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Vitamin content in seaweeds: A systematic review on water-soluble and fat-soluble vitamins for adult daily intake

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ABSTRACT

Background: With the global population on the rise, there is a growing imperative for scientists to innovate new foods utilizing the Earth's resources, catering to consumer preferences, and promoting health benefits. There is a claim that algae, particularly seaweeds, represent an exceptional source of vitamins. Seaweeds, belonging to the marine algae category, harbor potential functional compounds targeted at mitigating metabolic risk factors. They can be integrated into food and beverage preparation either as a whole plant or as extracts. Despite assertions regarding seaweed's vitamin richness, this aspect remains unverified in humans.

Objectives: This study aims to undertake a comprehensive literature review to evaluate the amount of water-soluble and fat-soluble vitamins in seaweeds, with a specific focus on vitamins B_{12}, C, and Carotenoids.

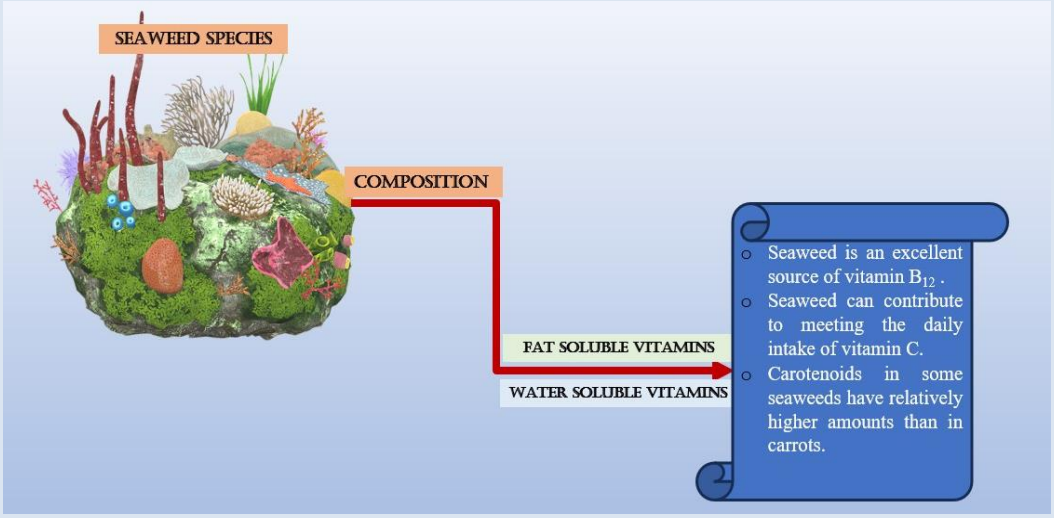
Methods: A comprehensive search for full-text, English-only publications was conducted on PubMed and Google Scholar, covering the period from 2016 to 2022. Two search terms were employed on PubMed, yielding 7 and 781 studies, respectively. From these, three studies met the pre-determined eligibility criteria for inclusion. On Google Scholar, the search generated 17,100 studies, and after screening, two studies met the eligibility criteria out of sixty. In total, five relevant publications were identified. The composition of seaweeds was then compared to other dietary sources and nutritional intakes.

Results: Seaweeds prove to be a superior source of vitamin C compared to iceberg lettuce, although not abundant for food consumption. They serve as an alternative source of vitamin B_{12} for the vegetarian population, and Vitamin A

(carotenoids) found in seaweeds surpasses that in carrots. The vitamin A content ranges from 2–10% of Reference Nutrient Intake (RNI), while vitamin C content varies from 1–23% of RNI, and vitamin B_{12} content varies from 107–446% of RNI. Seaweeds exhibit substantial potential as food supplements and as ingredients in the food industry, providing a noteworthy amount of nutritional value.

Conclusions: Seaweeds have the potential to enhance daily vitamin intake, particularly for vitamin B_{12}, C, and Carotenoids, in comparison to the recommended dietary allowance.

Keywords: Seaweeds, Algae, Marine Algae, Vitamins, Vitamin C



INTRODUCTION

Seaweeds have traditionally been dietary staples in Asian regions, with a history dating back ten thousand years [1]. While their first use as food was documented in China and Japan, seaweeds remain staples in countries such as Indonesia, South Korea, China, North Korea, Malaysia, Japan, and the Philippines. The recent surge in demand for seaweed products is attributed to their potential as functional foods [2-3], leading to a production of approximately sixteen million (15.8) tons in 2010 [4]. With the global population on the rise, there is a growing imperative for scientists to innovate new foods utilizing the Earth's resources, catering to consumer preferences, and promoting health benefits [5]. Seaweeds can serve as both a plant ingredient and an extract in food and beverage preparation, harnessing the bioactive components known to promote health. Demonstrating the health benefits of incorporating seaweed into the diet, research indicates that despite being a low-calorie vegetable, seaweeds are rich in vitamins, minerals, and essential trace elements [6]. Algae emerge as excellent sources of both water- and fat-soluble vitamins, encompassing vitamins A, C, D, and E, thiamin (B_1), niacin (B_3), cobalamin (B_{12}), folic acid (B_9), riboflavin (B_2), and pantothenic acid (B_5) [7-9]. Seaweeds, as a subset of marine algae, exhibit varying vitamin content influenced by factors such as species, season, and habitat (environment). As a result, seaweed encompasses diverse forms of antioxidants, including vitamins and protective compounds. Vitamin C is a crucial micronutrient as humans cannot synthesize it and must rely on dietary sources [10]. The Recommended Dietary

Allowance (RDA) for vitamin C is 90 mg/day for men and 75 mg/day for women [11]. For Vitamin A, the RDA is 700 mcg RAE/day for women and 900 mcg RAE/day for men over 19 years of age [12], while for vitamin B_{12}, it is 2.4 mcg/day for both women and men over 19 years of age [13]. Despite the assertion that seaweeds are rich in vitamins, this claim has not been firmly established in humans. Investigating how seaweeds contribute to the daily vitamin requirements for adults becomes an interesting endeavor. Seaweeds encompass over ten thousand species, categorized into brown, green, and red seaweed [14]. The nutritional composition of different seaweed species varies by season and location [15-18]. Therefore, a comprehensive examination of seaweed composition, specifically focusing on the vitamin content, is essential. Identifying seaweed species that serve as significant sources of vitamins and contribute substantially to daily intake in adults is paramount.

Purpose of the Study: The purpose of this study is to undertake a comprehensive literature review to evaluate the amount of water-soluble and fat-soluble vitamins in seaweeds, with a specific focus on vitamins B_{12}, C, and Carotenoids as compared to daily intake for adults.

METHOD

Literature Search: This review was written in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) statement (Page et al., 2021).

The PICOS (Population, Intervention, Comparator, Outcomes, Study design) criteria were used to determine study eligibility (Table 1).

Search Strategy: A comprehensive search was conducted on the PubMed and Google Scholar databases for English-language studies published between 2016 and 2022. The search utilized terms such as "seaweed vitamin C," "vitamin C in seaweed," "Seaweeds," and "Vitamins." Inclusion criteria encompassed interventional and observational studies that reported the chemical and nutritional composition of seaweeds, along with any significant effect on daily requirements. The study did not impose restrictions based on geographic location. Narrative reviews, conference abstracts, and dissertations were excluded.

Table 1. PICOS criteria for inclusion and exclusion of studies

Parameters	Definition
Population	Younger adults
Intervention	Seaweeds
Comparator	Non-Seaweed products established RDA
Outcome	Any effect on vitamin status
Study Design	Original research studies of any interventional or observational design were eligible. Narrative reviews, conference or dissertation abstracts, and information pieces were excluded. Studies were limited to those published in the English language between 2016 to 2022.

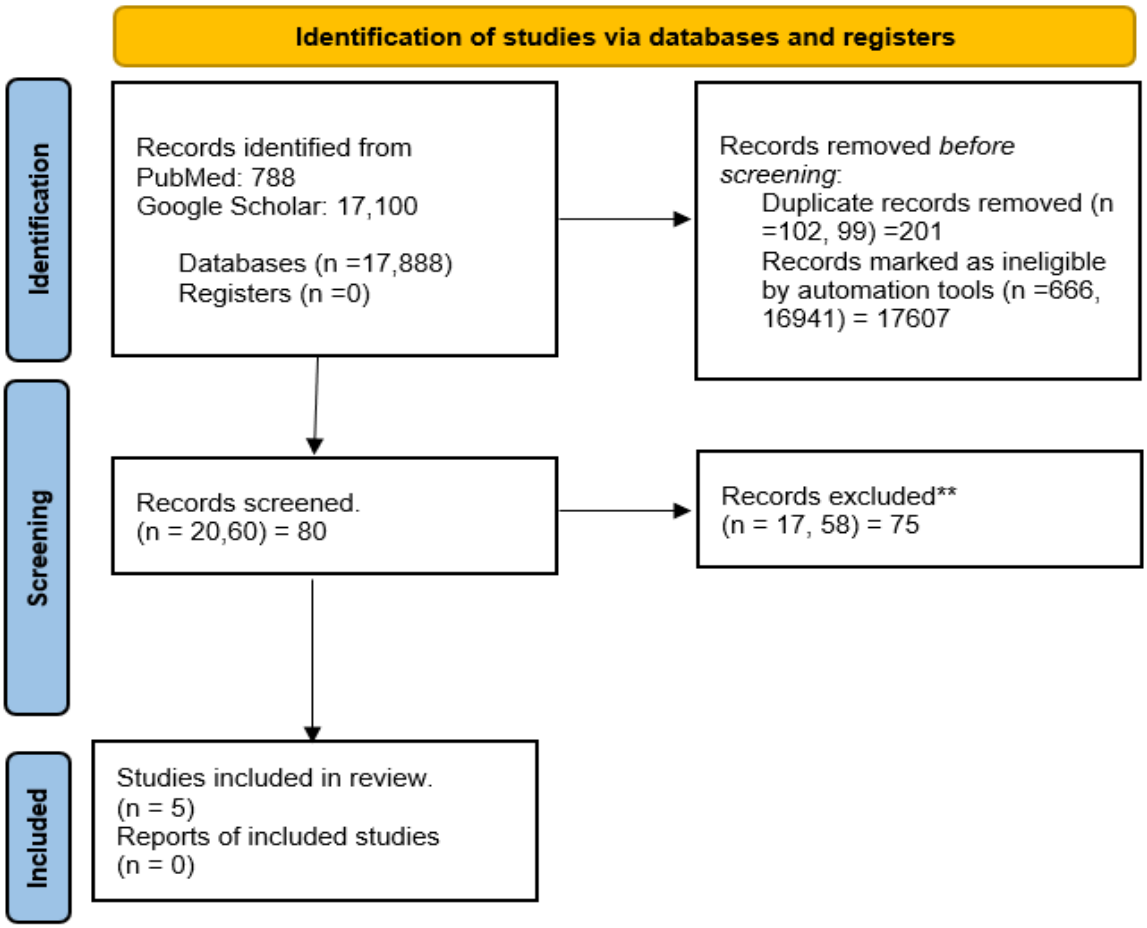


Figure 1. PRISMA Flow diagram

Table 2. Summary of Findings

Effect of seaweed intake on vitamin status			
Citation **Location**	**Study Design** **Intervention/Comparator**	**Efficacy Study Summary**	**Health Outcomes**
Nielsen et al., [19] Varied (Slovenia, Malaysia, Egypt, India, Chile, USA, Spain, Hong Kong, Vietnam, France, Mexico)	Cross-sectional, systematic review Seaweed/other food sources (Rosehip, Parsley, Broccoli, Strawberry, Grapefruit, Peas, Potato)	"Investigated the vitamin C content of various seaweed species". "Assessed whether seaweed can contribute as a vitamin C source compared to other foods".	Results showed that seaweed contains more vitamin C than iceberg lettuce. Seaweed vegetables play a part in meeting the recommendation of vitamin C. However, seaweed is not an excellent source of vitamin C.
Ganesan et al., [24] Not reported	Cross-sectional, cohort study Seaweed	"Investigated the therapeutic role of seaweed-derived compounds as a functional food ingredient for the maintenance of health".	Seaweed is a potential source of functional food substances. Seaweed is a good source of vitamins. Seaweed is an alternative source of vitamin B_{12} for groups at risk of deficiency. Vitamin A (carotenoids) found in seaweeds was more than those found in carrots.

Effect of seaweed intake on vitamin status			
Citation **Location**	**Study Design** **Intervention/Comparator**	**Efficacy Study Summary**	**Health Outcomes**
Cherry et al., [29] UK, Ireland	Cross-sectional, observational study Seaweed/RNI	"Summarized evidence on the potential health benefits of consuming whole seaweeds".	Seaweed is a source of both fat- and water-soluble vitamins. The vitamin B_{12}, A, & C content was from 107-446%, 2-10% & 1-23% of RNI respectively. Seaweed consumption may improve vitamin status
Peñalver et al., [39] Not reported	Cross-sectional, cohort study Seaweeds	"Examined seaweeds as a functional ingredient".	Seaweed is an excellent source of vitamins. The nutritional composition of seaweeds could contribute to enhancing the standard of living and sustaining an adequate diet if eaten occasionally.
Rosemary et al., [43] India	Randomized control trial, cohort study Red seaweeds	"Evaluated and compared the chemical composition and physicochemical properties of, *Gracilaria corticata* and *Gracilaria edulis".*	Both *G. corticata* and *G. edulis* have good amounts of vitamin content. G. corticata had more vitamin A (2.67mg/g) and vitamin B_9 contents (1.00mg/g) than *G. edulis*. However, *G. edulis* showed a significantly higher amount of vitamin B_2 (1.54 mg/g) and vitamin B_6 (4.77 mg/g) than *G. corticata*. *G. corticata* (12.82µg/g) had more carotenoid than for *G. edulis*. These seaweeds have great potential as food supplements. Food industries could benefit from the nutritional quality of the seaweeds examined to enhance the nutritional value of food products.

RESULTS

This review systematically and independently extracted information from five relevant articles. The search strategy was employed to retrieve titles and/or abstracts of relevant studies, followed by the retrieval and independent assessment of the full texts of potentially eligible studies. Data extraction, quality assessment, and evidence synthesis were conducted using a standardized form for the included studies. Table 2 summarizes the findings from the literature reviewed on the vitamin content of seaweed for daily adult intake.

REVIEW OF LITERATURE

Investigating the Vitamin C Composition in Species of Seaweed: Nielsen et al., [19] "investigated the vitamin C content of various seaweed species and assessed whether seaweed can contribute as a vitamin C source compared to other foods". From the reviewed studies, the vitamin C content of seaweed is an average of 0.77 mg/g dry weight (DW). The mean value for each category of seaweed is 0.78, 0.815, and 0.72 mg/g DW for Chlorophyta, Phaeophyceae, and Rhodophyta respectively. The three classifications of seaweed showed no notable difference (ANOVA: F= 0.126, p = 0.882). The composition of vitamin C of the reviewed categories varied widely. The maximum value measured

in Rhodophyta was 5 mg/g DW. Some species had a higher vitamin C content of above 3 mg/g DW which is comparable with peas. This included *Ulva flexuosa*, *Hydropuntia edulis*, *Dictyota dichotoma*, *Mesogloia vermiculata*, and *Ceramium ciliatum*. About 400g of seaweed fresh weight (FW) is needed to meet the Reference Nutrient Intake (RNI) which is more than Rosehip (6g) and less than iceberg lettuce (800g). Seaweed has more vitamin C than iceberg lettuce. The study found that seaweeds cannot alone meet the daily requirement of vitamin C but can contribute to meeting the RNI. Studies found that the maximum amount of vitamin C measured in the species of green; *Enteromorpha spp., Ulva intestinalis,* and brown; *Fucus vesiculosus, Saccharina latissimi* assessed in the north of the equator was from April to May [20-23].

Examining the Vitamin Composition and benefits of Various Seaweed species: Ganesan et al., [24] "investigated the therapeutic role of seaweed-derived compounds as a nutraceutical or functional food ingredients for health maintenance and disease prevention". Several seaweeds such as *Himanthalia elongate, Gracilaria changii,* and *Porphyra umbilicalis* have a greater quantity of vitamin C than terrestrial vegetables. The seaweed specie *Eisenia arborea* has 34.4 mg/100 g DW vitamin C contents which is more than the content found in mandarin oranges [25]. Vitamin B_{12} is produced by prokaryotes which are linked to eukaryotic algal surfaces. This contributes to the higher quantity of B_{12} found in seaweed. The microalgae Spirulina and Chlorella contain a higher quantity of vitamin B_{12} (15.3 and 33.3 µg/kg FW) than macroalgae nori (1 µg/kg FW). Incorporating nori in a smoothie can provide the daily requirement of biologically active vitamin B_{12} [26]. This study demonstrated that seaweed is an excellent source of vitamin B_{12} for the vegetarian population. Seaweed is the only plant that contains vitamin B_{12}. Typically, plants cannot synthesize B_{12}, but it is abundant in seaweed. Rats deficient in vitamin B_{12} were fed nori, and there was a significant increase in hepatic B_{12} levels than when fed a non-seaweed diet [27]. *Gracilaria chilensis* and *Codium fragile* have a higher content of carotenoids than carrots. Seaweed's total carotenoid content is between 25 to 100 µg/g DW. P. pavonica had a high number of carotenoids while *K. striatum*, *E. denticulatum*, and *C. lentillifera* were 33 to 65 µg/g DW [28].

Cherry et al., [29] "examined the potential risks and health benefits of consuming whole seaweeds, extracted bioactive components, and seaweed-based food products in humans". The vitamin levels of dried seaweed varied widely. Five grams of *Ulva rigida* were found to contain 14.5 µg (two percent of RNI) of vitamin A [30] and 70.5 µg in *Fucus spiralis* (ten percent of RNI) [31]. The vitamin C content was 0.41 mg in *Ascophyllum nodosum* (one percent of RNI) and that of *Undaria pinnatifida* was 9.24 mg (twenty-three percent of RNI) [32]. Folate (vitamin B_9) levels differed, with *Ulva spp*. containing 7.5 µg (approx. four percent of RNI) [32] to 5400 µg (two thousand seven hundred percent of RNI) in *Ulva rigida* [30]. It was suggested that the wide variation in vitamin content within the same genus may be attributed to geographical and seasonal differences. Variations were also observed in the vitamin D_3 content of dried seaweed (5g). *Porphyra* spp. and *Fucus spiralis* containing 1.05 mg/100 g (635% of RNI) and 0.83 mg/100 g DW (415% of RNI) respectively [31,33]. In a 100 g dry weight of seaweed, *Enteromorpha spp*. and *Porphyra spp* contain 32.26 to 133.8 µg of vitamin B_{12}, respectively [34,35]. This is interpreted to 3.18 µg/5g DW (two hundred and twelve percent of RNI), and from 1.6-6.69 µg/5g DW (107-446% of RNI) of vitamin B_{12} in *Enteromorpha spp* and *Porphyra spp*., respectively. Groups at risk of vitamin B_{12} deficiency can benefit from consuming seaweed with active B_{12} [36]. For example, children who maintained a vegan diet for 4 to 10 years credited healthy vitamin B_{12} status to consumption of

nori (*Porphyra spp*.) [37]. It was observed that the drying of *Porphyra spp* inactivated vitamin B_{12}. Thus, methods of processing seaweed may influence the bioavailability of vitamins [38].

Peñalver et al., [39] "examined seaweeds as a functional ingredient for a healthy diet". The study found that algae provide a good amount of vitamin E (tocopherols), B (especially B_1 and B_{12}), and A (carotenoids) [40-41]. Seaweed is an excellent alternative for cobalamin for a vegetarian diet. Carotenoids are antioxidants present in seaweeds [42]. The greatest number of carotenoids in seaweed are tocopherols and xanthophyll. The study concluded that the nutritional composition of seaweed has the potential to enhance the quality of life and support a balanced diet when consumed occasionally.

Rosemary et al., [43] "evaluated and compared the chemical composition and physicochemical properties of both, *Gracilaria corticata* and *Gracilaria edulis* from the Thondi coast of Palk Bay, southeast India". These species contained both water- and fat-soluble vitamins. However, *G. corticata* had more amounts of vitamin A (2.36-2.98 mg/g vs. 1.97-2.31 mg/g) and vitamin B_9 contents (0.93-1.07 mg/g vs. 0.39-0.51 mg/g) than *G. edulis*. The carotenoid quantity was higher for *G. corticata* (12.32-13.32 µg/g) than for *G. edulis* (2.43-3.55 µg/g). *Gracilaria edulis* showed a significantly higher amount of vitamin B_6 (4.54-5 mg/g vs. 3.49-4.09 mg/g) and vitamin B_2 (1.15-1.93 mg/g vs. 0.04-0.06 mg/g) than *G. corticata*. The vitamin composition of the two seaweed species in dry weight was evaluated in triplicate. The physicochemical characteristics and proximate analysis revealed that both *Gracilaria corticata* and *Gracilaria edulis* exhibit significant vitamin content.

DISCUSSION

This review examined the vitamin content in seaweed, comparing its composition with the recommended dietary allowance. In vitro studies were conducted on various seaweed species, including Green, Red, and Brown Seaweed, collected from diverse locations such as the United States, Mexico, United Kingdom, Ireland, India, Egypt, etc. Many people use multivitamin supplements to fulfill their daily vitamin needs. However, seaweeds offer a rich source of both water- and fat-soluble vitamins. There is potential for incorporating seaweed into fish, dairy, vegetable, and meat-based products, enhancing their nutritional profile, and turning them into functional foods with positive effects on health [44]. A comparison of the impact of consuming a serving (55g) of various seaweed products on the daily intake of vitamins B_{12}, C, and A for females over 19 years is presented in Table 3. Vitamin B_{12}, an essential cofactor in enzymatic processes, is more likely to be deficient in women than men beyond the age of 19 [45]. Since humans cannot produce vitamins B_{12} and C, they must be obtained from dietary sources [46,10]. Vitamin C, known for its antioxidant properties, plays a crucial role in maintaining optimal health and preventing diseases [47]. Vitamin A deficiency, particularly impactful for women of reproductive age, is vital for growth [48]. Against this backdrop, this review compared a serving (55g) of different seaweed products with the Recommended Dietary Allowance (RDA) for females over the age of 19 years. The findings indicated that a serving of *Enteromorpha spp*. and *Porphyra spp*. significantly contributed to daily vitamin B_{12} intake which is noteworthy as no other plant source provides vitamin B_{12}. Seaweed stands out as the only plant that offers vitamin B_{12}. *Ascophyllum nodosum* and *Undaria pinnatifida* significantly contributed to vitamin C intake, and all seaweed products except *Gracilaria edulis*, whose vitamin A content was assessed, made significant contributions to carotenoid intake.

Table 3. A comparison of a serving (55g) of seaweed products on the daily intake of vitamins B_{12}, C, & A for females > 19 years.

Study	Seaweed Products / Vitamins (µg/55g)	B $_{12}$	C	A (Carotenoids)
Nielsen, et.al., 2021	Chlorophyta		42955 (57.27% RDA)	
	Phaeophyceae		44825 (59.77% RDA)	
	Rhodophyta		39600 (52.8% RDA)	
Ganesan, et. al., 2019	Eisenia *arborea*		18920 (25.23% RDA)	
	C. lentillifera, K. striatum and E. denticulatum			1815-3575 (259.3-510.71% RDA)
	Chlorella	1.8315 (fw) (76.31% RDA)		
	Spirulina	0.8415 (fw) (35.06% RDA)		
	C. lentillifera, K. striatum and E. denticulatum			1815–3675 (259.29-525% RDA)
Cherry, et. al., 2019	Ulva *rigida/* Fucus *spiralis*			159.5-775.5 (22.79-110.79% RDA)
	Ascophyllum *nodosum/* Undaria *pinnatifida*		4510-101640 (6.01-135.52% RDA)	
	Enteromorpha spp	34.98 (1457.5% RDA)		
	Porphyra spp	17.6-73.7 (733.33-3070.83% RDA)		
Rosemary, et. al. 2019	G. *corticata*			705.1 (100.73% RDA)
	Gracilaria *edulis*			164.45 (23.49% RDA)
	RDA (ug) (>19yrs)	2.4	75000	700

Table 3 shows the composition of vitamins B_{12}, C, & A of selected seaweed species (55g) in comparison with the RDA for females > 19 years.

According to Nielsen et al. [19], regular consumption of seaweeds contributes to the requirement of vitamin C, although seaweed itself is not an outstanding source of vitamin C. Approximately 400g FW of seaweed is needed to meet the Recommended Nutrient Intake for vitamin C. The study found that processing methods such as boiling, storage duration, and drying can influence vitamin C content as it is susceptible to oxidation. Ganesan et al. [24] demonstrated that seaweed products have various commercial applications due to their high levels of vitamins, minerals, and fiber. The study highlighted seaweed as an excellent source of vitamin B_{12}, and the amount of Vitamin carotenoids was notably higher than in carrots. Cherry et al. [29] emphasized that the preparation process of seaweeds influences the bioavailability of their rich vitamin content, contributing to improved vitamin status. Peñalver et al. [39] demonstrated different beneficial effects of seaweeds aimed at enhancing the standard of living and sustaining

an adequate diet when consumed occasionally. Rosemary et al. [43] suggested that the food industry could leverage the nutritional quality of seaweeds as potential functional food/supplements to enhance the nutritional value of food products. The study revealed higher vitamin C content for *G. edulis* than reported in previous studies [49,50], and a lower carotenoid level [51]. The observed variation in vitamin content was attributed to environmental factors such as temperature, seasons, salinity, and processing methods, storage [49]. The comprehensive analysis of articles included in this review consistently demonstrates seaweed as a nutrient treasure, rich in various vitamins.

CONCLUSION

This review highlights the groundbreaking discovery that seaweed stands out as the only plant capable of providing vitamin B_{12}. The findings suggest that a daily serving of seaweed products has the potential to significantly contribute to the vitamin status of a healthy adult female. Given its abundance of vitamins and bioactive compounds, the incorporation of seaweed into the diet can enhance overall quality of life. While the taste of seaweed may pose a challenge for industry professionals in tailoring food products, promoting public awareness regarding the nutritional richness of seaweed is crucial. Seaweeds, offering both fat- and water-soluble vitamins, have the potential to serve as a holistic and readily available source of ingredients, promoting high nutritional and therapeutic effects in daily use. Notably, seaweed emerges as a valuable alternative source of vitamin B_{12} for the vegetarian population, and its consumption can contribute significantly to meeting vitamin C recommendations. In comparison to the Recommended Dietary Allowance for women over 19 years, seaweeds emerge as a suitable dietary choice aligning with recommendations for vitamins B_{12}, C, and carotenoids.

Further research: This review stands among the limited number of studies that have compiled information on the vitamin composition of seaweed and its contribution to daily intake in adults. Additional human studies are necessary to substantiate the assertions suggesting seaweed as a potential alternative source of health supplements.

Abbreviations: FAO: food and agricultural organization, RDA: recommended dietary allowance, RNI: reference nutrient intake, DW: dry weight, WW: wet weight, ANOVA: analysis of variance, Spp.: specie

Conflicts of Interest: There are no conflicts of interest associated with this systematic review.

Author's Contributions: MH led all aspects of this review from initiation to conclusion. MH conducted research, authored the manuscript, and contributed to its editing. NA provided supervision as the faculty instructor during the research process.

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