Fatty Acids Composition of Marine Macroalgae (Review)

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Abstract

Fatty acids (FA) are important nutritional substances and metabolites in living organism. Degenerative diseases related to inappropriate FAs consumption cause the two thirds cases of the population death who are living in affluent, industrialized nations. Marine algae represent a considerable part of the littoral biomass. Many algal species have long been used as human food, animal fodder and source of valuable substances. In addition, algal species are of interest from the pharmaceutical point of view. Marine algae are rich in essential fatty acids (FAs) especially polyunsaturated fatty acids (PUFAs) such as Omega-3(n-3 seri) and Omega-6 (n-6 seri),which are important in the nutrition of humans and animals. Because of high n-3 content, the n-6/n-3 ratio in macroalgae is lower than 10 which is congruent with WHO nutritional recommendations. Although each member of marine macrophytic algae has its characteristic FA pattern, but up to now, only a limited numbers of algal species have been investigated for their FAs composition. Hence, the objective of this review study is to explain briefly the FAs content and composition in some investigated marine macroalgae and also to assess the potential of some members of three phylum macroalgae, green (Chlorophyta), Brown (Phaeophyta) and red (Rhodophyta), as the sources of FAs especially PUFAs and very long chain PUFAs (VLCPUFAs) and their beneficial effects to cure and remedy some of the human diseases.

Keywords: FAs, Omega-3, PUFAs, Chlorophyta, Phaeophyta, Rhodophyta

Abbreviations: FAs: fatty acids, EFA: essential fatty acid, TFA: total fatty acid, FAME: fatty acid methyl ester, SFA: saturated fatty acid, MUFA: monounsaturated fatty acid, PUFA: polyunsaturated fatty acid, VLPUFA: very long chain polyunsaturated fatty acid, ALA: α-linolenic acid, LA: linoleic acid, EPA: eicosapentaenoic acid, DHA: docosahexaenoic acid, AA: arachidonic acid.

Introduction

Fatty acids (FA) are widely occurring in natural fats and dietary oils and they are also important nutritious substances and metabolites in living organism (Chem and Chung, 2002). Degenerative diseases related to in-

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appropriate FAs consumption cause the two thirds cases of the population death who are living in affluent, industrialized nations. (Salem et al., 1996). Sixty eight percent of the human deaths including cardiovascular disease (43.8%), cancer (22.4%), and diabetes (1.8%) are attributed to the FA degenerative diseases (Horrobin and Bennett, 1999; Terry et al., 2001). Some studies have recognized the vital role of conjugated FAs as bioactive molecules in the treatment of tumors and other cancer-related problems, with varying degree of cytotoxic effects on the cancer cells (Kohno et al., 2002 ; Kawagishi et al., 2002). The two main polyunsaturated fatty acid (PUFA) classes are n-3 (omega-3) and n-6 (omega-6) which play an important role in the prevention of cardio vascular diseases, osteoarthritis and diabetes. Several studies have found inverse correlation between the PUFA/SFA ratios and cardiovascular diseases and suggested that replacement of SFA with PUFA in the human diet will decrease these health problems (Simopolous et al., 2000; Erkkila et al., 2008). It is important to maintain an appropriate balance of n-3 and n-6 in the diet as these FAs work together to promote health. The n-3 FAs have been recognized to exhibit anti-inflammatory and antioxidant activity, which may contribute to their beneficial cardiac (Simopoulos, 2008, Mozafarian et al., 2005; Hang and Wang, 2004), and anticancer effects on the breast cancer (Patterson et al., 2011). In contrast, most n-6 FAs tend to promote inflammation and tumor growth (Okuyama et al., 1997). Higher n-3 FAs content which led to the low ratio of n-6/n-3 is considered as a positive characteristic associated with prevention of inflammatory, cardiovascular and neural disorders (Marszalek and Lodish, 2005). Recently, it became clear that besides prevention of cardiovascular diseases (Einvik et al., 2010, Mozafarian et al., 2005; Horrobin, 1998), some n-3 PUFAs, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are the major components of brain cells and crucial for proper development and functional role of brain and the nervous system (Sinclair et al., 2007; Murakami et al., 2010). Also with a worldwide increase in lifetime expectancy, some studies revealed that n-3 FA supplementary diet results in an increased muscle protein synthesis, which led to preventing the sarcopenia that result in loss of muscle tissue as a natural part of the aging process (Smith et al., 2011). PUFAs are essential nutrients which never or rarely synthesized by mammals. Therefore, they must be ingested via dietary sources (Gerster, 1998; Broadhurst et al., 2002). Moreover global nutritional security concerns have been raised in relation to the increasing trend of human population. Consequently, a quest to explore and utilize foods from nonconventional sources of both terrestrial and marine origins has been made. Marine macroalgae (seaweeds) are the examples of the living renewable sources of the oceans with potential applications in food. Today seaweeds are the raw material for many industrial productions like agar, alginate and carrageenan but they continue to be widely consumed as food in Asian

countries. They are nutritionally valuable as fresh or dried vegetables, or as ingredients in a wide variety of prepared foods which various types of seaweed are addressed as an appropriate candidate of potential food or nutritional supplement (Burtin, 2003). During the past 40 years, marine algae received a lot of attention as potential sources of compounds possessing a wide range of biological activities including antimicrobial, antiviral, anti-inflammatory, immunotropic, antitumor, as well as ichthyotoxic properties (Abu-Elwafa et al., 2009; Lima-Filho et al., 2002). Seaweeds have been used since ancient times as food, fodder, fertilizer and as source of medicine (Manivannan et al., 2008). Beneficial nutrients in seaweeds include vitamins, trace minerals, protein, lipids, amino acids, and dietary fibers, all of which form parts of a healthy diet (Dawczynski et al., 2007; Bocanegra et al., 2009). These properties confirm that seaweeds can be used as a low-calorie food, which might be important in body weight control, as well as cardiovascular health benefits (Bocanegra et al., 2009). FAs and lipids are constituents of all algae cells, where they function as membrane compounds, storage products, metabolites and as a source of energy (Chem and Chung, 2002). Lipids represent only 1–5% of algal dry matter and exhibit an interesting PUFA composition. Algal FAs are beneficial and act as prophylactic supplements for type-2-diabetes, atherosclerosis, coronary heart diseases, arrhythmias and cancer (Doughman et al., 2007). Moreover, long-chain unsaturated FAs (LA, Oleic acid, and Linolenic acid) show antibacterial activity and are the key ingredients of antimicrobial food additives and some antibacterial herbs (Zheng et al., 2005). They are bactericidal agent to important pathogenic microorganisms, including methicillin-resistant *Staphylococcus aureus, Helicobacter pylori*, and mycobacteria (Seidel and Taylor, 2004; Sun et al., 2003). This may be a more general characteristic of seaweeds because a similar result was observed in the edible macroalgae, e.g. *Grateloupia turuturu* where the most abundant FA were palmitic acid (C16:0) and EPA (C20:5 n-3) at proportions of 52% and 12%, respectively (Seidel and Taylor, 2004). PUFAs are unique features of lipids of marine organisms and have considerable health and economic significance (Bhaskar et al., 2004). The n-3 PUFAs are provided by fish and plant sources, whereas the n-6 PUFAs are ingested mainly via vegetable oil (Broadhurst et al., 2002 and Simopoulos, 2008). Until now fish oils have been known as the major source of n-3 and n-6 long-chain PUFAs, such as arachidonic acid (AA), eicosapentaenoic acid (EPA) and DHA (Van Ginneken et al., 2011). However, it is noteworthy that the original source of these long-chain PUFAs is not the fish itself, but marine algae and phytoplankton which form their major dietary source (Nordy and Dyerberg, 1989). Quality as well as quantity of algal lipids is very important in the nutrition of marine animals as algae are the main source of essential fatty acids (EFAs) which are stored and synthesized in marine animals' body (Brown et al., 1997). The red and brown algae are rich in FAs with 20 car-

bons: EPA (C 20:5, n-3) and AA (C20:4, n-6) (Banerjee et al., 2009). Marine algae are rich in PUFAs of the n-3 and n-6 series, which are considered essential FAs for humans and animals. Some of these FAs (20:4 n-6, 20:5 n-3) have high biological activity and are converted into eicosanoids. In addition, PUFAs are of interest in cosmetics such as sun lotions and as regenerating and anti-wrinkle products. Because of the huge and renewable biomass, seaweeds are a potential source of FAs for biotechnology and a dietary source of essential fatty acids (Khotimchenko et al., 2002). The total n-6 content in macroalgae is very low (only 3%) which leading to a low n-6/n-3 ratio which, based on current recommendation by the WHO should be lower than 10 in the diet(Sanchez-Machado et al., 2004).the higher ratio of n-6/n-3can possibly be improved by addition of certain edible seaweeds, because of their high n-3 content. Seaweeds are also reported to contain much lower concentrations of Trans FAs than today's diet (Simopoulos, 2008).

The objective of this review, is to explain briefly synthesis and structure of FAs and also to assess the potential of several Chlorophyta, Phaeophyta and Rhodophyta macroalgae as a source of FAs especially PUFAs and very long chain PUFAs (VLCPUFAs) and their beneficial effects to cure and remedy some of the human diseases.

Method and Search Strategy

To conduct this study key words such as fatty acids, saturated fatty acids, unsaturated fatty acids, polyunsaturated fatty acids, human healt, Human diseases, Inflamentory, nervous system diseases, cardiovascular diseases, Diabetics disease, Macroalgae, Seaweeds, Chlorophyta, Phaeophyta, Rhodophyta, EPA, DHA, Omega-3, Omega-6 were used and data sources of google scholar, web of science, science direct, pup med, elsevier and springer were searched using the combination of mentioned keywords.

Results

Natural source of FAs

The most common SFA in animals, plants and microorganisms is palmitic acid (16:0). Stearic acid (18:0) is a major FA in animals and some fungi, and a minor component in most plants. Myristic acid (14:0) has a widespread occurrence, occasionally as a major component. Shorter-chain saturated acids with 8–10 carbon atoms are found in milk and coconut triacylglycerol. Oleic acid (18:1 n-9) is the most common MUFA in plants and animals (Muller et al., 2001). Palmitoleic acid (16:1) also occurs widely in animals, plants and microorganisms, and is a major component in some seed oils. Linoleic acid (LA) (18:2 n-6) is a major FA in plant lipids. In animals it is derived mainly from dietary plant oils. Arachidonic acid (AA) (20:4 n-6) is a major component of membrane phospholipids throughout the animal kingdom. ALA (α-linolenic acid) (18:3, n-3) is found in higher plants (soya bean oil and rape seed oils) and algae (Rustan and Drevon, 2005). EPA (eicosapentaenoic acid) (20:5, n-3) and DHA (docosahexaenoic acid) (22:6, n-3) are major FA of marine algae, fatty fish and

fish oils. For example, DHA is found in high concentrations, especially in phospholipids in the brain, retina and testis (Krauss-Etschmann et al., 2007).

In terms of EFAs, fish and fish products are the most important sources of the highly n-3 unsaturated FAs in the human diet but their suitability and stability for human consumption is doubtful because of the biosafety aspects and declining trend of fish's resource. Some studies (Worm et al., 2009; Worm and Mayers, 2003) predict a rapid worldwide depletion of fishes population. Already 29% of edible fish species have been declined by 90% which, indicates collapse of fisheries activities and extinction of salt-water fishes by the year of 2048 (Worm et al., 2009). Therefore due to increasing commercial interest in these long chain fatty acids (Lindequist et al., 2001), an alternative source of high quality essential PUFA must be found (Ward and Singh, 2005). Generating alternative bio-resources (i.e. transgenic plants) of omega-3, i.e. eicosapentaenoic acid (20:5 n-3, EPA) and docosahexaenoic acid (22:6 n-3, DHA) has previously proved problematic. Vegetables are the main sources of 18:1, 18:2 and 18:3 FAs. The most important n–6 fatty acid, LA, is found in large amounts in corn oil, safflower oil, and soybean oil (Adam, 1989). Because of its oxidation stability, delicious flavor and wholesome characteristics increasing oil content and improving the FA composition in the seeds oil are important breeding goals for oil crops. Algae are the main resource of EFAs among photosynthetic organisms.

Structure and synthesis of fatty acids

Fatty acids are carbon chains with a methyl group at one end of the molecule (designated omega, ω) and a carboxyl group at the other end. Saturated fatty acids (SFA) are saturated with hydrogen. Most SFA are straight hydrocarbon chains with an even number of carbon atoms. The most common FAs contain 12–22 carbon atoms. Monounsaturated fatty acids (MUFA) have one carbon–carbon double bond, which can occur in different positions. The most common monounsaturated fatty acids have a chain length of 16–22 and a double bond with the cis configuration (Muller et al., 2001).Trans isomers may be produced during industrial processing (hydrogenation) of unsaturated oils and in the gastrointestinal tract of ruminants. In PUFAs the first double bond may be found between the third and the fourth carbon atom from the methyl end, these are called n-3 FA. If the first double bond is between the sixth and seventh carbon atom, then they are called n-6 FA. The double bonds in PUFAs are separated from each other by a methylene grouping (Rustan and Drevon, 2005). PUFAs, which are produced only by plants and phytoplankton, are essential to all higher organisms, including mammals and fish. Each FAs family has very different biochemical roles and distinct enzyme activities required for FA biosynthesis, almost all of the required long chain unsaturated fatty acids are synthesized by vertebrates through several elongation and desaturation steps. The exceptions are α-linolenic acid (ALA) and linoleic acid (LA) (Schmitz and Ecker, 2008; Radwan et

al., 1991).

Saturated fats and cholesterol represent the most established risk factor in our diets, whereas mono and PUFA probably are the most important lipids that would provide beneficial effects. Oleic acid is one of the major MUFA of membrane glycerolipids in both plants and animals. The (n-3) and (n-6) PUFAs (linolenate and linoleate, respectively) cannot be synthesized by mammals and therefore must be obtained from dietary sources. These precursors for the biosynthesis of all other n-3 and n-6 PUFA cannot be synthesized by vertebrates and must, therefore, be present in diet, hence classified as essential fatty acids (Lindequest et al., 2001). DHA and EPA are dietary fats which are incorporated in all cell membranes and play important role in anti-inflammatory processes and cell membrane viscosity (Swanson et al., 2012). DHA have essential role in properly fetal development (Conquer et al., 2000). DHA is the most important cell membranes component's which found in abundance in the brain and retina (Krauss-Etschmann et al., 2007). Humans can convert ALA to EPA and DHA, however, very long chain polyunsaturated fatty acids (VLCPUFA; >C18) are only synthesized to a limited extent of 8% and 21% for EPA and 4% and 9% for DHA in men and women respectively (Burdge et al., 2003; Emken et al., 1994). Hence, in addition to the essential fatty acids (EFAs), VLCPUFA must also be taken through dietary means or direct supplementation in order to meet with the European recommendations (EPA + DHA 250 mg/day) (EFSA, 2010). Synthesis of long chain n-3 and n-6 PUFA relies on the same enzymes and, generally, an increase in the amount of one of these EFAs implies a decrease in the levels of the other, due to competition for the same metabolic enzymes (Marszdek et al., 2005). This may cause an imbalance in the content of FA which causes a negative impact on human health. For example, a diet rich in n-6 PUFA may be linked to a prothrombotic and pro aggregatory physiological state (Simopoulos, 2002). Consequently, the health promoting effects of these EFAs are dependent on the maintenance of a proper balance between n-3 and n-6 PUFA (Sanchez-Machado et al., 2004).

PUFA are of the ut most importance for human metabolism. They are the major components of cell membrane phospholipids, may also be present in cellular storage oils (Gill and Valivety, 1997) and have beneficial effects in a number of inflammatory pathological conditions (Brouwer et al., 2006). In addition, PUFA are used in the biosynthesis of eicosanoids, hormone-like signaling molecules, which include thromboxane, prostaglandins and leukotrienes (Radwan, 1991). Considering their fundamental role in metabolism, it comes as no surprise that beneficial properties have been attributed to PUFA, like antibacterial (Guedes et al., 2011;Ward and Singh, 2005), anti-inflammatory (Schmitz and Ecker,2008 ; Pulz et al., 2004), antioxidant (Palza et al., 2009), prevention of cardiac diseases (Mozaffarian and Wu, 2011), and inhibition of tumor progression (Das et al., 2009; Field and Schely, 2004). Lipoxins are derived from AA, in addition to the an-

ti-inflammatory effects inhibit the producing of inflammatory cytokines, immune cell proliferation and migration (Simopoulos and Bazan, 2009).Such properties are indicative of the PUFA potentials for nutraceutical and pharmaceutical purposes and they cannot be synthesized by humans and are thus obtained through diet.

FAs in macroalgae

Demands for ω3 PUFAs is rapidly increasing day by day and seaweeds are a good source of PUFA. Despite their abundance, macroalgae are poorly exploited and, even though their total lipid content is usually low (Van Ginneken et al., 2011), they contain a high proportion of PUFA, combined with other interesting secondary metabolites (e.g., polysaccharides, vitamins, proteins). FAs from algae have further advantages over fish oils, such as the lack of unpleasant odor and potential for appropriate oil refining (Pulz and Gross, 2004). Also, the PUFAs presence in the fishes is the result of consuming primary producers, such as phytoplankton and seaweeds, which able to synthesize and store them in good quantities in their cells (Kumari et al., 2010), so the original source of long-chain PUFAs is not the fish itself, but marine algae and phytoplankton which form fishes major dietary source and enter the food chain through different trophic levels (Nordy and Dyerberg, 1989). with compare to the terrestrial vegetables, seaweeds are not a conventional source of energy since their lipid content is low, but their PUFA contents is as high as those of terrestrial vegetables (Darcy-Vrillon, 1993). These marine photosynthetic organisms can be viable and sustainable sources of PUFA, because many of them could easily be cultivated in the sea in a large scale (Kumari et al., 2010). Lipids represent only 1-5% of algal dry matter and contain much lower concentrations of trans FAs in compare to today's diets, but exhibit an interesting composition of PUFAs that are considered as essential fatty acids (EFAs) for humans and animals (Simopoulos et al.,1999; Simopoulos, 2008).

The red and brown algae are rich in FAs with 20 carbons such as EPA (C20:5, n-3) and AA (C20:4, n-6) (Banerjee et al., 2009). The total n-6 content in marine algae was estimated very low (only 3%) (Sanchez-Machado et al., 2004; Mishra et al., 1993). This issue leading to a low n-6: n-3 ratio, the properties have a lot of beneficial effects in medical view. Some of these FAs (20:3n-6, 20:4n-6, 20:5n-3) have high biological activity and are able to convert into eicosanoids. Because of the renewable and huge biomass, seaweeds are a potential source of FAs for biotechnological purposes and also are valuable sources of EFAs in dietary (Khotimchenko et al., 2002). Macroalgae species clustering into three divisions, Chlorophyta, Phaeophyta and Rhodophyta, suggesting that each phylum has a distinct FA profile and supporting earlier evidence that lipid composition may be a biochemical marker for each taxonomic group (Galloway et al., 2012; Kumari et al., 2010; Hanson et al., 2010). Profiles of some of the macroalgae species have already been characterized; intra-specific variability is common in macroalgae coming from

different geographical locations, resulting in different FA profiles (Harwood, 1984, Khotimchenko et al., 2002). Studies revealed that FAs composition and concentration is differ depend on seaweed species, seasonality (Floreto et al., 1993), different parts of thallus and growth conditions (Patterson et al., 2012; Khotimchenko, 1995). This might be explained by exposure to diverse abiotic factors (e.g., temperature) that are known to influence the content of PUFA in algae (Harwood, 2006; Khotimchenko et al., 2002). In this study, we review FAs profile of some macroalgae in three different phylums.

Chlorophyta (green algae) FAs contenten

Green seaweeds *like Caulerpa* sp. and *Ulva* sp. are rich in palmitic acid (C16:0) (Ratana and Chirapart, 2006). The C16 FAs were proposed to be taxonomically important among green macroalgae (Johns et al., 1997), relatively high contents of polyunsaturated C16-fatty acids, which are uncommon in terrestrial plants, are found in the green seaweeds *Ulva lactuca, Cladophora vagabunda* and *Cladophora taxifolia* (Ratana and Chirapart, 2006). Studies showed that these seaweeds also contain the essential fatty acids such as LA (C18:2, n-6), ALA (C18:3, n-3), AA (C20:4, n-6) and EPA (C20:5, n-3) (Ratana and Chirapart, 2006). Based on the study of Pereira et al.(2012), six species of different order in phylum Chlorophyta including Bryopsidales (*Codium sp.* and *Codium. fragile*), Cladophorales (*Cladophora albida* and *Chaetomorpha* sp.) and Ulvales (*Enteromorpha* sp. and *Ulva* sp.), showed that SFA form more than 50% of the total detected FA and the total concentration of PUFA ranged between 17% to 35% (Table1), which significantly were lower than those (37%–64%) reported by other authors (Vaskovsky et al., 1996; Li et al., 2002). Kumari et al. (2010) in their study on the members of the order Ulvales (*U. tubulosa, U. linza, U. fasciata U. rigida, U. reticulata, U. lactuca* and *Ulva* sp.) showed similar FA patterns expect docosanoic acid (C20:0) that significantly differed with the former studies and all the species of *Ulva* in this study showed higher SFAs (51.7–60.3%) (Table 1). LA (C18:2, n-6) is the main PUFA of most chlorophytes and the only exception was *Ulva* sp. As shown in Table1, higher percentages of ALA (16%) was reported (Periera et al., 2012) in compare to LA (5.7%) which was similar to earlier publications in which the FA content was considered as characteristic of the Ulvales (Kumari et al., 2010, Khotimchenko et al., 2002; Khotimchenko et al., 1993).

It must be considered that same species from several regions may show different contents of FA. For example, *Ulva* spp. from Ulvales order collected from the Bohai Sea showed 12.1–18.6% content of oleic acid (Li et al., 2002) and lower PUFA contents (14.7–29.1%) than species of the order collected and California (Khotimchenko et al., 2002). *Ulva* sp. collected from Turkey also high proportions of palmitic (C16:0), palmitoleic (C16:1), oleic (C18:1, n-9), LA (C18:2, n-6) and conjugated linolenic acids (C18:3, n-3 and n-6) were reported (El-Shoubaky et al., 2008) which was in agreement with the results of Van Ginneken et al. (2011),which in,

same compounds were found for *Ulva rigida* and *U. fasciata* (Table1) from Egypt but no C20:4 (n- 6) and C20:5 (n-3) were detected in these two species. Also Durmaz et al. (2008) reported less level of MUFA (19.50%) and lower level of 20:5 (n-3) in *Ulva* sp. (4.40%)(Table 1). Ivanova et al. (2013), detected C14:1 only in *Ulva rigida* and value of C18:2, n-6, was 14.26%. Despite the variations among the fatty acids composition, *Ulva rigida* was rich in C18 PUFAs (Table 1). A similar trends have already been reported in several studies (Kumari et al., 2010, Khotimchenko et al., 2002, Li et al., 2002, Kumari et al., 2011).The members of the Ulvales have been reported to have high levels of ALA as the characteristic PUFA (Khotimchenko et al., 2002, Li et al., 2002). In contrast, in a study by Kumari et al. (2011), LA content was found to be much higher (10-fold) than the ALA content. Ortiz et al. (2006) also observed twofold higher LA content than ALA in *U. lactuca* from the coast of Chile. Despite the low PUFA content in *Ulva* species, the DHA content (2.15–6.05%) was relatively higher than those values reported earlier for the same species(Kumari et al., 2010). The *U. lactuca* from Chile also had a DHA content up to 0.8% of TFA while it was absent in the same and other members of Ulvales from the Bohai Sea (Li et al., 2002) and California (Khotimchenko et al., 2002).

Caulerpa taxifolia in order Caulerpales contained low amounts of PUFAs but C20:4 (n-6) and C20:5 (n-3) also were detected in this species (van Ginneken et al., 2011) (Table 1), which was in agreement with Matanjun et al. (2009). In their study *Caulerpa lentillifera* showed low PUFA content in comparison to *Euchema cottonii* and *Sargassum polycystum*. Van Ginneken et al. (2011), found that *C. lentillifera* contained all the EFAs, LA (C18:2, n-6), ALA (C18:3, n-3), and EPA (C20:5, n-3) (Table 1). *Caulerpa racemosa* and *Caulerpa veravalensis*, also exhibited higher SFA contents (55.0–62.2%) (Table 1) same as Ulvales but registered low oleic acid 2.2–4.75%, and higher (27.2–40%) PUFA contents (Kumari et al., 2010). Khotimchenko (1995) also reported low content of C18 MUFA for *Caulerpa* species (Table1).

Ivanova et al. (2012), were found *Cladophora vagabunda* (Cladophorales), was rich in C18 PUFAs, same as several studies had already been reported (Kumari et al., 2011, Kumari et al., 2010, Khotimchenko et al., 2002 and Li et al., 2002) but no C14:1, C22:1(n-9) and C20:3 (n-6) were found in the species. DHA was only detected in *Cladophora albida* (0.8%) (Pereira et al., 2012), and has been reported lower than 1% (Li et al., 2002 and Graeve et al., 2002). In general, the C20 PUFA content in *Caulerpa* species ranged between14.7% - 22.8% of TFA while *Ulva* species had a 3–5 times lower content of C20 PUFA than C18 PUFA. In compare with earlier reports, *Caulerpa* sp. had higher PUFA (Kumari et al., 2010). However, study on *C. lentillifera* (Matanjun et al., 2009) revealed lower PUFA contents and a typical FA profile of Chlorophyta with higher C18 PUFA contents, oleic acid and low C20 PUFAs. The observed variations in PUFA content could be attributed to the interspecific differences.

Table 1. Fatty acids composition (percentage of total fatty acids) of some species of Chlorophyta phylum. SFA: Saturated fatty acids, HSFA: the highest SFA, MUFA: mono unsaturated fatty acid, HMUFA: the highest MUFA, PHMUFA: percentage of HMUFA, HPUFA: the highest polyunsaturated fatty acids, PHPUFA: percentage of HPUFA, LA: linoleic acid, ALA: α-linolenic acid, AA: arachidonic acid, EPA: eicosapentaenoic acid, DHA: docosahexaenoic acid.

Species	Σ SFA (%)	HSFA (%)	ΣMUFA (%)	HMUFA (%)	Total n-3(%)	Total n-6 (%)	HPUFA PHPUFA (%)	LA (%)	ALA (%)	AA (%)	EPA (%)	DHA (%)	n-6/ n-3	Ref.
Cladophora vagabunda	62.0	C16:0 (42.0)	10.0	C18:1 n-9 (4.0)	8.0	17.0	C18:2 n-6 (14)	14.1	2.2	1.4	1.5	1.4	2.84	Ivanova et al., 2012
Cladophora albida	50.0	C16:0(33.0)	27.4	C18:1 n-9 (13.9)	22.2	2.9	19.3	15.5		1.4	2.0	0.7	6.73	Pereira et al., 2012
Chaetomorpha sp.	60.5	C16:0 (33.0)	11.8	C18:1 n-9 (8.4)	27. 6	0.8	26.7	24.6	_	_	0.6	_	31.5	Pereira et al., 2012
Ulva rigida	70.0	C16:0 (63.5)	6.5	C18:1 n-9 (3.1)	6.5	15.6	C18:2 n-6 (14.3)	14.3	5.2	0.5	0.4	-	2.43	Ivanova et al., 2013
Ulva lactuca	13.0	C16:0 (12.0)	24.0	C18:1 n-9 (20.0)	32.0	32.0	C18:2 n-6 (25.0)	25.0	20.0	2.0	1.0	-	1	Van Ginneken et al., 2011
Ulva tubulosa	56.3	C16:0 (49.2)	21.1	C18:1 n-9 (18.6)	8.0	14.5	C18:2 n-6 (10.5)	10.5	1.0	1.8	2.4	4.8	1.83	Kumari et al., 2010
Ulva linza	51.7	C16:0 (40.9)	19.3	C18:1 n-9 (15.3)	13.0	16.0	C18:2 n-6 (11.4)	11.4	1.2	3.9	4.2	5.5	1.42	Kumari et al., 2010
Ulva fasciata	60.3	C16:0 (52.9)	14.7	C18:1 n-9 (12.1)	9.8	16.2	C18:2 n-6 (11.7)	11.7	1.3	1.6	2.4	6.1	1.60	Kumari et al., 2010
Ulva rigida	57.9	C16:0 (48.2)	22.8	C18:1 n-9 (18.8)	7.7	12.0	C18:2 n-6 (8.9)	8.9	1.5	1.8	0.9	5.8	1.45	Kumari et al., 2010
Ulva reticulate	63.7	C16:0 (52.3)	21.6	C18:1 n-9 (17.1)	5.5	9.2	C18:2 n-6 (7.6)	7.6	0.9	0.8	1.7	2.8	1.84	Kumari et al., 2010
Ulva lactuca	54.9	C16:0 (43.0)	25.0	C18:1 n-9 (17.8)	5.1	14.7	C18:2 n-6 (9.4)	9.4	2.3	2.5	0.9	2.2	3.03	Kumari et al., 2010
Ulva spp	38.0	C16:0 (26.5)	1.2	C16:1 n-7 (19.5)	24.0	6.0	C18:4 n-3 (7.0)	2.2	1.7	0.1	4.4	1.1	0.25	Durmaz et al., 2008
Ulva spp.	59.0	C16:0 (50.0)	17.3	C16:1 n-7 (11.8)	23.6	18.0	C18:2 n-6 (5.6)	5.7	16.5		1.5		0.31	Pereira et al., 2012
Enteromorpha spp.	64.8	C16:0 (52.6)	17.5	C18:1 n-9 (9.0)	17.6	4.0	C18:2 n-6 (13.6)	10.1		2.8	3.5		3.39	Pereira et al., 2012
Codium fragile	62.3	C16:0 (40.7)	15.0	C16:1 n-7 (5.4)	22.3	7.4	C18:2 n-6 (14.9)	9.2		3.4	1.5		2.02	Pereira et al., 2012
Codium sp.	51.0	C16:0 (32.7)	13.6	C18:1 n-9 (9.0)	35.0	9.5	C18:2 n-6 (25.6)	12.2	_	6.0	1.4	_	2.69	Pereira et al., 2012
Caulerpa racemosa	62.2	C16:0 (57.1)	10.7	C16:1 n-7 (5.4)	11.0	16.0	C18:2 n-6 (10.3)	10.3	0.8	4.0	9.5	0.8	1.44	Kumari et al., 2010
Caulerpa veravalnensis	55.0	C16:0 (51.2)	5.0	C16:1 n-7(2.6)	8.8	31.2	C18:2 n-6 (13.7)	13.7	0.8	14.6	6.6	1.1	3.49	Kumari et al., 2010
Caulerpa taxifolia	41.0	C16:0 (39.0)	13.0	C18:1 n-9(7.0)	38.0	4.0	C18:3 n-3 (18.0)	_	18.0	3.0	8.0	_	0.11	Van Ginneken et al., 2011
Lambia antarctica	24.9	C16:0 (19.8)	13.5	C18:1 n-9(10.7)	33.3	27.6	C18:3 n-3 (22.3)	22.3	23.7	5.2	5.0	0.9	1.2	Graeve et al., 2002
Prasiola crispa	30.1	C16:0 (28.6)	24.1	C18:1 n-7(20.9)	37.1	8.7	C18:3 n-3 (23.7)	6.3	26.1	2.4	8.4	_	4.3	Graeve et al., 2002

In the lipid profiles of some green algae, two species, *Codium* sp. and *Chaetomorpha* sp., were the richest in terms of PUFA, while *Enteromorpha* sp. had the lowest PUFA content (Pereira et al., 2012). *Codium* sp. was the only representative of this phylum in which γ-linolenic acid (GLA; C18:3 n-6) was detected in, same as previous studies which had been reported minimal amounts (0.2%–2.3%) of FA in *Codium* species (Li et al., 2002 and Khotimchenko et al., 1993). *Codium* species presented relatively high concentrations of hexadecatrienoic acid (C16:3, n-3), though this is a common FA within the *Codium* species (Pereira et al., 2012).

Biefly, FA content in green marine algae (*Enteromorpha* spp.) was higher as compared to soybeans and beans. So, *Enteromorpha* spp. was especially recommended for human consumption by Aguilera-Morales et al. (2005). Despite typical profiles of FAs the most abundant SFA in phylum of Chlorophyta were palmitic (C16:0), myristic (C14:0), behenic (C22:0) and important VLCPUFA such as EPA (C20:5, n-3), LA (C18:2, n-6) and AA (C20:4, n-6) that were found in significant levels. Linoleic acid was found to be the most dominant USFA of the most Chlorophytes. In Chlorophyta SFA relative amounts varied between 25% to 38% and the total concentration of PUFA ranged between 37%–64%. In Ulvales significant content of ALA (16%) was considered as characteristic of the Ulvales (Kumari et al., 2010 and Khotimchenko et al., 2002). They also contained C20 PUFAs AA (C20:4, n-6) and EPA (C20:5, n-3) but their contents were significantly lower than those of Rhodophyta and Phaeophyta species. *Codium* sp. was the only representative of this phylum in which γ-linolenic acid (C18:3, n-6) was detected. EPA (20:5, n-3) was detected in all Chlorophytes at medium concentrations. In Chlorophyta, EPA content ranged between 1% to 4% of the total fatty acid content and among the three analyzed phyla, Chlorophyta showed a trend similar to that of total PUFA, which was reported by other authors (Kumari et al., 2010). DHA was only detected in some species of this phylum (lower than 1%) (Pereira et al., 2012).

In general all the studies show that the warm water macroalgal species have been reported to have higher SFAs, oleic acid and lower PUFA contents (Khotimchenko, 2003) than the cold water species (Bhaskar et al, 2004; Colombo et al., 2006). The n-6/n-3 ratio in the Chlorophyta members in the study ranged from 1.42:1 in *U. linza* to 3.49:1 in *C. veravalensis* (Kumari et al., 2010). The unsaturated index varied from 70.9 to 124, indicating a lower degree of total instauration than in Rhodophyta and Phaeophyta members.

Phaeophyta (Brown algae) FAs content

Several studies of FA contents of brown macroalgae have shown that all the seaweeds also contained the essential fatty acids LA (C18:2, n-6), linolenic acid (C18:3, n-3), the AA (C20:4, n-6), EPA (C20:5, n-3) and except palmitic acid (C16:0), the most abundant FA were generally C18:1 and C20:4 n-6 (and also C22:6, n-3 in *C. sinuosa*). A study on five species of brown algae (Phaeophyta)

belonging to the two orders Dictyotales and Fucales (23) showed, that *Padina tetrastromatica* and *Stoechospermum marginatum* as the members of the Dictyotales differed from those of Fucales (*Cystoseira indica, Sargassum tenerrimum*) and registered higher C18 PUFA contents, with 12.1–15.0% of TFA, and lower C20 PUFA content, with 26.6–35.4% of TFA. The obtained data for Fucales were 7.77–10.3% and 37.9–39.2% of TFA, respectively. Tabarsa et al. (2012), have examined the FA profile of three brown seaweeds, namely, *Padina pavonica, Dictyota dichotoma,* and *Colpomenia sinuosa* from Qheshm Island in south of Iran, the total lipid contents in this study were between 1.46 ± 0.38 g.100 g^{-1}dwt in *C. sinuosa* to 2.94 g.100 g^{-1}dw in *D. dichotoma* whereas this difference was not statically significant. Also, 12 FA were identified in the studied species and total SFAs were much greater than MUFAs. The sum of SFAs ranged from 31% of total FAME in *P. pavonica* to 26% of total FAME in *D. dichotoma*. Among the analyzed seaweed species, palmitic acid (C16:0) was the most abundant SFA. The content of C16:0 was the highest in *C. sinuosa* with 20% of total FAME, and the lowest in *D. dichotoma* (13%) of total FAME (Table 2). Kamariah et al. (2012) in their studies found in *D. dichotoma*, C22 PUFAs has the highest amount followed by C22 and C18 PUFAs and C18 PUFAs dominantly was linolenic acid (LA) while C20 PUFA was EPA.

In study performed on brown algae of Iran (Tabarsa et al., 2012), *P. pavonica* had the highest proportion of MUFAs in FAME content and oleic acid (C18:1) was the predominant MUFA within FA which showed 10%-13% of total content. The FA profile of *Padina tetrastomatica* in the study by Kumari et al. (2010) was including myristic acid (up to 7.29%), palmitic (35.9%), elaidic (6.51%), oleic (1.38%), LA (7.92%), AA (21.4%) and EPA (3.5%) of TFA. Also Bhaskar and Miyashita (2005) found similar FA patterns, particularly higher palmitic and PUFA content for *P. tetrastomatica* from the west coast of India, so *P. tetrastomatica* has considerable amount of AA (Table 2). Van Ginneken et al. (2011) showed that, palmitic (C16:0) and oleic acids (C18:1, n-9) were the most abundant FAs in *Sargassum polycystum* (Matanjun et al., 2009) and Matanjun et al. (2008) described significantly lower contents of AA (0.63%) and EPA (1.71%) of TFA for the same species. A Lower AA (10–21%) and EPA (1%) content of TFA have also been reported for *Sargassum* kjellmanianum and *Sargassum thunbergii* collected from Bohai Sea (Li et al., 2002). In contrast, Kamariah (2012) showed that, in the case of *S. granuliferum*, C18 PUFAs were higher compared to C20 and C22 PUFAs. *Sargassum tenerrimum* was also rich in AA and EPA (Kumari et al., 2010) (Table 2). However, researchers found no (C22:5, n-6) but found 13% of docosapentaenoic acid (C22:6, n-3) in *Sargassum natans* and their observations for the PUFA content of S. natans correspond to those for other *Sargassum* sp. (Matanjun et al., 2009; Herbreteau et al., 1997; Hamdy and Dawes, 1989). In general, Khotimchenko et al. (1991), stated that phaeophyta algae

typically contained high concentrations of C18 and C20 PUFAs, but Kamariah (2012) said that this characteristic feature was observed for *Sargassum granuliferum* but not in *Dictyota dichotoma*, so the signature of C18 and C20 PUFAs dominance in *S. granuliferum* were also similar to the results which has been reported by Khotimchenko et al. (1991) on seven species of *Sargassum*. The highest relative total PUFA levels were found (Table 2) in *C. sinuosa* and were significantly higher than those in the two other seaweeds (*P. pavonica* and *D. dichotoma*) and there was no significant difference among tested seaweeds on C20:4n-6 and C20:5n-3, whereas C22: 6n-3 was determined only in *C. sinuosa* (12.3%) (Tabarsa et al., 2012). In report of Van Ginneken et al. (2011), concentrations of palmitic acid (C16:0), AA (C20:5, n-3), oleic acid (C18:1, n-9) in *Laminaria hyperborea* were comparable to the observations of Dawczynski et al. (2007). Van Ginneken et al. (2011), who have found no ALA (C18:3, n-3) in *L. hyperborea*. Characteristic for *Undaria pinnatifida* is the relatively high concentration of stearidonic acid (C18:4, n-3) which corresponds to earlier studies (Dawczynski et al., 2007; Fleurence et al., 1994; Takagi et al., 1985). Pereira et al. (2012), analyzed six Phaeophyta species belong to three different orders: Sphacelariales (*Halopteris scoparia* and *Cladostephus spongiosus*), Dictyotales (*Dictyota dichotoma, D. spiralis* and *Taonia atomaria*) and Fucales (*Sargassum vulgar*). Total SFA concentrations ranging from 20% to 44% for different phaeophytes (Table 2) but still, some exceptions could be found. For example, it has been reported a total SFA content of 66% and 53% for *Desmarestia viridis* and *Punctaria plantaginea*, respectively (Li et al., 2002). In Homorsira banksii, in contrast with other phaeophytes, myristic (C14:0) and palmitic (C16:0) FA are the main SFA, in which the FA C17: 1, n-9 is a major MUFA and this species is the only phaeophyte shows this FA (Pereira et al., 2012; Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Khotimchenko et al., 1998). In the study of Pereira et al. (2012) concentration of PUFA for three species, *Halopteris scoparia, Taonia atomaria* and *Cladostephus spongiosus* were between 47%–57%, that is in contrast with the reported content for several species, namely: *Scytosiphon lomentarius, Colpomenia sinuosa, Dictyosiphon foeniculaceus, Laminaria bongardiana, L. solidungula, Desmarestia muelleri, D. antartica* and *Myelophycus simplex* in which PUFA concentrations are between 19%–25% (Pereira et al., 2012; Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996). Conversely, DHA was only detected in *Halopteris scoparia, Taonia atomaria* and *Sargassum vulgare* at low concentrations (0.8%–1.5%). In the literature, this FA is generally absent or exists in very little amounts in different phaeophytes (Periera et al., 2012; Li et al., 2002; Graeve et al., 2002). Kamariah et al.(2012) found that *Dictyota dichotoma* exhibited higher presence of fatty acids with 26 compounds compared to *Sargassum granuliferum* which exhibit only 22 compounds and EPA (C20:5, n-3) was highest amount for C20 PUFAs in

both species. In Ivanova et al. (2013) study, *Cystoseira barbata* was rich in both C18 and C20 PUFAs, such trends have already been established earlier in several studies (Kumari et al., 2010; Kumari et al., 2011).*Cystoseira indica* had slightly lower PUFA content, with 47.5% of TFA (Kuamri et al., 2010), as compared to *Cystoseira, Osmundaea*, with 54% of TFA from the Pacific coast (Khotimchenko et al., 2002) (Table 2). In the study of Durmaz et al. (2008), the high level of MUFA was seen in *Cystoseira* sp. (32.37%). The FA 20:5 (n-3) was dominant (10.96%) which was found in *Cystoseira* sp. (Ivanova et al., 2012). Second major FA in *Cystoseira crinita* were LA (C18:2, n-6) and EPA (C20:5, n-3) accounting 7.15% and 8.15% of TFA, respectively (Table 2). Kamenarska et al. (2002) investigated lipid composition of *Cystoseira crinita* from Eastern Mediterranean in which the main FA was palmitic acid, followed by myristic (C14:0) and oleic acids (C18:1, n-9). C22:1 (n-9) and also important VLCUPFA such as EPA (C20:5, n-3), LA (C18:2, n-6) and AA (C20:4, n-6) were found in significant levels in *Cystoseira* crinite. LA was found to be the most dominant FA in both PUFA's groups. The obtained value of (C18:2, n-6) was 7.15% for *Cystoseira crinita*. Despite the variations among the FA composition, both macroalgae *Cystoseira barbata* and *Cystoseira crinite* showed typical profiles corresponding to their respective phyla, i.e. *Cystoseira crinita* being brown alga was rich in both C18 and C20 PUFAs. Such trends have already been established earlier in several studies (Kumari et al., 2010; Khotimchenko et al., 2002; Li et al., 2002; Kumari et al., 2011). *Stoechospermum marginatum*, a species from Dictyotales, was found to have an exceptionally high myristic acid (C14:0) content with 21.8% of TFA, which might be a characteristic of the genus and also such high content was not found in any other algal species in the study of Kumari et al. (2010) (Table 2).

In briefly, compared with the chlorophytes, the phaeophytes presented low contents of SFA ($p < 0.05$), ranging from 30% to 45% of the total FAME detected. This is consistent with other studies, which reported total SFA concentrations ranging from 20% to 44% for different phaeophytes (Li et al., 2001; Graeve et al., 2002). Despite the marked morphological variations among different species of this phylum, they had similar FA profiles. Myristic (C14:0) and palmitic (C16:0) FA were the main SFA detected in this phylum. Total MUFA concentrations (12%–30% of total FA) were significantly lower than those of SFA ($p < 0.05$) and the major MUFA detected were palmitic (C16:1, n-7) and oleic (C18:1, n-9c) acids (Dawczynski et al., 2007; Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Khotimchenke et al., 1998). The total PUFA concentration in these algae varied between 30% and 56% of the total FA, This was a typical characteristic of all Phaeophyta members and it distinguished them from other Rhodophyta and Chlorophyta members and significantly higher than in green and red algae. The main PUFA detected in this phylum are LA (C18:2, n-6), AA (C20:4, n-6) and EPA.

Table 2. Fatty acids composition (percentage of total fatty acids) of some species of Phaeophyta phylum. SFA: Saturated fatty acids, HSFA: the highest SFA, MUFA: mono unsaturated fatty acid, HMUFA: the highest MUFA, HPUFA: the highest polyunsaturated fatty acid, LA: linoleic acid, ALA: α-linolenic acid, AA: arachidonic acid, EPA: eicosapentaenoic acid, DHA: docosahexaenoic acid.

Species	ΣSFA (%)	HSFA (%)	ΣMUFA (%)	HMUFA (%)	Total n-3(%)	Total n-6 (%)	HPUFA (%)	LA (%)	ALA (%)	AA (%)	EPA (%)	DHA (%)	n-6/n-3	Ref
Colpomenia sinuosa	28.0	C16:0(21.0)	14.0	C18:1 n-9(11.0)	19.0	9.0	C 22:6 n-3(12.0)	2.7	1.3	6.5	5.0	12.3	0.8	Tabarsa et al., 2012
Dictyota dichotoma	26..0	C16:0(13.0)	15.0	C18:1 n-9(11.0)	11.0	7.0	C 20:4 n-6(7.0)	1.8	1.7	7.5	4.8		0.70	Tabarsa et al.2012
Dictyota spiralis	40.2	C16:0(21.7)	29.3	C16:1 n-7 (19.5)	-	30.5	C20:4 n-6(18.4)	6.1	–	18.4	–	–	-	Pereira et al.2012
Dictyota dichotoma	45.9	C16:0(24.7)	24.9	C16:1 n-7 (5.49)	6.6	23.2	C20:4 n-6(11.4)	5.5		11.5	6.6		3.52	Pereira et al., 2012
Padina. pavonica	31.0	C16:0(18.0)	19.9	C18:1 n-9(14.0)	8.0	11.0	C 20:4 n-6(6.0)	1.6	3.7	6.48%	4.1	–	0.71	Tabarsa et al., 2012
Padina tetrastromatica	46.6	C16:0(35.9.0)	14.0	C18:1 n-9(6.5)	7.2	32.0	C20:4 n-6(21.4)	7.9	2.0	21.%	3.51	0.8	4.46	Kumari et al., 2010
Sargassum natans	48.0	C16:0(41.0)	20.0	C18:1 n-9 (15.0)	20.0	11.0	C22:6 n-3(13.0)	3.0	2.0	8.0	5.0	13.0	0.55	van Ginneken et al., 2011
Sargassum vulgare	42.3	C16:0(31.2)	19.0	C16:1 n-7 (8.6)	10.1	28.5	C20:4 n-6(18.6)	7.6	–	18.6	8.6	1.5.0	2.82	Pereira et al., 2012
Sargassum tenerrimum	41.0	C16:0(33.8)	10.8	C16:1 n-7 (4.8)	7.9	38.5	C20:4 n-6(29.7)	8.5	1.0	29.7	5.8		5.15	Kumari et al., 2010
Laminaria hyperborea	24.0	C16:0(18)	22.0	C18:1 n-9(20.0)	39.0	14.0	C20:5 n-3(26.0)	2.0	–	12.0	26.0	–	0.36	van Ginneken et al., 2011
Laminaria solidungula	21.2	C16:0 (15.5)	8.0	C18:1 n-9(5.1)	55.0	13.8	C20:5 n-3(25.0)	5.7	11.3	8.1	25.0	–	4	Graeve et al., 2002
Undaria pinnatifida	23.0	C16:0(16.0)	19.0	C18:1 n-9(13.0)	35.0	21.0	C20:4 n-6(16.0)	4.0	7.0	16.0	16.0		0.6	van Ginneken et al., 2011
Fucus serratus	26.0	C16:0(16.0)	43.0	C18:1 n-9(41.0)	9.0	22.0	C20:4 n-6(13.0)	8.0	3.0	13.0	4.0	–	2.44	van Ginneken et al., 2011
Ascophyllum nodosum	16.0	C16:0(8.0)	56.0	C18:1 n-9(54.0)	8.0	22.0	C18:2 n-6(11.0)	11.0	2%	10.0	4.0		2.75	van Ginneken et al., 2011
Cystoseira barbata	62.0	C16:0(54.0)	8.0	C18:1 n-9(4.0)	12.0	17,0	C18:2 n-6(13.0)	1.5	1.0	13.3	9.2	–	1.45	Ivanova et al., 2012
Cystoseira spp	37.0	C16:0(31)	32.0	C16:1 n-7(20.0)	16.0	10,0	C20:5 n-3(11.)%	2.9	0.8	42	11.0	2.3	0.65	Durmazet al., 2008
Cystoseira crinita	65.4	C16:0(56.0)	11.9	C18:1 n-9(6.3)	10.4	10.5	C20:5 n-3(8.0)	1.2	1.0	7.2	–	8.2	1.01	Ivanova et al., 2013
Cystoseira indica	40.9	C16:0(34.4)	11.7	C16:1 n-7 (4.8)	8.6	38.8	C20:4 n-6(31.9)	6.4	0.8	31.9	7.3	0.5	4.49%	Kumari et al., 2010
Cladostephus spongiosus	31.7	C16:0(21.3)	12.1	C18:1 n-9(6.4)	11.4	44.6	C18:2 n-6(23.1)	23.1	–	16.4	11.5	–	3.89	Pereira et al., 2012
Taonia atomaria	35.4	C16:0(25.4)	17.3	C16:1 n-7 (8.0)	14.4	32.8	C20:4 n-6(18.6)	10.1		18.6	13.5	0.8	2.28	Pereiraet al., 2012
Halopteris scoparia	34.8	C16:0(24.3)	14.0	C18:1 n-9(5.6)	15.3	35.6	C18:2 n-6 (20.3)	20.3	–	14.0	14.4	0.2	2.32	Pereira et al., 2012
Spatoglossum asperum	36.0	C16:0(24.5)	14.4	C16:1 n-7(6.9)	17.7	32.0	C20:4 n-6(22.7)	6.0	5.5	22.7	11.7	0.1	1.81	Kumari et al., 2010
Stoechospermum marginatum	46.3	C16:0(22.3)	9.2	C18:1 n-9(6.6)	18.2	26.4	C20:4 n-6(21.0)	3.5	9.9	21.0	7.76	0.3	1.52	Kumari et al., 2010
Desmarestia antarctica	16.4	C16:0 (11.5)	9.3	C18:1 n-9	55.3	18.0	C20:5 n-3(25.4)	3.6	8.0	14.6	25.4	–	0.32	Graeve et al., 2002
Desmarestia muelleri	16.3	C16:0(12.5)	6.3	C18:1 n-9(4.7)	52.0	24..0	C18:3 n-3 (24.8)	10.1	24.8	14.6	13.2		0.47	Graeve et al., 2002

In all studied species, the concentration of C20 PUFA was always 2–3 fold higher than that of C18 PUFA (Narayan et al., 2004; Li et al., 2002; Khotimchenkeet al., 1998). All phaeophytes displayed relatively high amounts of EPA between 6–14%. In the literature, DHA is generally absent or exists in very little amounts in different phaeophytes (Li et al., 2002; Graeve et al., 2002). Of the two major classes of n-6 and n-3 PUFAs, n-6 remained the dominant one in all the species and their n-6/n-3 ratio ranged from 0.61-3.48.

Rhodophyta (Red algae) FAs content

Van Ginneken et al. (2011) investigated two red seaweeds (*Chondrus crispus* and *Palmaria palmate*). Their results showed that, the highest relative concentration of PUFAs in the red seaweed *Palmaria palmata* was observed for EPA (C20:5, n-3) accounting for 59% of TFA content. *Palmaria palmata* is very interesting red seaweed, it contains EPA (C20:5, n-3) as the predominant FA, and marginal concentrations of AA (C20:4, n-6), LA (C18:2, n-6). 13 red algal species, belonging to the orders Ahnfeltiales (*Ahnfeltia plicata*), Gracilariales (*Gracilaria debilis, Gracilaria dura, Gracilaria furgosonii*) Cryptonemiales (*Grateloupia indica, Grateloupia wattii*) Corallinales (*Amphiora anceps*), Gigartinales (*Hypnea musciformis, Hypnea esperi, Kappaphycus alverzii, Sarconema filiforme*) and Ceramiales (*Laurencia cruciate, Laurencia papillosa*) were investigated by Kumari et al. (2010). In these species palmitic acid, oleic acid, AA and EPA showed high concentration, these FAs together accounted for 65–86.6% of TFA, whereas C18 PUFAs were present as minor components, ranging from 2.64% to 4.54% of TFA, except in *Amphiora anceps*, in which C18 PUFA content was 10.8% TFA (Table 3). In study of Van Ginneken et al. (2011), *Chondrus crispus* have shown a high level of AA (C20:4, n-6), which is in agreement with studies of Fleurence et al. (1994), and (C22:4, n-9) FA is one of the rare FA that have been found in *C. crispus*. Ivanova et al. (2012) also found that *Ceramium rubrum* being a red alga was rich with C20 PUFAs (Table 3), Such trends have already been demonstrated in several studies (Kumar et al., 2011; Kumari et al., 2010; Khotimchenko et al., 2002; Li et al., 2002). Pereira et al. (2012), studied the five representatives of the Rhodophyta phylum belong to five different orders, namely Corallinales (*Jania* sp.), Gelidiales (*Pterocladiella capillacea*), Bonnemaisoniales (*Asparagopsis armata*), Peyssonneliales (*Peyssonnelia* sp.) and Ceramiales (*Bornetia secundiflora*). They found that, total concentration of SFA can be seen between 39% (*Peyssonnelia* sp.) and 80% (*A. armata*) (Table 3) and this variability was also reported by other studies in which relative amounts of SFA ranged between 26% and 71% (Li et al., 2002).The most abundant SFA in all studied strains were myristic and palmitic acids (Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Johns et al., 1979). Almost total MUFA content of this phylum was lower than 10% of the TFA profile, except for *A. armata* and *B. secundiflora*, which presented slightly higher concentrations and palmitoleic (C16:1,

n-7) and oleic (C18:1, n-9c) acids were once more the main MUFA (Table 3) (Pereira et al., 2012). Other authors have described relatively higher amounts of MUFA in other Rhodophytes although these were consistently the least representative of all FA (Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Johns et al., 1979). PUFA content in *A. armata* displayed only 5%, whereas in *Peyssonnelia* sp. PUFA content reached 52% (Table 3) of the TFA (Pereira et al., 2012). Wide variability of PUFA content was also found by Graeve et al. (2002).

Similarly, Li et al. (2002) described PUFA contents ranging from 8% to 55% in Rhodophyta from the Bohai Sea, LA (C18:2, n-6) reaching only 2% of the total FA and the most abundant PUFA in this phylum were AA (C20:4, n-6) with high concentration in *Peyssonnelia* sp. 26.59% and EPA (20:5, n-3), high concentration in *Bornetia secundiflora* (27.26%), which are usually the most predominant FA in red algae (Pereira et al., 2012; Galloway et al., 2012; Khotimchenko et al., 2002; Li et al., 2002; Graeve et al., 2002). In a study by Pereira et al., (2012), except for *A. armata*, all strains exhibit considerably high amounts of EPA (15% and 27% of TFA) (Table 3). Similar results were shown in other literature (Li et al.,2002; Graeve et al., 2002; Vaskovsky et al.,1996; Fleurence et al., 1994; Johns et al.,1979). In study of Kumari et al. (2010), as shown in table3, from the comparative data analysis of PUFAs, the members of the Rhodophyta can be divided into three groups. The first group included *Amphiora anceps, Ahnfeltia. plicata, Gracilaria debilis, Gracilaria dura, Gracilaria furgosonii,* and *Sarconema filiforme*, in which the content of n:6 PUFAs were higher than that of the n:3 PUFAs, with n-6/n-3 ratio ranging from 1.77:1 in *Ahnfeltia plicata* to 27.7:1 in *Gracilaria dura* and AA > EPA. The *Grateloupia indica* and *Grateloupia* wattii was included in the second group where n-3 PUFAs were higher than n-6 PUFAs, with n-6/n-3 ratio ranging from 0.61:1 to 0.74:1 and EPA > AA. The third group included *Hypnea musciformis, Hypnea esperi, Kappaphycus alverzii* and *Laurencia cruciata* and *Laurencia papillosa* in which the contents of n-6 and n-3 PUFAs were nearly same with n-6/n-3 ratio being close to 1 and the contents of AA and EPA were also more or less equal (Table 3). DHA was absent in most of the red algal species studied, except in *Ahnfeltia plicata, Hypnea musciformis, H. esperi* and *Laurencia cruciate,* in which it ranged from 0.27% of TFA in *L. cruciate* to 1.56% in *A. plicata* (Kumari et al., 2010) and *Peyssonnelia* sp. presented significantly higher concentrations of DHA than all algae studied, reaching nearly 5% of the TFA (Pereira et al., 2012) and other authors also have reported low concentration of DHA in their studies (Graeve et al., 2002; Fleurence et al., 1994).

In brief, FA compositions in Rhodophyta relatively showed higher levels of palmitic acid, oleic acid, AA and EPA. Contrary to the other phyla, there was a greater variability in the lipid profile among the Rhodophyta, as it can be seen by the total concentration of SFA that ranged between 26% and 80% (Pereira et al.,

Table. 3. Fatty acid compositions (percentage of total fatty acids) of some species of Rhodophyta phylum. SFA: Saturated fatty acids, HSFA: the highest SFA, MUFA: mono unsaturated fatty acid, HMUFA: the highest MUFA, HPUFA: the highest polyunsaturated fatty acids, LA: linoleic acid, ALA: α-linolenic acid, AA: arachidonic acid, EPA: cicosapentaenoic acid, DHA: docosahexaenoic acid.

Species	ΣSFA (%)	HSFA (%)	ΣMUFA (%)	HMUFA (%)	Total n-3 (%)	Total n-6 (%)	HPUFA(%)	LA (%)	ALA (%)	AA (%)	EPA (%)	DHA (%)	n-6/n-3	References
Ceramium rubrum	72.0	C16:0(58.0	12.0	C18:1 n-9(4.0)	6.0	8.0	C20:4 n-6(4.0)	4.5	1.9	0.9	1.9	1.4	1.24	Ivanova et al., 2012
Bornetia secundiflora	46.0	C16:0(32.9)	18.7	C16:1 n-7(12.7)	27.2	7.9	C20:5 n-3(27.3)	1.6		3.8	27.3		0.29	Pereira et al., 2012
Peyssonnelia spp	39.0	C16:0(29.5)	8.9	C16:1 n-7(3.4)	23.4	28.6	C20:4 n-6(26.6)	1.6		26.6	18.5	4.7	1.92	Pereira et al., 2012
Asparagopsis armata	81.0	C16:0(53.2)	14.0	C18:1 n-9(6.3)	2.9	1.8	C20:5 n-3(2.9)			1.8	2.9		0.62	Pereira et al., 2012
Pterocladiella capillacea	60.0	C16:0(47.9)	8.4	C18:1 n-9(3.3)	16.1	14.7	C20:5 n-3(15.2)	2.3	0.9	10.3	15.3	_	0.91	Pereira et al., 2012
Jania spp.	51.0	C16:0(44.4)	7.6	C18:1 n-9(2.5)	22.5	15.3	C20:5 n-3(25.7)	2.4	_	13.0	25.5	_	0.60	Pereira et al., 2012
Palmaria palmata	31.0	C16:0(25.0)	4.0	C18:1 n-9 (2.0)	6.4	3.0	C20:5 n-3(25.0)	1.0	2.0	2.0	59.0	_	0.05	van Ginneken et al., 2011
Chondrus crispus	27.0	C16:0(19.0)	28.0	C18:1 n-9(17.0)	22.0	20.0	C20:4 n-6(15.0)	2.0	2.0	15.0	8.0	_	0.91	van Ginneken et al., 2011
Ahnfeltia plicata	34.5	C16:0(26.7)	9.9	C16:1 n-7(6.4)	20.7	35.8	C20:4 n-6(34.0)	1.4	0.9	34.0	18.0	1.6	1.78	Kumari et al., 2010
Gracilaria debilis	43.5	C16:0(34.4)	5.5	C18:1 n-9(2.4)	2.7	48.6	C20:4 n-6(46.8)	1.2	2.5	46.8	0.2	_	18.8	Kumari et al., 2010
Gracilaria dura	33.2	C16:0(27.8)	4.1	C18:1 n-9(1.4)	2.2	60.5	C20:4 n-6(58.3)	2.2	1.9	58.3	0.3	_	27.7	Kumari et al., 2010
Gracilaria furgesonii	58.6	C16:0(52.7)	7.4	C18:1 n-9(3.7)	1.8	32.5	C20:4 n-6(28.0)	3.2	1.4	28.0	0.4%	_	18.7	Kumari et al., 2010
Grateloupia indica	33.0	C16:0(26.4)	5.1	C18:1 n-9(2.6)	38.8	23.5	C20:5 n-3(37.0)	1.8	1.8	21.0	37.0	_	0.61	Kumari et al., 2010
Grateloupia wattii	54.4	C16:0(43.4)	6.8	C18:1 n-9(3.2)	22.5	16.6	C20:5 n-3(21.4)	1.3	1.2	14.8	21.4	_	0.74	Kumari et al., 2010
Amphiora anceps	63.9	C16:0(48.9)	9.4	C16:1 n-7(3.1)	6.1	20.5	C18:2 n-6(10.0)	10.1	0.6	9.5	5.0	_	3.37	Kumari et al., 2010
Hypnea musciformis	67.9	C16:0(50.4)	13.3	C18:1 n-9 (3.6)	9.9	8.6	C20:5 n-3(7.1)	2.5	1.3	6.7	7.1	1.0	1.03	Kumari et al., 2010
Hypnea esperi	68.6	C16:0(49.9)	12.7	C18:1 n-9(5.5)	10.7	8.6	C20:5 n-3(8.6)	2.1	1.2	6.1	8.6	0.7	0.83	Kumari et al., 2010
Kappaphycus alverzii	47.2	C16:0(36.3)	25.8	C16:1 n-7(19.8)	12.6	14.5	C20:4 n-6(13.2)	1.1	1.5	13.2	11.0		1.28	Kumari et al., 2010
Sarconema filiforme	34.1	C16:0(30.6)	8.8	C16:1 n-7 (6.6)	12.7	44.4	C20:4 n-6(42.6)	1.6	0.6	42.6	12.0		3.55	Kumari et al., 2010
Lawrencia cruciata	46.9	C16:0(38.8)	16.0	C16:1 n-7(10.0)	17.8	19.5	C20:5 n-3(17.2)	4.0	0.2	14.7	17.2	0.3	1.1	Kumari et al., 2010
Lawrencia papillosa	45.4	C16:0(37.8)	7.4	C18:1 n-9 (3.0)	22.8	24.7	C20:5 n-3(22.8)	2.7		21.4	22.8		1.07	Kumari et al., 2010
Phycodrys rubens	31.9	C16:0(28.0)	25.1	C16:1 n-7(18.0)	5.1	35.6	C20:4 n-6(35.3)	0.5		35.3	4.8	0.3	7.01	Graeve et al., 2002
Ptilota gunneri	33.2	C16:0(27.9)	47.5	C16:1 n-7(40.0)	12.3	3.5	C20:5 n-3(9.4)	2.6	0.4	0.9	9.4	0.6	0.28	Graeve et al., 2002
Delesseria lancifolia	41.6	C16:0(37.7)	20.9	C18:1 n-9 (5.3)	5.4	31.4	C20:4 n-6(31.1)	0.3	_	31.1	4.4	1.0	5.81	Graeve et al., 2002
Georgiella confluens	19.7	C16:0(17.0)	17.7	C18:1 n-7 (3.9)	46.0	2.6	C20:5 n-3(41.0)	0.7	1.2	1.9	40.9	1.3	0.05	Graeve et al., 2002
Myriogramme smithii	29.0	C16:0(27.5)	7.6	C18:1 n-7 (5.6)	48.3	14.7	C20:5 n-3(48.3)	1.7	_	13.0	48.3	_	0.3	Graeve et al., 2002
Neuroglossum ligulatum	30.4	C16:0(27.8)	22.4	C18:1 n-9(11.6)	36.8	9.4	C20:5 n-3(35.3)	1.7	_	7.7	35.3	1.5	0.25	Graeve et al., 2002
Pantoneura plocamioides	35.3	C16:0(33.7)	12.6	C18:1 n-9 (5.7)	25.9	13.2	C20:5 n-3(26.0)	0.6		12.6	25.9		0.5	Graeve et al., 2002

2012; Li et al., 2002; Johns et al., 1979). The most abundant SFA in all strains have ever been studied were myristic acids and palmitic acids (Pereira et al., 2012; Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Johns et al., 1979). Total MUFA content of this phylum was lower than 10% of the TFA, except for *A. armata* and *B. secundiflora*, which presented slightly higher concentrations (Pereira et al., 2012). Contrary to the other two phyla studied, LA (C18:2, n-6),-forms only 2% of the TFA and compaired to earlier studies where C20 PUFAs (AA and EPA) were recorded as the dominant fraction of FA in red algae (Dawczynski et al., 2007; Khotimchenko, 2002; Khotimchenko and Gusarova, 2004; Sanchez-Machado et al., 2004). In general, Rhodophyta and phaeophyta display a lipid profile clearly enriched in pentadecyclic, stearic, EPA, DHA, AA and eicosenoic (C20:1) fatty acids. Chlorophyta phylum display increased content in n-3 hexadecatrienoic (C16:3, n-3), behenic (C22:0) and lignoceric (C24:0) acids (Pereira et al., 2012).

There was variability in total concentration of PUFA within the species of Rhodophyta and showed a high contents of 18%–63% in red algae from Arctic and Antarctic waters. In fact, rhodophytes and phaeophytes exhibited considerably higher concentrations of C20 PUFA than chlorophytes (Simopoulos, 2008; Dawczynski et al., 2007; Li et al., 2002; Vaskovsky et al., 1996; Johns et al., 1979). Rhodophytes are commonly reported are good EPA producers, which suggests that red algae may be the best source of this nutritionally important FA (Li et al., 2002; Graeve et al., 2002; Vaskovsky et al., 1996; Fleurence et al., 1994; Johns et al., 1979). DHA is often not found in red algae, or when present exists at low concentrations. Researcher showed DHA amounts between 0.3% to 1.5%, in several Rhodophytes except *Peyssonnelia* sp. (Pereira et al., 2012; Li et al., 2002; Fleurence et al., 1994).

Conclusion

In general, although macroalgae showed low lipid contents (<4 g.100 g^{-1} DW), their PUFA contents are equivalent or even higher than those of terrestrial vegetables. *Statistical analysis* exhibited that FA signatures can be used to unravel chemotaxonomic relationships among macroalgae species. The overall results of our review showed that the palmitic acid (C16:0) appeared to be the most abundant SFA, irrespective of species. Its content was significantly higher in Chlorophyta (average 42% TFA), followed by Rhodophyta (average 33% TFA) and Phaeophyta (average 25% TFA). The availability of important PUFAs, such as LA, ALA, AA, EPA and DHA, with proven biomedical and nutraceutical applications, indicates their potential utilization in preparation of low fat foods. Palmitoleic acid (C16:1, n-7) and oleic acid (C16:1, n-9) were the major MUFAs of the three groups studied and ranged from 2.6% to 26.1% of TFA for Chlorophyta, 4.6–51% for Phaeophyta and 1.36–40% for Rhodophyta members. The contents of PUFAs were noticeably higher within most of the reviewed algal species. Furthermore,

most of the reviewed species contained approximately 90% TFA as long-chain FAs (C15–C24). Surprisingly, the short-chain FAs (C4–C10) were detected in some of species and also the FAs with C11–C14 carbon chains were generally low. Macroalgae are also reported to contain much lower concentrations of trans FAs than today's diet (Simopoulos, 2008; Simopoulos et al., 1999). Our review substantiate the conclusion that an appropriate choice of macroalgal species, given their high PUFA content and low n-6/n-3 ratio, may form a promising strategy to enhance food quality, e.g. to prevent inflammatory, cardiovascular diseases and nervous system disorders. Given the growing world population and increasing demand for qualitative and quantitative food supply, the present food sources, also for PUFAs, will almost certainly be insufficient in the near future. Therefore, new sources have to be explored from which Integrated Multi-Trophic Aquaculture is a strategy, which is presently being investigated for its economic and agronomic feasibility. Marine macroalgae form a good, durable and virtually inexhaustible source for PUFAs with an n-6/n-3 FA ratio of about 1.0. The n-6/n-3 ratio, which is currently recommended by the WHO (Sanchez-Machado et al., 2004) to be lower than 10 in the diet disorders, can possibly be improved by addition of certain edible seaweeds, because of their high n-3 content can be suggested as good candidates to reduce inflammatory, cardiovascular and nervous system diseases. Some marine macroalgal species, like *Palmaria palmata*, contain high proportions of the "fish FA" EPA (C20:5, n-3), while in *Sargassum natans* also DHA (C22:6, n-3) was detected. EPA and DHA are especially crucial for proper development of the nervous system and prevention of cardiovascular diseases.

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