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Original article

A comparison of nutritional value of underexploited edible seaweeds with recommended dietary allowances

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ABSTRACT

The present study evaluated the nutritional composition of under-exploited edible seaweeds and its comparison with recommended dietary allowances (RDA) of pregnant women. Some under-exploited seaweeds were identified such as *Acanthophora spicifera, Gracilaria edulis, Padina gymnospora, Ulva fasciata* and *Enteromorpha flexuosa* were not utilized directly as a food, thus evaluated their wholesome nutrients for food application. Results showed that micronutrients were found to be high in selected seaweeds such as iron in the range of 14.8–72 mg/100 g, iodine 38.8–72.2 mg/100 g, and calcium 410–870 mg/100 g. The essential aminoacids were between 189.2 and 306 mg/g, essential fatty acid like arachidonic acid was 0.80% and 0.59% of linoleic acid, monounsaturated fatty acid were 3.05–14.08% in *U. fasiciata.* Heavy metals were within the tolerable limit, mercury was found 0.030 ppm *A. spicifera* and not detected in other species, arsenic 0.012–0.076 ppm, cadmium content ranges between 0.012 and 0.081 ppm in all species. These nutrients meet more than 70% of macro and micronutrients in precise combination of RDA suggested for pregnant women. Therefore, seaweed would be better alternative food source to meet food security challenges.

1. Introduction

Seaweeds are macrophytic algae primitive type of plants lacking true roots, stems and leaves which belongs to Chlorophyta (green algae), Phaeophyta (brown algae) and Rhodophyta (red algae). Seaweeds are grown abundantly in the coastal region of Tamil Nadu, Gujarat, Lakshadweep, Andaman and Nicobar Islands. Edible seaweeds are rich in protein content with all essential aminoacids and used as a nutraceutical supplement nowadays. With accordance to high protein and aminoacid composition, red seaweeds appear to be potential source of food protein. Some species of green algae such as *Ulva, Caulerpa* contain high level of arginine and glycine, in addition histidine and taurine has pharmacological activity and necessary for fetus development. In general, seaweeds are rich in fatty acids with essential fatty acids and omega fatty acids. Amongst, red algae contains 33 fatty acid and green algae contain 29 fatty acids (Fouda et al., 2019). Further, polyphenols from seaweeds has beneficial effects for cancer chemoprevention (Abirami and Kowsalya, 2012), by acting either as an antioxidant (Ganesan et al., 2018) or as a pro-oxidant on food (Ganesan et al., 2019b). More than 30% DW contains ash with various minerals such as iron, iodine (Miller, 2006), Ca, Na and K (James, 2012). Thus, desirable combination of diet rich in Ca and K are associated with lower risks of hypertension and seaweed contains right proportion of potassium suited for blood plasma level essential during pregnancy (Kumar et al., 2008; Arokiyaraj et al., 2015; Boovaragamoorthy et al., 2019; Gurusamy et al., 2019).

The micronutrients requirement were increasing during pregnancy for physiological function and development of foetus. This

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might leads to micronutrient deficiency which is common throughout the world, particularly in women during pregnancy due to the raising demand of fetal development. Hence, this demand may negatively impact both mother as well as foetus (Chittimoju and Pearce, 2019). Further, nutraceutical supplementation attain focus among all ages especially in gestational age, thus seaweeds found to be a best alternative source of supplementation without any side effects (Roopan et al., 2019; Valsalam et al., 2019; Ilavenil et al., 2015; Balachandran et al., 2015; Lucas et al., 2019). Some edible seaweeds are non-toxic and free from heavy metals were not used as a wholesome food, which reported in our earlier research and used in this research (Abirami, 2012; Abirami and Kowsalya (2017)). Among them, *Acanthophora spicifera*, and *Gracilaria edulis*, *Padina gymnospora*, *Ulva fasciata* and *Enteromorpha flexuosa* are grown in abundance in the shores of Gulf of Mannar, India.

Therefore, the main objective of this work was to examine various edible seaweeds with detailed emphasis on under-exploited edible seaweeds. These species were further analyzed for nutritional composition and compared with recommended daily allowances (RDA) of pregnant women for their food security and nutritional challenges. Therefore, data obtained and presented in this research on dietary composition of edible seaweeds would fill the gaps for future researchers in formulation of functional foods especially during nutritional inadequacy period of life.

2. Materials and methods

2.1. Selection and analysis of underexploited seaweeds

From our earlier research on consumption pattern of seaweeds five underexploited seaweeds were identified through questionnaire method (Abirami, 2012). Those seaweeds (*A. spicifera, G. edulis, P. gymnospora, U. fasciata* and *E. flexuosa*) were authenticated by scientists at CSMCRI, Ramanathapuram, India. The method of analysis of nutrient content for each compounds were listed in Table 1 with limit of quantification (LOQ) and reproducibility (LOR).

2.2. Data interpretation and statistical analysis

All nutrients were analyzed in triplicate and measured for parametric test in Microsoft excel, 2016. Data reported in metric units per 100 g of edible fresh seaweed. Heavy metals were found in trace amount in few samples, therefore, LOQ was not identified and not given in table values. All these values were compared with RDA for pregnant women (RDA, 2010) suggested by Indian Council of Medical Research (ICMR).

3. Results and discussion

3.1. Proximate composition of underexploited seaweeds

The carbohydrate content varied from 24.8 to 32 g/100 g; protein content ranges between 12.07 and 22.78 g/100 g (Table 2), as compared to other protein-rich foods from terrestrial plants sources such as pulses and moong dhal etc, the obtained values were found to be complementary protein. According to FAO (2001), daily allowance of protein should be 1 g/kg BW; therefore, the selected seaweed would be balancing protein with high biological value of essential amino acids. Thennarasan et al. (2015) stated that protein from green seaweed ranges 5.8–10.41% DW, and brown seaweed 10–17% FW, red seaweed 21–35% DW were comparable to the present value. The polysaccharide derived from seaweed is a potential ingredient to improve food texture (Ganesan et al., 2019b).

Table 1
Analytical methods used for nutrient composition analysis.

Analyte	Standard methods	Limit of quantification	Limit of reproducibility
Carbohydrate, g/100 g	Anthrone*	0.2	0.3%
Protein, g/100 g	Nitrogen digestion*	0.1	0.6%
Fat, g/100 g	Soxhlet method*	0.17	0.6%
Ash, g/100 g	Muffle furnace*	0.1	8%
Iron, mg/100 g	AAS	0.48	8%
Zinc, mg/100 g	AAS	0.32	7%
Calcium, mg/100 g	AAS	1.06	10%
Phosphorus, mg/100 g	AAS	1.98	10%
Magnesium, mg/100 g	AAS	0.84	8%
Sodium, mg/100 g	AAS	1.73	10%
Potassium, mg/100 g	AAS	1.7	10%
Iodine, μg/100 g	AAS	0.9	10%
Vit-B2, mg/100 g	AOAC*	0.01	7%
Vit-B3, mg/100 g	AOAC*	0.01	7%
Vit-C, mg/100 g	AOAC*	0.01	5%
Chlorophyll, mg/g	HPLC	–	–
Carotenoids, mg/g	HPLC	–	–
Beta-carotene, mg/g	HPLC	0.01	5%
Aminoacids, mg/g of protein	GC–MS*	4.3	10%
Fatty acids, mg/100 g	GC–MS (FAME-method)	8.6	10%
Mercury, ppm	Acid digestion#	nd	–
Cadmium, ppm	Acid digestion#	0.01	10%
Lead, ppm	Acid digestion#	nd	–
Arsenic, ppm	Acid digestion#	0.011	10%
Copper, ppm	Acid digestion#	0.02	10%

*Raghuramulu et al. (2003), #-Atomic absorption spectroscopy, FAME method-Liu et al. (1995), nd-not detected.

The total lipid in the samples ranges from 0.48 to 1.4 g. The lipid content was high in *P. gymnospora* (1.4 g) followed by *U. fasciata* (0.89 g),a low value found in *A. spicifera* (0.48 g). This values are on par with other red and brown seaweed i.e. 0.7–1.05 g (Sánchez-Machado et al., 2004). Seaweeds reported with low level of lipids in comparison with other foods. However, fat is essential for foetal development and substantially energy for pregnant women to obtain total weight gain of 12 kg, this should be derived from protein and fat (FAO/WHO, 2004). Ash content ranges from 21 to 32.20 g/100 mg was considered to be high and associated with high mineral elements. Highest in *E. flexuosa* (32.20 g) followed by *U. fasciata* (27 g) and least in *A. spicifera* (21 g). Sea vegetables recorded high amount of ash compared to terrestrial vegetables (Thennarasan et al., 2015). Further, seaweeds originated with large volume of minerals plays significant implications in food.

3.2. Micronutrient content of underexploited seaweeds

The Ca content of seaweeds ranges from 410 to 820 mg, *P. gymnospora* (820 mg) had high Ca, and low Ca found in *G. edulis* (410 mg). Phosphorus was high in *E. flexuosa* (270 mg) and low P found in *G. edulis* (124 mg). In general, dairy food provides 305 mg Ca as compared to this, seaweed serves 820 mg/100 g which found to be best alternative for pregnant women. As they require 1200 mg/day for the fetal development. Thus, seaweed is far more valuable source of calcium during gestational period. Furthermore, bioavailability of calcium is essential to monitor its release from food to bloodstream. Therefore, bioavailability and bio-accessibility of seaweeds need to be studied further. Magnesium ranges from 420 to 780 mg in the tested seaweeds with highest value in *P. gymnospora* (780 mg) and less Mg present in *U. fasciata* (420 mg). As per ICMR RDA (2010) the intake of magnesium varies between 540 mg and 1000 mg/d from Indian regional diet, and simultaneously absorption also varied from 20% to 50%.

Table 2
Nutrient composition of underexploited seaweeds and comparison with RDA.

Nutrients	*A. spicifera*	*G. edulis*	*P. gymnospora*	*U. fasciata*	*E. flexuosa*	*RDA* Pregnant women*
Carbohydrates, g	26.20 ± 0.02	24.80 ± 0.12	28.0 ± 0.12	32.0 ± 0.04	30.10 ± 0.18	136
Proteins, g	20.2 ± 0.12	18.04 ± 0.03	12.07 ± 0.78	22.7 ± 0.22	17.29 ± 1.24	82.2
Fat, g	0.48 ± 0.04	0.72 ± 0.04	1.4 ± 0.82	0.89 ± 0.12	0.76 ± 0.24	30
Ash, g	21.0 ± 0.08	22.8 ± 0.04	23.2 ± 0.03	27.0 ± 0.024	32.20 ± 0.92	–
Calcium, mg	430 ± 0.14	410 ± 0.08	820 ± 0.34	740 ± 0.28	712 ± 0.04	1200
Phosphorus, mg	210 ± 0.12	124 ± 0.08	164 ± 0.28	142 ± 0.18	270 ± 0.02	1200
Iron, mg	52 ± 0.24	72 ± 0.24	14.8 ± 0.32	47 ± 0.04	40 ± 0.28	35
Magnesium, mg	480.0 ± 1.02	580 ± 0.98	780 ± 0.08	420 ± 0.02	436 ± 0.24	310
Sodium, mg	36.08 ± 1.08	32.03 ± 0.28	36.36 ± 0.18	20.12 ± 0.02	13.20 ± 0.8	1902
Potassium, mg	52.08 ± 0.22	52.12 ± 0.07	30.02 ± 0.17	27.20 ± 1.02	22.32 ± 1.08	3225
Iodine, μg	64.8 ± 0.12	72.20 ± 0.08	46.2 ± 1.03	38.89 ± 1.08	42.03 ± 1.02	200
Zinc, μg	4.080 ± 0.28	5.210 ± 0.24	4.187 ± 0.08	2.342 ± 0.48	1.518 ± 0.81	8
Vitamin B2, mg	0.14 ± 0.32	0.12 ± 0.15	0.08 ± 0.18	0.32 ± 0.29	0.26 ± 0.32	1.7
Vitamin B3, mg	0.78 ± 0.56	0.52 ± 0.28	0.34 ± 0.16	1.02 ± 0.41	0.92 ± 0.48	18
β-Carotene, mg/g	0.24 ± 0.04	0.11 ± 0.02	0.48 ± 0.23	0.37 ± 0.02	0.32 ± 0.04	6400
Vitamin C, mg/g	0.17 ± 0.02	0.25 ± 0.06	0.29 ± 0.02	0.38 ± 0.04	0.36 ± 0.02	500
Chlorophyll *a*, mg/g	1.17 ± 0.18	0.66 ± 0.26	1.75 ± 0.42	2.09 ± 0.15	1.90 ± 0.25	–
Chlorophyll *b*, mg/g	0.24 ± 0.02	0.13 ± 0.08	0.38 ± 0.04	1.40 ± 0.46	1.24 ± 0.06	–
Total Chlorophyll, mg/g	1.41 ± 0.62	0.79 ± 0.05	2.13 ± 0.43	3.49 ± 0.62	3.14 ± 0.09	–
Total Carotenoid, mg/g	0.32 ± 0.12	0.13 ± 0.02	0.78 ± 0.08	0.60 ± 0.06	0.49 ± 0.12	–

*RDA-recommended daily allowances by ICMR RDA (2010).

Iron (Fe) was in the range 14.8 to 72 mg, the higher amount recorded in *G. edulis*, and low Fe in *P. gymnospora* (14.8 mg). Few researchers reported that Fe in *Gracilariopsis* was 360 mg/100 g, followed by *Sargassum* spp 289.50 mg/100 g and *Ulva* spp 236.60 mg/100 g of Fe (Maria et al., 2010), are on par with our study. According to ICMR, RDA suggested that 35 mg of Fe for pregnant women; therefore, this amount could meet the recommended level of Fe through seaweed in a daily basis. A study conducted by Banu and Mageswari (2015) on bioavailability of *U. recticulata* showed 11.80 mg from 56 mg/100 g of Fe which shows four-fold of reduction in Fe from actual values. Therefore, Fe in seaweeds would be complementary and relatively equivalent to meet the physiological demands of iron.

Sodium and potassium accumulation was found to be high in the selected seaweeds. *G. edulis* contains more K- 52.12 mg and Na- 32.03 mg, followed by *A. spicifera* K-52.08 mg and Na-36.08 mg, respectively. All other seaweeds were found to be less amount of Na and high amount K (Table 2). Therefore, the salty taste is mostly derived from high value of K not from Na was cleared from data. Further, Na:K ratio varied from species to species in the range of 0.59–0.82. Overall, the selected seaweeds would replace synthetic form of diuretics during pregnancy. Therefore, this combination in regular basis might balance Na:K ratio in diet as compared to terrestrial diuretic plants like asparagus and fennel (Ortego et al., 1993). The iodine ranges from 0.5 mg to 8.0 mg/g. The terrestrial plant contains trace amount of iodine 0.001 mg/g (Donald, 2006) as compared to the present results. RDA of iodine for pregnant women was 200 μg/day and toxic level-2000 μg/day for adults (Rolfes et al., 2014). Further, the iodized salt consists of 150 g and 30%of lose might occurs during cooking; thus the remaining105g could be absorbed in GI system (Miller, 2006). In comparison with these data, Iodine present in seaweed would be significant amount for physiological needs. Further, Iodine deficiency still remains leading cause of brain retardation (De Leo and Braverman, 2019), this would be reverse when seaweed is consumed in daily basis.

Riboflavin ranges from 0.08 mg to 0.32 mg, highest in *U. fasciata* (0.32 mg) and least value seen in *G. edulis* (0.12 mg). Similarly, niacin found to be 1.02–0.32 mg. Seaweeds consist of high amount of vitamins as compared to land plants with high level of vitamin A, D, E, B-complex and B12 (Fouda et al., 2019). The land plants contains riboflavin from 0.08 to 0.2 mg/100 g; these values found to be less as compared to the seaweeds. Moreover, maternal riboflavin intake is positively correlated with fetal growth (Tang et al., 2019); this level is lower than (0.5 mg riboflavin) the recommended level (FAO/WHO, 2004), however, the obtained values will meet 70% of vitamins need during pregnancy and lactation. Total carotenoid ranges from 0.13 to 78mg/g, *P. gymnospora* contains highest of all and least found in *G. edulis* (refer Table 2). Beta carotene was high in *P. gymnospora* (0.48 mg) followed by *U. fasciata* (0.37 mg), *E. flexuosa* (0.32 mg) *A. spicifera* (0.24 mg) and *G. edulis* (0.11 mg). Vitamin C was found to be high in *U. fasciata* and *E. flexuosa* (0.38–0.36 mg). These vitamin C values found are on par with other seaweed *L. variegate* found in Indian coast (Thennarasan et al., 2015; Abirami and Kowsalya, 2017). Further, seaweed carotenoids such as cryptoxanthin, β-carotene, α-carotene (Zielińska et al., 2017) are transformed into usable form of vitamin A in human to meet biological needs during pregnancy and lactation.

3.3. Heavy metal content in seaweeds

Heavy metals like Hg, As, Cd, Pb and Cu were shown in Table-3. Hg level was detected in *A. spicifera* (0.031 ppm). Arsenic (As) content varied from 0.026 to 0.212 ppm, highest in *A. spicifera* and lowest in *U. fasciata*. Further, ingestion of Hg was a leading cause of nervous and renal damage when it crosses the placenta to reach the fetus. Furthermore, inorganic As bioaccessibility should be monitored and evaluated to study the impact on regular basis. Laparra et al. (2004) evaluated the effect of inorganic As during cooking, they found that 78–88% of this compound solubilized in gastrointestinal digestion which remains unavailable for absorption in the intestinal mucosa. Therefore, data obtained in these seaweeds will not cause any internal damage to tissue or metabolism even during pregnancy.

Further, inorganic As in seaweed, would removed (20–60%) during washing, soaking or boiling (Roleda et al., 2019). Inorganic As from seaweeds found to be high in rice cracker (152 μg/Kg) and lobster (89 μg/Kg) as per Swedish food consumption survey (Kollander et al., 2019). Therefore, the amount detected in this study were lesser than other inorganic As food source. Arsenic deficiency impairs metabolism of methionine which resulted in decreased S-adenosylmethonine decarboxylation activity. Tolerable weekly intake of inorganic As was 50 μg/kg BW (WHO, 2001). Therefore, the tested seaweed consists of 3 μg/g or ppm of inorganic As, to exceed this WHO limit one would have to eat 162 g or almost 6 oz daily. Hence, As content in the present study found lesser than the WHO limit is clear. The Cd ranges from 0.012 to 0.081 ppm, found high in *P. gymnospora* and low in *G. edulis*. The tolerable daily intake of Cd in humans ranges between 50 and 150 µg (WHO, 2009). Lead was not detected in *A. spicifera, U. fasciata* and *E. flexuosa*. Besides, Pb content in *G. edulis* was 0.196 ppm, *P. gymnospora*-0.103 ppm. Desirable limits given by French for edible seaweeds were Pb < 0.5 mg/kg d.w, Hg < 0.1 mg/kg d.w, and inorganic As < 3 mg/kg d.w (Peña-Rodríguezet al., 2011).

Copper ranges from 0.025 to 0.979 ppm and high in *G. edulis* 0.979 ppm and low in *E. flexuosa* (0.025 ppm). Further, the role of sulfated polysaccharide in seaweeds will not allow the heavy metals to digest in human. Sulfated polysaccharides from seaweeds *A. spicifera*, carrageenan (Ganesan et al., 2019b), ulvan in these seaweeds may prevent metal absorption and eliminate them through excreta. Thus, regular consumption of seaweeds can significantly remove toxic elements in the body. Seaweeds have the ability to regulate these metals to great extent (Qari and Siddiqui, 2010). In terms of toxicological criteria, seaweeds must meet safety regulations as compared to food safety authority of Ireland (FSAI, 2011) given in Table 3. Further, France gave the quality criteria for *Ulva* species should be as less than 3 ppm for As, 5 ppm Pb, 0.5 ppm Cd and 0.1 ppm Hg. In the present study, the heavy metal concentration was found to be within the tolerable value as compared to the above values.

3.4. Amino acid profile of seaweeds

The ratios of EAA to non-EAA of seaweeds ranged from 0.72 to 1.02 and ratio of EAA to total amino acids were almost 0.41–0.5 given in Table 4. EAA such as leucine, isoleucine and lysine were found to be high in all the selected seaweeds. The non-EAAs such as histidine, aspartic acid, glutamic acid, serine, proline, glycine, and alanine were relatively high levels. The total amino acid ranges from 444.5 to 647.5 mg/g protein in *U. fasciata* and low in *E. flexuosa*. The result of present study was on par with the study reported by Benjama and Masniyom (2011).

The glutamic acid gives unique fishy flavor, glycine and alanine gives sweet flavor to seaweeds (Ratana-arporn and Chirapart, 2006). Wong et al. (2000) stated that green seaweed possess high amount of amino acid which correlated with protein content in our study. Similarly, proteins in cereals and pulses are deficient in EAA such as lysine and methionine. However, EAA in precise combination found in this study. Therefore, this ratio of TAA and EAA would be best combination for pregnant women for the development of fetus. Further, fetal liver and placenta requires adequate amount of glycine, serine, glutamine for circulation of nutrients uptake in placenta. Individual amino acid exhibits different physiological role during pregnancy (Elango and Laviano, 2019).

3.5. Fatty acid composition of seaweeds

The total fat content in all species were more than 0.4 g/100 g which contains more than 20 fatty acids is shown in Table 5. The selected seaweed contains saturated, monounsaturated and polyunsaturated fatty acids. *G. edulis* contains 0.80% and *U. fasciata*-0.59% of arachidonic acid with C6. The simple fatty acids like capric, lauric, myristric, pentadecyclic, palmitic, margaric acid and stearic acid were found in all species. *U. fasciata* contains high amount of monounsaturated and polyunsaturated as compared to saturated fatty acids, whereas, *P. gymnospora* contains high amount of saturated fatty acids, as compared to other fatty acids. Further, seaweed contains more unidentified fatty acids, and all species displayed high amount of unsaturated fatty acids. These values found to be promising and functional food for brain cells and vision of fetus which requires arachidonic acid (AA) and docosahexaenoic acid (DHA) during pregnancy. This confirms PUFA

Table 3
Heavy metal content in underexploited seaweeds.

Heavy metals	*A. spicifera*	*G. edulis*	*P. gymnospora*	*U. fasciata*	*E. flexuosa*	*FSAI Maximum limit mg/Kg*
Mercury	0.031 ± 0.008	nd	nd	nd	nd	0.5–1.0
Arsenic	0.012 ± 0.002	0.120 ± 0.004	0.076 ± 0.008	0.026 ± 0.002	0.018 ± 0.007	0.12*
Cadmium	0.016 ± 0.002	0.012 ± 0.018	0.081 ± 0.012	0.046 ± 0.003	0.028 ± 0.003	3.0
Lead	nd	0.196 ± 0.003	0.103 ± 0.023	nd	nd	3.0
Copper	0.421 ± 0.012	0.979 ± 0.043	0.340 ± 0.081	0.146 ± 0.018	0.025 ± 0.002	1.68#

nd-not detected, Food safety authority of Ireland (FSAI), *Equivalent mg/day for a 60 kg adult, #total dietary intake.

Table 4
Amino acid content of underexploited seaweeds and its comparison.

Amino acid	*A. spicifera*	*G. edulis*	*P. gymnospora*	*U. fasciata*	*E. flexuosa*	FAO/WHO *(mg/g)*
Aspartic acid[b]	45	40.5	40.2	60.8	63.2	–
Glutamic acid[b]	76	62.6	70.3	72.6	68.2	–
Histidine[b]	42.6	33	16.2	14.3	7.2	15
Glycine[b]	37.54	48.3	20.2	52.2	42.3	–
Threonine[a]	52.3	30.4	24.6	38.8	42.8	–
Arginine[b]	12.6	8.6	18.3	29.2	40.3	–
Alanine[b]	34.2	34.2	22.6	45.4	32.4	–
Tyrosine[b]	46.3	44	68.2	33.6	22	–
Valine[a]	44.5	28.6	32.3	46.7	40	39
Methonine[a]	16.2	20.9	12.7	12.8	10.2	16
Phenylalanine[a]	54.6	76	40.3	42.2	33.6	38
Isoleucine[a]	36.8	63	20.2	40.2	25	30
Leucine[a]	49	36	32.7	68.4	48.4	59
Lysine[a]	52.6	32.4	26.4	52.4	20.2	45
Proline[b]	17.8	12.4	24. 6	37.8	29	
Total Aminoacid	618.04	570.9	445.2	647.4	524.8	277
Essential Aminoacids	306	287.3	189.2	301.5	220.2	–
Non EAA	312.04	283.6	256	308.1	304.6	–
EAA/Non-EAA	0.98	1.02	0.73	0.97	0.72	–
EAA/Total EAA	0.49	0.5	0.42	0.46	0.41	–

FAO/WHO (2004). a- essential amino acid, b-non essential amino acid

Table 5
Fatty acid profile of underexploited seaweeds.

Carbon chain	Fatty acids	Retention time	*A.spicifera*	*G.edulis*	*P.gymnospora*	*U.fasciata*	*E.flexuosa*
Saturated monocarboxylic fatty acids							
C9:0		2.727	3.00	0.83	–	–	–
C10:0	Capric, decylic	3.253	1.86	2.83	2.35	–	–
C11:0		3.968	1.98	–	3.59	1.33	
C12:0	Lauric, laurostearic	4.925	4.39	2.03	2.89	1.49	9.78
C13:0		6.120	0.27	–	–	0.25	–
C14:0	Myristic	7.537	3.95	2.25	4.29	3.39	–
C15:0	Pentadecyclic acid	9.089	0.90	0.95	1.68	0.79	–
C16:0	Palmitic	10.783	23.93	56.41	62.46	54.40	50.02
C17:0	Margaric	12.548	0.50	–	–	–	1.61
C18:0	Stearic	14.302	2.97	2.45	2.82	2.98	–
Sum			43.75	67.75	80.08	64.63	61.39
Monounsaturated							
C14:1ω-5		7.382	0.84	–	–	–	–
C15:1ω-5		8.940	–	–	–	0.41	–
C15:1ω-8		8.773	2.19	–	–	–	0.36
C16:1ω-7	Hexadecaenoic acid	9.758	–	0.34	–	2.32	–
C17:1 ω-7		12.218	–	–	–	1.54	–
C18:1ω-5		14.181	–	1.44	0.21	–	–
C18:1ω-7	Decenoic acid	14.011	5.70	1.93	0.67	–	–
C18:1ω-9	Oleic acid	13.915	3.62	8.84	2.82	9.78	10.32
Sum			12.35	12.55	3.07	14.05	10.68
PUFA							
C18:3ω-6	Gamma Linoleic acid	13.572	–	–	–	0.59	–
C20:4ω-6	Arachidonic acid	16.788	–	0.80	–	–	–
Sum			0	0.80	0	0.59	0
Others *			13.63	55.16	61.94	31.35	11.59

*Non-identified fatty acids.

and MUFA were 0.59–0.80% and 3.07–14.05%, respectively. As compared to flaxseed, soy bean (8–11% PUFA/ MUFA), our result shows less amount of fats. However, studies showed that during pregnancy high level of fish consumption will improve fetal and infant brain development depends on the maternal source of LA, AA, ALA and DHA through tissue stores and dietary intake (Hauser et al., 2019).

Tasende (2000) found that *Chondrus crispus* contains fatty acids such as palmitic, palmitoleic, oleic, arachidonic and eicosapentaenoic acids was on par with our results. These five fatty acids occupied major proportion lipid profile here in our data. Further, in our study unsaturated fatty acids found to be greater quantity (>80%) than saturated fatty acids (Sánchez-Machado et al., 2004). However, other red seaweed *Champia parvula* showed long chain saturated fatty acid like eicosanoic acid in its structure (Vinoth Kumar et al., 2019), which is not seen in the present study. Further, it was observed that conjugated EPA and AA obtained by alkali isomerization showed higher cytotoxicity effect on human cancer cell lines. The role of EPA and other unsaturated fatty acids during pregnancy is crucial for the transport of these compounds across placenta for the production of prostaglandins. A study shows that high DHA and unsaturated fatty acids will improve the visual acuity, mental development and psychomotor skills of fetus (James, 2012).

4. Conclusion

Seaweed is an alternative source of protein with micronutrient which considered as a safe food for pregnant women and also for all age groups; since the heavy metal concentration were below the toxic level (Ganesan et al., 2020) and this concentration was within the tolerable limit. In addition, *Ulva fasciata* and *Graciliaria edulis* contains all EAA and EFA which found to be excellent source for pregnant women for cognitive development of fetus. Further, micronutrients like iron, iodine, and zinc in these seaweeds might prevent micronutrient deficiency during pregnancy and related disorders in the fetus. The combination of essential and non-essential amino acids, omega–3 fatty acids, are precursors for the production of neurotransmitters which are indispensable during pregnancy for brain health. Therefore, the results obtained from the underexploited seaweeds would be a potential food for humans to elevate deficiency and improve the therapeutic values, can be considered as a futuristic functional food.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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