SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; UI, unsaturation index; AI, atherogenic index; TI, thrombogenic index.

ranged from 13% of TFA in *C. humilis* to 23% of TFA in *C. baccata* (Table 1). Palmitoleic acid (C16:1) varied from 2% in *C. nodicaulis* to 13% in *C. baccata*. Oleic acid (C18:1) corresponded to 9% and 17% of TFA in *C. tamariscifolia* and *C. compressa*, respectively. These MUFA are commonly reported as the majors MUFA in *C. barbata* (Frikha et al. 2011), *C. nodicaulis, C. tamariscifolia*, *C. usneoides* (Silva et al. 2013), *C. abies-marina* (Patarra et al. 2013), *C. crinita* (Ivanova et al. 2013) and *C. osmundacea* (Khotimchenko et al. 2002). Diets rich in MUFA (and PUFA) have shown to reduce the total cholesterol in plasma and low density lipoprotein cholesterol in clinical studies (Ginsberg et al. 1990). Regarding PUFA, *C. compressa*, *C. tamariscifolia* and *C. nodicaulis* were the species with the highest PUFA levels (Table 1). Total PUFA contents varied from 29% in *C. barbata* and 46% of TFA in *C. compressa*. Arachidonic acid (AA, C20:4n-6) was the most abundant PUFA detected in all studied species (12–27% of TFA) except for *C. humilis* which presented a higher abundance of LA (C18:2n-6). These results are in accordance with previous studies, where AA was reported to be the main PUFA in *C. osmundacea* (Khotimchenko et al. 2002). Although AA may have a proinflammatory role, recent studies have shown that AA supplementation can contribute to lower coronary risk (Chowdhury et al. 2014) and might be beneficial for the development of the nervous central system (Uauy et al. 2001). Interestingly, n-3 PUFA, such as eicosapentaenoic acid (C20:5n-3, EPA), which was detected in most species at relatively high amounts (5–10%), has been shown to compete with the conversion of LA to AA, regulating in this way the relative amounts of n-3 and n-6 PUFA (Calder 2012). Moreover, EPA presents potential beneficial applications in asthma, psoriasis, rheumatoid arthritis, antibiotic, inflammatory bowel disease, depression, allergies, cardiovascular diseases and cancer treatment, among others (Calder 2010). Considering all these benefits, there is increasing interest in the incorporation of EPA in diet in order to meet the European recommendations of n-3 PUFA, namely EPA + docosahexaenoic acid (DHA): 250 mg/day (EFSA 2010). Although DHA was not detected in any of the samples evaluated in this work, these species can be interesting sources of EPA. DHA is generally absent or is present at low levels in different ochrophytes, including *C. nodicaulis*, *C. tamariscifolia* and *C. usneoides* (Pereira et al. 2012; Silva et al. 2013).

2.3. *Nutritional assessment*

The PUFA/SFA ratio was found to be between 1.34 for *C. compressa* and 0.53 for *C. barbata* (Table 2). Since the mean ratio of PUFA/SFA recommended by the British Department of Health is 0.45 or higher (HMSO 1994), all examined species exhibit a favourable PUFA/SFA ratio. A growing attention has been given to the n-6 PUFA/n-3 PUFA ratio. In fact, WHO currently recommends a ratio lower than 10 in order to prevent inflammatory, cardiovascular and neurological disorders (Kumari et al. 2013). The n-6 PUFA/n-3 PUFA ratios determined in this study ranged from 3.36 in *C. tamariscifolia* to 7.63 in *C. nodicaulis* (Table 2), which are within the values recommended by WHO. The only exception was obtained with *C. barbata* (12.15). The present Western diet is considered to be deficient in n-3 PUFA, with estimated n-6 to n-3 ratios of 15–20 (Simopoulos 2008). Hence, brown macroalgae, and *Cystoseira* in particular, could decrease n-6 PUFA/n-3 PUFA ratios if used in nutraceuticals applications or in food products. Furthermore, the high unsaturation indices (UI) determined for *Cystoseira* algae (Table 2) suggests that these macroalgae may also be beneficial for the prevention of type-2 diabetes mellitus, as higher flexibility of biological membranes has been linked to improved glucose transport effectiveness (Weijers 2012). Lastly, in this study, the atherogenicity (AI) and thrombogenic (TI) indices ranged from 0.67 to 1.94 and 0.54 to 1.61, respectively (Table 2). These low AI and TI are similar to those reported by Kumari et al. (2013) for other *Cystoseira* species, such as *C. indica* (AI = 0.8 and TI = 0.8) and *C. trinodis* (AI = 0.6 and TI = 0.5). These results are significant, as it has been shown that the introduction of brown algae in the diet of hyperlipidemic-induced rats decreases the AI of their serum lipid profile (Yoon et al. 2008). Moreover, López-López et al. (2009) have shown that the addition of macroalgae to meat products improved their TI and AI, thereby illustrating the potential of macroalgae in development of healthier lipid formulations.

3. Conclusions

Among the FAME profiles described for the first time, *C. compressa* stands out for its high content of unsaturated fatty acids (especially PUFA), its low n-6 PUFA/n-3 PUFA ratios and AI and TI indices as well as high PUFA/SFA and UI. Overall, this species, together with *C. tamariscifolia* and *C. nodicaulis*, presents a FA profile that would be considered as beneficial if incorporated in the formulation of low fat food and feed and PUFA-rich nutraceuticals.

Supplementary material

Experimental details relating to this paper are available online.

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Note

1. Current address: School of Chemistry,Yachay Tech, Yachay City of Knowledge, 100119-Urcuqui, Ecuador.

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