CHAPTER 28

Seaweed Vitamins as Nutraceuticals

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Abstract

Seaweeds are a good source of some water- (B_1, B_2, B_{12}, C) and fat-soluble (β-carotene with vitamin A activity, vitamin E) vitamins. To ensure that the adequate intake of all vitamins is received in the diet, people (especially people on special diet, strict vegetarians, and vegans) can consume foods enriched with vitamins, for example, in the form of functional foods with vitamins as nutraceuticals, extracted from natural sources such as seaweeds. Seaweed vitamins are important not only due to their biochemical functions and antioxidant activity but also due to other health benefits such as decreasing of blood pressure (vitamin C), prevention of cardiovascular diseases (β-carotene), or reducing the risk of cancer (vitamins E and C, carotenoids).

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I. INTRODUCTION

Vitamins are organic essential compounds needed in the human body in trace amounts for different chemical and physiological processes. Vitamins are commonly classified into two groups according to their solubility: water-soluble vitamins (members of the vitamin B group and vitamin C) and fat-soluble vitamins (vitamin A and its provitamins—carotenoids with vitamin A activity, vitamins E, D, and K).

Even though vitamins are required only in very small quantities, to ensure that the adequate intake of vitamins in the diet is received, people can consume foods enriched with vitamins, for example, in the form of functional foods with vitamins as nutraceuticals. In addition, certain vitamins extracted from natural sources such as seaweeds have antioxidant activity and other health benefits such as decreasing of blood pressure, prevention of cardiovascular diseases, or reducing the risk of cancer.

II. IMPORTANCE OF VITAMINS FOR HUMANS

As mentioned above, vitamins are essential substances which cannot be synthesized by humans or only in limited quantities; therefore, they should be obtained from human diet. Vitamin deficiency can be caused not only by insufficient intake from foodstuffs but also because of increased requirement by certain group of people (people on special diet, smokers), poor absorption, or inadequate utilization.

Seaweeds are generally a good source of some B group vitamins (B_1, B_2, B_{12}). Other vitamins of B-complex are present too, but only in low or trace amounts (niacin, B_6, biotin, folates). Certain seaweeds contain great quantities of vitamins with antioxidant activity, vitamins C and E, and the provitamin forms of vitamin A, carotenoids.

A. Function of vitamins in human body

The hydrosoluble vitamins are needed as enzyme cofactors. The vitamin can have one or a few very specific roles or much more extensive roles. Several B group vitamins serve as coenzymes for enzymes with function in the catabolism of foodstuffs to produce energy for the body. Some of them are fundamental even for their antioxidant activity and other health benefits. Thus low levels of some B group vitamins (B_2, B_6, B_{12}) can result in reduced levels of DNA methylation and therefore in some kinds of cancer (Hernandez *et al.*, 2003).

The following vitamins are presented in seaweeds in great amounts—thiamin, riboflavin, cobalamin, and ascorbic acid. Thiamin (vitamin B_1)

has a key role in the intermediary carbon metabolism and is essential for several enzymes such as pyruvate dehydrogenase, pyruvate decarboxylase, and transketolase. Riboflavin (vitamin B_2) is used ubiquitously throughout the cell. Cobalamin (vitamin B_{12}) is required for the activity of cobalamin-dependent biosynthetic enzymes: methionine synthase and methylmalonyl CoAmutase. Interestingly, although vitamin B_{12} is not found in vascular plants, it is abundant in algae. As only prokaryotes have the ability to synthesize cobalamin, all of the vitamin B_{12} found in algae must have originally been produced by bacteria (Croft *et al*., 2006). Ascorbic acid (vitamin C) is fundamental antioxidant in the ascorbate–glutathione pathway. Moreover, it protects enzymes that have prosthetic transition metal ions and is a cofactor of enzymes such as violaxanthin deepoxidase, ascorbate oxidase, and ascorbate peroxidase.

Fat-soluble vitamins, which are present in seaweeds, are vitamin E and provitamins A. Vitamin E (tocopherols and tocotrienols) is important liposoluble antioxidant which is conclusive for the prevention of oxidation of polyunsaturated fatty acids absorbed from the diet. Tocopherols block the production of reactive oxygen species formed during oxidation and help inhibit the low-density lipoprotein (LDL) oxidation as namely oxidatively modified LDL are considered to play a vital role in the development of atherosclerosis (Steinberg, 1991). Vitamin A, retinal, as visual pigments' chromophore, is important in the vision process. Besides the epithelial tissue maintenance and prevention of its keratinization, vitamin A also presents important systematic functions in the growth and reproductive efficiency (Ribeiro *et al*., 2011). However, plant food such as algae does not contain intrinsic vitamin A, but its provitamins, carotenoids, linear polyenes with a cyclic structure which possesses a β-ring. The most abundant carotenoid with provitamin function in seaweed is β-carotene. It can be cleaved by a β-carotene-15,15′-dioxygenase, resulting in the formation of retinal (DellaPenna and Pogson, 2006; Ribeiro *et al*., 2011).

B. Vitamin requirements for humans

The recommended daily allowances (RDA) values are based on our knowledge of the minimal requirement for maximal protection for each vitamin-dependent function. Because requirements are not known exactly, these data can differ according to country experts and nutrition organization. Recommendations for some vitamins intake or RDA have been established without taking into consideration their need for enhancing body function and preventing some diseases. Therefore, the intake of vitamins which prevent certain diseases due to its strong antioxidant activity (e.g., prevention of cardiovascular disease and cancer) should be higher than that of RDA values (Weber *et al*., 1997).

The presented ranges of RDA and median RDA values, from data collected from up to 30 countries, recalculated Brubacher (1989).

RDA for vitamins B_1 and B_2 are 0.5–2.2 and 0.8–3.2 mg/day, respectively, with the median of 1.2 and 1.6 mg/day. The minimum daily requirement for vitamin B_{12} is thought to be in the range of $\sim$0.1 μg, the amount of 0.2–0.25 μg absorbed from food is generally adequate, and 1 μg daily would treat people with no stores of vitamin B_{12}, for example, those with vegan diet (Herbert, 1988). According to Brubacher data (1989), RDA value for vitamin B_{12} is 1–5 μg/day, the median 2 μg/day. The high value of vitamin B_{12} is presented in red seaweed *Porphyra* sp. (nori)—33.8 μg/100 g dw (Miyamoto *et al.*, 2009). Therefore, a consumption of only 1.5 g of this seaweed would complement the RDA of this vitamin. In result, seaweed can provide an alternative source of this vitamin for strict vegetarians and vegans. However, the bioavailability of different forms of vitamin B_{12} in seaweeds should be discussed as some introduced results are contradictory. RDA value of vitamin C is 15–100 mg/day, the median 60 mg/day of ascorbic acid.

Concerning the fat-soluble vitamins, the range of RDA value of vitamin E is 5–50 mg of α-tocopherol equivalent per day, the median 10 mg/day. The RDA value of vitamin A is 360–1650 μg/day of retinol equivalent (RE) with the median of 800 RE/day. As mentioned before, seaweed does not contain intrinsic vitamin A, but its provitamins, with β-carotene as the most abundant. The relevant dose of β-carotene intake is about 15 mg/day (Krinsky, 1998). The vitamin A activity (μg RE/100 g) is recalculated from determined content of β-carotene.

III. VITAMIN COMPOSITION IN SEAWEED

There is only few published data concerning vitamin content and bioavailability of vitamin forms contained in edible seaweeds. Generally, seaweeds contain both water- and fat-soluble vitamins, B-complex vitamins, vitamin C, provitamin A, and vitamin E, but some of them only in relatively low content.

A. Factors influencing vitamin content in seaweed

The composition and therefore the vitamin profile of seaweeds vary and are affected by algal species, algal grown stage, geographic area and salinity, season of the year, availability of light, and temperature of sea water (Mabeau and Fleurence, 1993; Norziah and Ching, 2000).

The content of some vitamins in seaweeds, for example, vitamin B_{12} (Yamada *et al.*, 1996a), varies greatly among samples of the same species. In many cases, light is an important regulator of vitamin biosynthesis;

thus plants growing in bright light have higher ascorbate content (Smith *et al.*, 2007). Moreover, algae growing in the littoral zone or on the surface tend to have higher level of vitamin C than algae which is harvested from depth from 9 to 18 m (Norris *et al.*, 1937). Further, other environmental parameters, such as concentration of certain compounds in the sea, can play the important role for vitamin occurrence in algae (Smith *et al.*, 2007).

The importance of vitamins to plants themselves is often overlooked, but they play the essential roles in a plant metabolism too (Smith *et al.*, 2007). Some algal species require different combinations of certain vitamins such as vitamins B_{12} and B_1. Because the concentration of these vitamins in the natural environment is quite low, their absorption is insufficient (Croft *et al.*, 2006). According to Yamada *et al.* (1996a), red algae *Porphyra tenera* can take up the free (not protein-bounded) form of vitamin B_{12} from the incubation medium by concentration- and temperature-dependent processes. The amount of uptake increases with the time of incubation.

Loss of vitamins can be induced by storage conditions such as the influence of light and oxygen. Moreover, there is a negative influence on a vitamin content caused by technological processing such as drying (sun-, oven-, freeze-drying) and sterilization, and culinary processes such as cooking, roasting, or baking, which could decline vitamin content due to water extrusion and high temperature during these procedures. This was observed, for example, in instable ascorbic acid (Norris *et al.*, 1937).

According to the vitamin determination by Hernández-Carmona *et al.* (2009), there are significant differences of certain vitamins content caused by seasonal variations, for example, in *Eisenia arborea*. It was observed that the highest content of some vitamins (A, B_1, B_2, and partly also vitamin C) was in spring opposite to the lowest spring value of vitamin E. Moreover, season was observed as the factor of carotenes content affection also in *Palmaria*. The highest content of carotenes was found in summer and the lowest in winter (Løvstad Holdt and Kraan, 2010).

B. Bioavailability and absorption of vitamins

Although certain macroalgae are rich in vitamins, the bioavailability of these compounds has not been studied sufficiently yet, so there is not enough data to clarify this problem for all vitamins satisfyingly. Bioavailability is influenced by several factors as follows: characteristics of the food source, location of the vitamin in the plant source, particle size, the presence of other influencing dietary components and interactions with other dietary factors, the type and extent of processing (Rock *et al.*, 1998).

The bioavailability of vitamins is primarily related to solubility of each vitamin, which cohere with their intestinal absorption and therefore with their uptake by tissues as well. Bioavailability and absorption of some fat-soluble vitamins depend on whether they are consumed together with foodstuffs containing lipids or not. As being fat-soluble, these vitamins follow the same intestinal absorption path as dietary fat. Further, it is also important which of vitamin form is present in food. Therefore, for example, significant contributions to vitamin E activity are α- and γ-tocopherols (Weber *et al.*, 1997).

Although only little is known about the origin of vitamin B_{12} in the seaweeds, the bioavailability of algal vitamin B_{12} is quite contradictory. Generally, edible algae contain large amount of vitamin B_{12}; some of them (e.g., *Porphyra* sp.) comprise a substantial amount of the form bioavailable to mammals. However, van den Berg *et al.* (1991) mentioned that at least part of the cobalamins may be analogues not bioavailable for humans as pseudo-B_{12}. These compounds have adenosyl moiety instead of 5,6-dimethylbenzimidazole of the B_{12} molecule (Yamada *et al.*, 1996b). Miyamoto *et al.* (2009) reports that dried purple laver (*Porphyra* sp.) could be well digested only under pH 2.0 conditions. Further, digestion rate of B_{12} would be estimated to be 50% in persons with normal gastric function.

It also appears that vitamins which are bound to fibers or some other carbohydrates in foods are not as available as the vitamins taken in the pure form. This is shown in seaweeds such as hijiki, which has a high percentage binding (42.7–45.6%) for thiamin. In contrast, kombu and susabi-nori showed the lowest binding for this vitamin (Suzuki *et al.*, 1996).

C. Vitamin composition of seaweed

It is said that 100 g of seaweed provides more than the daily requirements of vitamin A, B_2, B_{12}, and two-thirds of the vitamin C requirement (Ortiz *et al.*, 2006). Most of the red seaweeds (*Palmaria*, *Porphyra*) contain large amounts of provitamin A and significant quantities of vitamins B_1, B_2, and B_{12}, which are also present in green seaweeds. The vitamin content of brown seaweeds (*Undaria*, *Laminaria*) appears to be less remarkable, but brown seaweeds have high content of vitamin C (Mabeau and Fleurence, 1993). Some seaweed (such as *Porphyra*) can supply adequate amount of vitamin B_{12} in vegans.

The following summary is concerned with the most abundant seaweed vitamins which can sufficiently contribute to daily vitamin requirements, such as water-soluble vitamins B_1, B_2, B_{12}, and C and fat-soluble provitamins A (β-carotene) and E. Because some results are given for fresh samples, some for dry ones, there is quite disputable to compare the data presented thereby.

Vitamin B_1 and B_2 are present in sufficient amount especially in brown and red marine algae. The highest amount of both vitamins was detected in wakame and kombu—0.3 and 0.24 mg B_1/100 g dw; 1.35 and 0.85 mg

B_2/100 g dw, respectively (Kolb *et al.*, 2004). Lower levels of these vitamins are present in arame (0.06–0.12 and 0.65–0.92 mg/100 g dw, respectively), *Caulerpa lentillifera* and *Ulva reticulata* (Hernández-Carmona *et al.*, 2009; Ratana-Arporn and Chirapart, 2006). French Institut de Phytonutrition (FIP) describes much higher content of these vitamins, for example, in wakame—5 mg B_1/100 g dw or 11.7 mg B_2/100 g dw (MacArtain *et al.*, 2007).

The intake of vitamin B_{12} in strict vegetarian and vegan diet is usually quite low. Therefore, this vitamin can easily become deficient. Lower levels of vitamin B_{12} in a diet may result in reduced levels of DNA methylation or elevated levels of homocysteine which is a risk factor for cardiovascular diseases (Hernandez *et al.*, 2003). A particularly rich dietary source of the vitamin is seaweed, foods enriched with them or seaweed extracts, which are good alternate source of vitamin B_{12} for vegans. Thus consumption of some seaweed (nori) may keep vegans from suffering B_{12} deficiency (Suzuki, 1995). The highest content of vitamin B_{12} in seaweed is presented in red *Porphyra* sp. (nori)—133.8 μg B_{12}/100 g dw, in the form active for human (Miyamoto *et al.*, 2009). Other results of B_{12} content in this algae are present in range 12.02–68.8 μg/100 g dw (Takenaka *et al.*, 2003; van den Berg *et al.*, 1988; Watanabe *et al.*, 1999, 2000). Further marine algae contain much less of B_{12}; high content is found in green laver *Enteromorpha* sp., following by dulse, and low levels in *Ulva* sp., wakame, kombu, and hijiki (MacArtain *et al.*, 2007; Watanabe *et al.*, 1999; Yamada *et al.*, 1996b).

Vitamin C is present especially in brown and green seaweeds, less in red algae. The highest levels of vitamin C were discovered in *Enteromorpha flexuosa* and *Ulva fasciata* (300 and 220 mg/100 g dw, respectively) (McDermid and Stuercke, 2003). FIP states that the highest level of vitamin C is found in wakame (184.75 mg/100 g dw), red laver, and sea lettuce (MacArtain *et al.*, 2007). Chan *et al.* (1997) determined the high content of vitamin C in freeze-dried algae *Sargassum hemiphylum*—153.8 mg/100 g dw, smaller amount in oven- and sun-dried seaweed. Other seaweeds contain much less of vitamin C; high content is found in red algae *Kappaphycus alvarezzi* (107.1 mg/100 g dw) and low levels in arame, ogonori, *Sargassum polycystum*, *Eucheuma cottonii*, *U. reticulata*, and *C. lentillifera* (Fayaz *et al.*, 2005; Hernández-Carmona *et al.*, 2009; Hong *et al.*, 2007; Matanjun *et al.*, 2009; Norziah and Ching, 2000; Ratana-Arporn and Chirapart, 2006).

Despite the low lipid content in seaweed, their fat contains high level of vitamin E. Generally, brown seaweeds contain more α-tocopherol (also β- and γ-tocopherols) than red and green algae which contain only α-tocopherol. The highest amount of vitamin E was detected in kelp *Macrocystis pyrifera*, 132.77 mg/100 g fat (α-tocopherol), with total tocol content of 145.72 mg/100 g fat, and in *Ulva lactuca* with γ-tocopherol value

96.35 mg/100 g fat (Ortiz *et al.*, 2006, 2009), so compared to traditional plant oils, the fat of these seaweeds contain a high level of tocols. Moderate levels were found in *Durvillaea antarctica* (Ortiz *et al.*, 2006). Low content of tocols was determined in *Gracilaria chilensis*, followed by *S. polycystum*, *C. lentillifera*, *E. cottonii*, and *E. arborea* (Hernández-Carmona *et al.*, 2009; Matanjun *et al.*, 2009; Ortiz *et al.*, 2009). FIP states that the highest level of vitamin E is in wakame and dulse (MacArtain *et al.*, 2007).

Plant food such as algae does not contain intrinsic vitamin A, but its provitamins such as β-carotene. The high values of β-carotene with vitamin A activity were found in red seaweeds *Gracilaria changgi*, *K. alvarezzi*, and in brown algae kombu (5.2, 5.26, and 2.99 mg/100 g dw, respectively, recalculated to 865, 865, and 481 RE/100 g dw) (Fayaz *et al.*, 2005; Kolb *et al.*, 2004; Norziah and Ching, 2000). Moderate levels of vitamin A were determined in wakame, arame, sea grapes, and sea lettuce (Hernández-Carmona *et al.*, 2009; Ratana-Arporn and Chirapart, 2006).

D. Antioxidant activity of some vitamins contained in seaweed

Among the compounds found in seaweeds, those with antioxidant activity have an excellent potential for application in food industry and also in cosmetics and pharmacology industry, and for consumer interest too. Due to the presence of these compounds, marine algae may also have other health beneficial effects and therefore they could be used as nutraceuticals or in functional foodstuffs.

When seaweeds are exposed to a combination of light and high oxygen concentrations, the formation of free radicals and other oxidative reagents is induced. The absence of structural damage in the structural components suggests that seaweeds are able to generate the necessary compounds to protect themselves against oxidation (Jiménez-Escrig *et al.*, 2001). Therefore, marine algae can be considered the important source of antioxidants. According to Tsuchihashi *et al.* (1995), the antioxidant potency is determined by several factors such as intrinsic chemical reactivity of antioxidant toward radical, site of generation and reactivity of the radicals, site of antioxidant, concentration and mobility of the antioxidant at the microenvironment, stability and fate of antioxidant-derived radical, and interaction with other antioxidants.

The compounds which are responsible for antioxidant activity in seaweed include vitamin E (α-tocopherol), carotenoids (β-carotene), and vitamin C (ascorbic acid), and partially vitamin B_1 and niacin.

Oxidative forms, which arise in foodstuffs, are responsible for various free-radical-induced diseases such as cardiovascular diseases and certain types of cancers. Vitamins with a strong antioxidant capacity can be used as the first line therapeutic defense against cancer before cancer treatment (Simon, 2002).

The antioxidant activity of carotenoids is associated with its binding capacity with singlet oxygen by conjugated double bonds systems. The maximum protection is given by carotenoids with more than nine double bonds (Ribeiro *et al.*, 2011). The effectiveness of carotenoids as antioxidants is also dependent upon their interaction with other coantioxidants, especially vitamins E and C. It was demonstrated that β-carotene is 32 times less reactive toward peroxyl radical than α-tocopherol and 11 times less reactive toward carbon-centered radical. Therefore, β-carotene is less potent as an antioxidant than α-tocopherol. Carotenoids may, however, lose their effectiveness as antioxidants at high concentration or at high partial pressures of oxygen. It is unlikely that carotenoids actually act as prooxidants in biological systems; they rather have a tendency to lose their effectiveness as antioxidants (Young and Lowe, 2001).

In certain experimental studies, there is an indication for the correlation between the diet rich in carotenoids (β-carotene) and a diminishing risk of cardiovascular diseases and some type of cancer—lung cancer, and probably also cancer of the esophagus, stomach, colon, rectum, breast, and cervix (Kohlmeier and Hastings, 1995; Krinsky, 1991). Presumably, they are capable of seeking for free radicals and neutralizing them and thus they inhibit cell proliferation (Simon, 2002).

Despite the low lipid content in seaweed, the presence of vitamin E is relevant as it acts as a strong antioxidant which prevents the formation of free radicals. α-Tocopherol, the most important member of tocol group, is capable of fixing free radicals via its phenol group in the structure and thus is considered to play an important role in oxidation of biological membranes, lipoproteins, and fat deposits, controlling or reducing lipid peroxidation (Sánchez-Machado *et al.*, 2002).

It was discovered that vitamin E is associated with lower mortality from cerebrovascular diseases as this vitamin improves endothelial dysfunction and ameliorates vascular health and reduces vascular damage (Houston, 2005). There is also evidence that vitamin E may protect against cancer—the reduction in the risk of both lung and cervical cancers (Iso and Kubota, 2007; Simon, 2002). Vitamin E may protect against the development of cancer through several mechanisms such as reacting with genotoxic radicals, reducing mutagenic activity, inhibiting carcinogenic nitrosamine formation, protecting cell membranes against peroxidation, and/or enhancing the immune system (Weber *et al.*, 1997).

Ascorbic acid inhibits the oxidation quite efficiently for a long period and also neutralizes free nitrites which are a substrate for carcinogens. Vitamin C acts as a potent synergist in the presence of α-tocopherol and spares this antioxidant.

It is believed that ascorbic acid prevents cancer by neutralizing free radicals before they can damage DNA and initiate tumor growth, or it may act as a prooxidant helping body's own free radicals to destroy tumors in their early stages (Naidu, 2003). It appears that there is a very strong relationship between vitamin C and the reduction of stomach cancer, and a possible relationship with the reduction of the risk of mouth, pharyngeal, lung, and gall bladder cancer in men (Iso and Kubota, 2007; Simon, 2002). The dietary intake of vitamin C is also inversely correlated with systolic and diastolic blood pressure as it reduces blood pressure in hypertensive patients, hyperlipidemics, and diabetics. Combination of vitamin C with other antioxidants (vitamin E, β-carotene) provides synergic antihypertensive effects (Houston, 2005).

IV. CONCLUSIONS

There is a great prospective potential of the usage of vitamins as nutraceuticals from natural sources such as seaweed, or application of seaweed as a part of functional foods. Not only do vitamins possess considerable vitamin functions for the body, but they also possess other important qualities such as antioxidant activity and other benefits for human health. Certain groups of people (e.g., people on special diet, smokers) are prone to vitamin deficiency. Therefore, nutraceuticals or functional foods could help them to retrieve good health condition. The reason of vitamin deficiency can be caused not only by insufficient intake from foodstuffs but also by increased requirement, poor absorption, and inadequate utilization. Seaweeds are generally a good source of some B group vitamins (B_1, B_2, B_{12}) and vitamins with antioxidant activity, vitamins C and E, and the provitamins A, carotenoids (β-carotene). The highest content of vitamin B_{12}, which is deficient in vegan diet, is found in great amount in seaweed, mainly in red algae *Porphyra* sp. (nori). Vitamin C with antioxidant function shows the reduction of the risk for stomach cancer. Despite the low lipid content in seaweeds, their fat contains high level of vitamin E. It was found that vitamin E has a positive influence on mortality from cerebrovascular diseases and on the reduction of risk of both lung and cervical cancers. There is also an indication of the relation between the diet rich in β-carotene and a lower risk of cardiovascular diseases and reduction of lung cancer.

Therefore, research and following usage of seaweed vitamins as nutraceuticals or ingredients for functional food show prospective possibilities for developing food industry also for consumers who can benefit from added health properties of foods.

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