Antioxidants from macroalgae: potential applications in human health and nutrition

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The underlying physiology of algal antioxidant compounds is reviewed in the context of seaweed biology and utilization. The application of seaweed antioxidants in foods, food supplements, nutraceuticals and medicine is considered from the perspective of benefits to human health. We advocate that direct consumption of seaweed products for their antioxidant composition alone provides a useful alternative to non-natural substances, while simultaneously providing worthwhile nutritional benefits. Economic utilization of seaweeds for their antioxidant properties remains in its infancy. This review provides examples ranging from laboratory studies through to clinical trials where antioxidants derived from seaweeds may provide major health benefits that warrant subsequent investigative studies and possible utilization.

Key Words: antioxidants; homeostasis; human health; oxidative stress; ROS

Abbreviations: CVD, cardiovascular disease; ROM, reactive oxygen metabolism; ROS, reactive oxygen species; RS, reactive species

INTRODUCTION

Responses of organisms to increased levels of antioxidants are diverse (Halliwell and Gutteridge 1984, Yan et al. 1998). In a human context, the potential negative impacts of such compounds are widely recognized, and both modern science and ‘folk remedy’ utilization has responded by providing functional products that involve food, medicines and cosmetics. Consumption of products high in antioxidant compounds is thought to alleviate cellular stresses brought about by the influence of reactive species (Schwartz 1996, Halliwell and Gutteridge 2007). While antioxidant benefits associated with consuming various terrestrial plants (e.g., green vegetables and berries) have long been accepted, relatively little emphasis has been placed on the merits of consuming marine macroalgae for the same benefits. Appendix A summarizes the most relevant literature available to date in relation to seaweed. It provides the reader with information on a number and variety of species investigated and the potential applications of the antioxidant components detected. While research shows that many macroalgae possess considerable antioxidant activity, the diversity of assays used for detection and assessment make interpretation of many results problematic (Schwarz et al. 2001, Ou et al. 2002, Decker et al. 2005, Kranl et al. 2005, Dudonné et al. 2009, Barahona et al. 2011). Significant antioxidant capacity may be expected based on the ecology
of seaweeds and metabolism (Table 1); however, there is considerable work remaining between merely establishing the occurrence of antioxidant activity and demonstrating that a beneficial response may be obtained by consumption or application of the putative compounds, particularly by humans. The numerous potential human health advantages associated with the utilization of marine macroalgae containing an assortment of antioxidant compounds depends upon both the respective intake of the plants, and the bioavailability of anticipated antioxidant activities (Manach et al. 2004). See Table 2 for a selection of perceived health benefits related to specific chemical components.

All energy-producing metabolic processes are intrinsically driven by an electron transport chain, maintenance of which is essential to the health and integrity of an organism. The hazards of a prolonged imbalance include formation of reactive species, unstable molecules or molecular fragments that, if not neutralized, can react with non-target molecules, causing a variety of (negative) cellular impacts (Dring 2005). These may include the initiation of increased cell proliferation, mitochondrial damage, excessive DNA strand breakage and deleterious chemical chain reactions leading to lipid peroxidation, enzyme inhibition and protein degradation (Halliwell and Gutteridge 1984, Yan et al. 1998, He and Häder 2002, Table 1.

<table>
<thead>
<tr>
<th>General category</th>
<th>Example compounds</th>
<th>Algal source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotenoids</td>
<td>β-carotene</td>
<td>Chondrus crispus, Mastocarpus stellatus</td>
<td>Lohrmann et al. 2004</td>
</tr>
<tr>
<td>Phenolic compounds</td>
<td>Styphodiol, isoepitaondiol, taondiol</td>
<td>Taonia atomaria</td>
<td>Nahas et al. 2007</td>
</tr>
<tr>
<td></td>
<td>Terpenoids</td>
<td>Cystoseira sp.</td>
<td>Foti et al. 1994</td>
</tr>
<tr>
<td>Polyphenols</td>
<td>Catechin, epicatechin, gallate</td>
<td>Halimeda sp.</td>
<td>Devi et al. 2008</td>
</tr>
<tr>
<td></td>
<td>Flavonoids</td>
<td>Palmaria palmata</td>
<td>Yuan et al. 2005a</td>
</tr>
<tr>
<td></td>
<td>Phlorotannins</td>
<td>Sargassum pallidum</td>
<td>Ye et al. 2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fucus vesiculosus</td>
<td>Díaz-Rubio et al. 2009</td>
</tr>
<tr>
<td>Sulphated polysaccharides</td>
<td>Fucoidan, algicin acid, laminaran</td>
<td>Turbinaria conoides</td>
<td>Chattopadhyay et al. 2010</td>
</tr>
<tr>
<td></td>
<td>Fucoidan</td>
<td>Laminaria japonica</td>
<td>Luo et al. 2009</td>
</tr>
<tr>
<td></td>
<td>Sulphated galactans (lambda carrageenan)</td>
<td>Some marine red algae</td>
<td>Rocha de Souza et al. 2007, Barahona et al. 2011</td>
</tr>
<tr>
<td></td>
<td>Galactans</td>
<td>Most red algae</td>
<td>Costa et al. 2010</td>
</tr>
<tr>
<td></td>
<td>Sulphated glycosaminoglycan</td>
<td>Sargassum wightii</td>
<td>Josephine et al. 2008</td>
</tr>
<tr>
<td></td>
<td>Porphyran</td>
<td>Porphyra sp.</td>
<td>Athukorala et al. 2006</td>
</tr>
<tr>
<td>Vitamins</td>
<td>Ascorbate</td>
<td>Chondrus crispus, Mastocarpus stellatus</td>
<td>Lohrmann et al. 2004</td>
</tr>
<tr>
<td></td>
<td>Vitamin A</td>
<td>Sargassum sp.</td>
<td>García-Casal et al. 2009, Kappaphycus alvarezii</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kumar et al. 2008</td>
</tr>
</tbody>
</table>

See Appendix A for species authorities.
In healthy biological systems, reactive oxygen species are continually produced (Alscher et al. 1997). Dring (2005) highlighted the role of reactive oxygen metabolism (ROM) in seaweeds, the stress factors that trigger it and details of the antioxidant response mechanisms. He emphasized the potential importance of ROM in seaweed ecophysiology and cautioned against making generalizations about the occurrence and function of antioxidants amongst various species. With this preface, this article reviews seaweed antioxidants in the context of human health.

The functional complexities associated with antioxidant defense mechanisms are diverse, and their relative importance against reactive species in vivo depends upon how, where and which reactive species (RS) is generated and what target of damage is measured. For example, polyphenols are well-known potent antioxidants, but their wide diversity and chemical complexity makes it challenging to correlate antioxidant potency in vitro with specific biological activity in vivo (Scalbert et al. 2005). In simplest terms, an antioxidant may be considered as an agent that delays, prevents, or removes oxidative damage from a target molecule (Halliwell and Gutteridge 2007). Biological systems strive for an intricate balance of electronically charged molecules necessary to maintain homeostasis, and selectivity in neutralizing specific RS is secondary to the activation of cellular defenses. If commercialization of seaweeds for their antioxidant activity is to be considered, additional research is required to establish bioavailability of specific compounds (Fran-

In a comprehensive literature review Yoshiki et al. (2009) identified a number of compounds in marine algae to which antioxidant activity has been attributed. These included polyphenols, phycocyanins, various enzymes, carotenoids, catechins, and ascorbic acid (Table 1).

**ANTIOXIDANTS IN HUMAN HEALTH**

ROS, along with reactive nitrogen species (collectively labelled RS) have been identified as agents in various pathogenic diseases and deleterious clinical conditions related to human health. These include cancer, cardiovascular disease, atherosclerosis, hypertension, ischemia / re-perfusion, diabetes mellitus, hyperoxaluria, neurodegenerative diseases such as Alzheimer’s and Parkinson’s diseases, rheumatoid arthritis and ageing (Cerutti 1985, Borek 1993, Hercberg et al. 1998, Cadenas and Davies 2000, Kang et al. 2003, Park et al. 2005, Valko et al. 2007, Veena et al. 2007, Halliwell 2009). RS have been implicated in over 150 human disorders, ranging from haemorrhagic shock, through cardio-myopathy, cystic fibrosis, AIDS and even male-pattern baldness (Halliwell and Gutteridge 2007). The defense response to excess RS metabolism can involve preventative mechanisms, repair mechanisms and up-regulation of endogenous antioxidant defenses (Demmig-Adams and Adams 2002, Valko et al. 2007).

Melanoma and non-melanoma skin cancers are among the most prevalent cancers in the human population. They are often caused by large, or prolonged doses of UV radiation that overwhelm the natural protective antioxidant capacity of the skin (Steenvoorden and van Hengouwen 1997, Sander et al. 2004). Using whole tissue extracts in a naked mouse study, polyphenols derived from certain brown algae (e.g., Ecklonia spp.; see Appendix A) and applied either topically or administered through the diet provided highly protective effects against UVB induced skin carcinogenesis (Hwang et al. 2006). Fuchs and Kern (1998) evaluated the dietary effects of non-seaweed derived commercial supplements of D-alpha-tocopherol...
and L-ascorbic acid on the sunburn reaction in humans, a potential elicitor for skin cancer. They determined that large doses of the two antioxidants acted synergistically to protect against sunburn damage. However, the effects of long-term administration of megadoses of these antioxidants requires more investigation.

In a study of female nurses and dietary intake of vitamins A, C, and E, folate and certain carotenoids, Fung et al. (2002) could not conclusively demonstrate that these antioxidants protected against basal cell carcinoma under their experimental conditions. More recently, Hercberg et al. (2007) suggested that regular dietary antioxidant supplementation may even be associated with harmful effects, especially in women. However, results of a two-year cohort study (Asgari et al. 2009) refuted this conclusion and that group observed no increased melanoma risk with supplementation of comparable doses of beta carotene and selenium. Although these trials relate to non-seaweed sources of antioxidants, marine macroalgae possess complements of such active compounds in various amounts and ratios (Yoshiki et al. 2009). Experiments showed human and monkey cancer cell lines were inhibited by extracts of various seaweeds, especially by the brown algae Hydroclathrus clathratus and Padina arborescens (Wang et al. 2008). The extracts, either in a crude state or after purification, demonstrated antioxidant activity and tumor suppression in a mouse model.

Cardiovascular disease (CVD) encompasses a broad range of primary and secondary conditions and its manifestation is a major cause of death – 30% worldwide (Haliwell and Gutteridge 2007). Risk factors for CVD include age, male gender, elevated low-density lipo-protein cholesterol levels, low high-density lipo-protein cholesterol levels, diabetes mellitus, smoking, chronic overeating and obesity. The adverse complications of obesity and unhealthy lifestyle factors are heightened by oxidative stress (Oben et al. 2007, Bocanegra et al. 2009, Riccioni 2009).

Extensive studies in patho-physiologic research clearly suggest that CVD represents a continuum of processes which include oxidative stress, endothelial dysfunction, inflammatory processes and vascular remodeling (Riccioni 2009). Foods rich in antioxidants have long been touted as aids in disease prevention. Shimazu et al. (2007) assessed the association between the traditional Japanese dietary patterns and CVD. They concluded that a diet high in antioxidant foods, including seaweeds, decreased the risk of CVD mortality. Kang et al. (2003) undertook an eight-week human clinical trial to assess the effect of orally administered polyphenolic compounds from brown algae on erectile dysfunction. Compounds from the five algae tested, Eisenia bicyclis, Ecklonia stolonifera, Ecklonia cava, Ecklonia kurome, and Hizikia fusiformis demonstrated positive effects against the risk factors associated with CVD. Deterioration of erectile function is a key in vivo indicator of cardiovascular health. Results from this trial showed significant improvement in erectile function and associated vascular health based on peripheral blood circulation.

Numerous studies into the synergistic effects of antioxidants and antioxidant enzymes and their interplay with RS suggest that the ideal protective mechanisms against clinical aspects of cellular damage should involve combinations, or whole suites of antioxidant compounds. Cellular homeostasis is thus more readily assured, and the possibility of profound imbalances brought about by high doses of single compounds can be effectively averted (Steenvoorden and van Henegouwen 1997).

Considerable research demonstrates the human health benefits of naturally occurring antioxidant compounds. Claims of anti-viral, anti-inflammatory, anticancer, anti-mutagenic, anti-tumour, and hepatoprotective properties have been substantiated, albeit mostly from in vitro trials (Yan et al. 1998, Yan et al. 1999, Yuan et al. 2005a, Hwang et al. 2006, Lim and Murti jaya 2007, Kumar et al. 2008, Yuan et al. 2009) (Table 2).

**FOOD VALUE AND HEALTH POTENTIAL OF MARINE ALGAE**

Intensive marketing programs and the popular health food press have raised the public profile of antioxidants considerably. However, clinical trials must be undertaken and publicized in order to educate and maintain consumer confidence. Aside from the direct health benefits, antioxidants from natural sources that combat lipid oxidation of foods, especially during processing and storage, are in high demand. The current use of synthetic antioxidants such as butylated hydroxyanisole, butylated hydroxytoluene, tert butylhydroxyquinone and propyl gallate is strictly regulated in many countries because they can in themselves pose potential health hazards, including carcinogenic effects (Matanjun et al. 2008, Wang et al. 2009).

Seaweeds are eaten as whole foods by a relatively small percentage of the world population (Yuan and Walsh 2006), in a relatively limited geography. Japanese form the largest consumer group eating on average, 1.6 kg dry weight per person, per year (Chandini et al.
Scientists in Asian countries have demonstrated the health benefits derived from eating seaweeds (Nishizawa 2002), and the official Japanese Food Guide (see Rhatigan 2009 for discussion) promotes seaweed as a nutritional foodstuff. Research is advancing into using marine macroalgae for production of novel foods, such as health beverages and processed meat products. The objective is to take advantage of their naturally occurring antioxidant compounds and other nutritive components (Nagai and Yukimoto 2003, López-López et al. 2009). This is a more holistic approach, based upon the observation that supplements of manufactured vitamins do not significantly decrease levels of oxidative damage in well-nourished individuals who already eat a balanced diet (Halliwell and Gutteridge 2007, Halliwell 2008). Hwang et al. (2006) demonstrated that extracted brown algal polyphenols from Ecklonia sp. decreased UVB-induced skin tumor development in mice regardless of whether the polyphenols were administered topically, or ingested as a dietary component, suggesting that the viability of these seaweed based antioxidants is unaffected by digestive processes. A growing awareness of the functionality of seaweeds beyond basic nutritive value will enhance the development of science and technology in this area of study (Holdt and Kraan in press).

**FINAL PERSPECTIVES**

The publication of Gerschman et al.’s (1954) free radical theory of metabolic oxygen toxicity instigated significant interest in ROS and the various mechanisms associated with redox homeostasis within biological systems. Since then, volumes have been written and commercialization of antioxidants has evolved to include functional foods, beverages, cosmeceuticals, nutraceuticals and health supplements. However, much work remains before we are able to establish and target site-specific reactions within biological systems, much less determine what, if any, synergistic effects may occur in the process (Le Tutour et al. 1998). Indeed, it could be challenging to aim for a targeted antioxidant response, considering the potential complexities of in vivo associations and interactions of the numerous compounds and metabolites that contribute to the biological efficacy of cells.

The potential for commercialization of seaweed based, antioxidant compounds as food supplements or nutraceuticals ensures continued dedicated efforts to eventually develop functional, condition-specific, antioxidant products. Seaweeds are indeed suitable natural agents for producing and delivering these products based on the multi-functional aspects of secondary seaweed metabolites and the presence of a wide variety of associated non-toxic antioxidants (Smit 2004, Bocanegra et al. 2009). Such relatively non-toxic associations can enhance the synergistic effects of multiple antioxidants and provide buffering capacity if necessary for those compounds which may have been intentionally increased. Algae are efficient harvesters and proficient managers of electromagnetic energy and as highly nutritional foodstuffs, can be regularly consumed without fear of metabolic toxicities. As part of a balanced diet, seaweeds can provide fibre, protein, minerals, vitamins and low fat carbohydrate content (Yuan and Walsh 2006). The versatility of algae as food allows consumption in fresh, dried, pickled or cooked forms and as a component in a wide assortment of other products. We advocate the regular consumption of a variety of marine algae, primarily for their anticipated in vivo antioxidant capacities and associated synergistic effects. Rather than striving for targeted cause and effect mechanisms, which are developed and isolated and are generally fraught with the complexities of endogenous cellular activities, a diet rich in a diversity of seaweeds would provide healthy, whole food sustenance and competent antioxidant balance. Ideally, algae destined for human use would be derived from managed, sustainable sources, thus ensuring traceability and a high level of food safety and security. Core research avenues should include investigations into the bioavailability of seaweed based antioxidants (Frankel and Finley 2008). Organisms do not normally function in isolation at any metabolic level, and oxidation-reduction reactions and subsequent cellular exposures to RS are fundamental to all living things. It is the imbalance of RS that can compromise homeostasis, and it is a legion of relevant seaweed antioxidants that may mitigate, and even help reduce the impacts of cellular impairment.

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## Appendix A

Algal species evaluated for antioxidant activity and potential applications of detected compounds. With each application category R indicates Rhodophyta, P indicates Phaeophyta and C indicates Chlorophyta.

<table>
<thead>
<tr>
<th>Application</th>
<th>(Phylum) species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antiangiogenic activity</strong></td>
<td>(P) <em>Undaria pinnatifida</em> (Harvey) Suringar</td>
<td>Sugawara et al. 2006</td>
</tr>
<tr>
<td><strong>Antiaging</strong></td>
<td>(R) <em>Porphyra haitanensis</em> Chang &amp; Zheng</td>
<td>Zhang et al. 2003</td>
</tr>
<tr>
<td><strong>Antibacterial</strong></td>
<td>(P) <em>Colpomenia peregrina</em> Sauvageau; <em>Cystoseira crinita</em> Duby; <em>Punctaria latifolia</em> Greville; <em>P. plantaginea</em> (Roth) Greville; <em>Stilophora tenella</em> (Esper) Silva; <em>Zanardinia prototypus</em> (Nardo) Nardo; (R) <em>Bangia fuscopurpurea</em> (Dillwyn) Lyngbye; <em>Callithamnion granulatum</em> Druceau; <em>Ceramium diaphanum</em> var. <em>elegans</em> (Roth) Roth; <em>Chondrophycus papillosus</em> (C. Agardh) Garbary &amp; Harper; <em>Corallina elongata</em> Ellis &amp; Solander; <em>Gelidium spinosum</em> (Gmelin) Silva; <em>Haliphtilon virgatum</em> (Zanardini) Garbary &amp; Johansen; <em>Laurencia coronopus</em> J. Agardh; <em>Polysiphonia denudata</em> (Dillwyn) Greville ex Harvey; <em>P. denudata f. fragilis</em> (Sperk) Voronikh</td>
<td>Kamenarska et al. 2009</td>
</tr>
<tr>
<td><strong>Anticancer</strong></td>
<td>(P) <em>U. pinnatifida</em>; <em>Fucus vesiculosus</em> Linnaeus</td>
<td>Aisa et al. 2005, You et al. 2010</td>
</tr>
<tr>
<td><strong>Anticoagulant</strong></td>
<td>(R) <em>Acrosorium flabellatum</em> Yamada; <em>Ahnfeltiopsis flabellicornis</em> (Harvey) Masuda; <em>Carpopeltis affinis</em> (Harvey) Okamura; <em>Chondria cassisculus</em> Harvey; <em>Chondrophycus undulatus</em> (Yamada) Garbary &amp; Harper; <em>Chondrus crispus</em> Stackhouse; <em>Gelidium amansii</em> (Lamouroux) Lamouroux; <em>Gloiopeltis furcata</em> (Postels &amp; Ruprecht) J. Agardh; <em>Gracilaria textorii</em> (Suringar) De Toni; <em>G. verrucosa</em>; <em>Grateloupia elliptica</em> Holmes; <em>G. lanceolata</em> (Okamura) Kawaguchi; <em>Halymenia dilatata</em> Zanardini; <em>Laurencia okamurae</em> Yamada; <em>Lithophyllum okamurae</em> Foslie; <em>Lomentaria catenata</em> Harvey; <em>Martensia denticulata</em> Harvey; <em>Prionitis cornea</em> (Okamura) Dawson; <em>Pterocladiella capillacea</em> (Gmelin) Santelices &amp; Homsersand; <em>Schizymenia dubyi</em> (Chauvin ex Duby) J. Agardh; <em>Scinaia okamurae</em> (Setchell) Huisman; <em>Sinkoraena lancifolia</em> (Harvey) Lee, Lewis, Kraft &amp; Lee</td>
<td>Lee et al. 2008</td>
</tr>
<tr>
<td><strong>Antidiabetic</strong></td>
<td>(P) <em>Ascophyllum nodosum</em> (Linnaeus) Le Jolis</td>
<td>Zhang et al. 2007a</td>
</tr>
<tr>
<td><strong>Anti inflammatory</strong></td>
<td>(P) <em>Ecklonia cava</em> Kjellman</td>
<td>Shin et al. 2006</td>
</tr>
<tr>
<td><strong>Anti inflammatory</strong></td>
<td>(R) <em>Gracilaria verrucosa</em> (Hudson) Papenfuss</td>
<td>Dang et al. 2008</td>
</tr>
<tr>
<td><strong>Antimicrobial</strong></td>
<td>(P) <em>Cystoseira mediterranea</em> Sauvageau; <em>Padina pavonica</em> (Linnaeus) Thivy; <em>Scytosiphon lomentaria</em> (Lyngbye) Link</td>
<td>Taskin et al. 2010</td>
</tr>
<tr>
<td><strong>Antiproliferative</strong></td>
<td>(R) <em>Hypnea musciformis</em> (Wulfen) Lamouroux; <em>Spyridia filamentosa</em> (Wulfen) Harvey</td>
<td>Yuan et al. 2005b, Athukorala et al. 2006, Yuan and Walsh 2006</td>
</tr>
<tr>
<td><strong>Antiretroviral (HIV-1)</strong></td>
<td>(P) <em>Adenocystis utricularis</em> (Bory) Skottsberg; <em>Fucus vesiculosus</em> Linnaeus</td>
<td>Béress et al. 1993, Trinchero et al. 2009</td>
</tr>
<tr>
<td><strong>Antitumoural</strong></td>
<td>(P) <em>Alaria esculenta</em> (Linnaeus) Greville; <em>Asperococcus bullosus</em> Lamouroux; <em>Bifurcaria bifurcata</em> Ross;</td>
<td>Ye et al. 2008, Zubia et al. 2009,</td>
</tr>
</tbody>
</table>
Cystoseira mediterranea Sauvageau; C. tamariscifolia (Hudson) Papenfuss; Desmarestia ligulata (Stackhouse) Lamouroux; Dictyota dichotoma (Hudson) Lamouroux; Fucus ceranoides Linnaeus; F. serratus Linnaeus; Halidrys siliquosa (Linnaeus) Lyngbye; Padina pavonica (Linnaeus) Thivy; Saccorhiza polyschides (Lightfoot) Batters; Sargassum pallidum (Turner) C. Agardh; Scytosiphon lomentaria (Lyngbye) Link
(R) Hypnea musciformis (Wulßen) Lamouroux; Spyridia filamentosa (Wulßen) Harvey

Antiviral
(P) Colpomenia peregrina Sauvageau; Cystoseira crinita Duby; Punctaria latifolia Greville; P. plantaginea (Roth) Greville; Scytosiphon lomentaria (Lyngbye) Link; Stilophora tenella (Esper) Silva; Zanardinia prototopus (Nardo) Nardo
(R) Bangia fuscorupurea (Dillwyn) Lyngbye; Callithamnion granulata Ducluzeau; Ceramium diaphanum var. elegans (Roth) Roth; Chondrophycus papillosus (C. Agardh) Garbary & Harper; Corallina elongata Ellis & Solander; Gelidium spinosum (Gmelin) Silva; Haliptilon virgatum (Zanardini) Garbary & Johansen; Laurencia coronopus J. Agardh; Polysiphonia denudata (Dillwyn) Greville ex Harvey; P. denudata f. fragilis (Sperk) Voronikh

Chemopreventive
(P) Fucus vesiculosus Linnaeus

Cytotoxic activity
(P) Colpomenia peregrina Sauvageau; Cystoseira crinita Duby; Punctaria latifolia Greville; P. plantaginea (Roth) Greville; Scytosiphon lomentaria (Lyngbye) Link; Stilophora tenella (Esper) Silva; Zanardinia prototopus (Nardo) Nardo
(R) Bangia fuscorupurea (Dillwyn) Lyngbye; Callithamnion granulata Ducluzeau; Ceramium diaphanum var. elegans (Roth) Roth; Chondrophycus papillosus (C. Agardh) Garbary & Harper; Corallina elongata Ellis & Solander; Gelidium spinosum (Gmelin) Silva; Haliptilon virgatum (Zanardini) Garbary & Johansen; Laurencia coronopus J. Agardh; Polysiphonia denudata (Dillwyn) Greville ex Harvey; P. denudata f. fragilis (Sperk) Voronikh

Dietary antioxidants
(P) Chorda filum (Linnaeus) Stackhouse; Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier; Desmarestia viridis (Müller) Lamouroux; Dictyopteris diversicata (Okamura) Okamura; Dictyota cervicornis Kützing; D. dichotoma (Hudson) Lamouroux; D. ciliolate Sonder ex Kützing; D. crenulata J. Agardh; Ecklonia cava; E. vesiculosus; Laminaria japonica Areschoug; L. ochroleuca Linnaeus; Leathesia diffirns Areschoug; Lobophora variegata (Lamouroux) Womersley ex Oliveira; Myelophyllum simplex (Harvey) Papenfuss; Padina gymnospora (Kützing) Sonder; Padina spp.; Petalonia binghaniae (J. Agardh) Vinogradova; Punctaria plantaginea (Roth) Greville; Sargassum kjellmanianum Yendo; S. polycystum C. Agardh; S. pteropleuron Grunow; S. ramifilium Kützing; S. thunbergii (Mertens ex Roth) Kuntz; Sargassum sp.; Scytosiphon lomentaria (Lyngbye) Link; Turbinaria tricostata Barton; Undaria pinnatifida
(R) Acanthophora spicifera (Vahl) Bergesen; Bryothamnion triquetrum (Gmelin) Howe; Ceramium boydenii Gepp; C. nitens (C. Agardh) J. Agardh; C. kondoii Yendo; Champa salicornioides Harvey; Chondria atrupurpurea Harvey; C. baileyana (Montagne) Harvey; Chondrophycus papillosus (C. Agardh) Garbary & Harper; C. poiteaui (Lamouroux) Nam; Chondrus crispus Stackhouse; Corallina pilulifera Postels & Ruprecht; Digenea simplex (Wulffen) C. Agardh; Eucheuma cottonii Weber-van Bosse; E. isiforme (C. Agardh) J. Agardh; Gelidium amansii (Lamouroux) Lamouroux; Gloiosiphon capillaries (Farlow) J. Agardh; Gracilaria bursa-pastoris (Gmelin) Silva; G. caudata J. Agardh; G. cornea J. Agardh; G. cylindrica Bergesen; G. tenuisitipitata var. tenuisitipitata Chang & Xia; G. tenuissimae McLachlan; Gracilaria euracosa; Gracilariapis tenuifrons (Bird & Oliveira) Fredericq & Hommersand; Halymenia durvillaei Bory; H. floresii (Clemente & Rubio) C. Agardh; Heterosiphonia gibbesii (Harvey) Falkenberg; Hyalosiphonia caespitosa Okamura; Hypnea spinella (C. Agardh) Kützing; Laurencia intricata Lamouroux; L. obtusa (Hudson) Lamouroux; Laurencia surculigera Tseng; Liagora ceranoides Lamouroux; Nemalion helminthoides (Velley) Batters; Polysiphonia urceolata (Lightfoot ex Dillwyn) Greville; Porphyra umbilicalis (Linnaeus) J. Agardh; Rhodomela confervoides; R. teres (Perestenko) Masuda

Taskin et al. 2010
Kamenarska et al. 2009
Parys et al. 2010
Yan et al. 1998,
Jiménez-Escrig et al. 2001,
Rupérez et al. 2002,
Kuda et al. 2006,
Zubia et al. 2007,
Matanjun et al. 2008,
Yangthong et al. 2009
(C) Acetabularia schenckii Möbius; Arrainvillea longicaulis (Kützing) Murray & Boodle; Caulerpa asmeadii Harvey; C. cupressoides (West in Vahl) C. Agardh; Caulerpa lentillifera J. Agardh; C. pas-paloides (Bory) Greville; C. prolifera (Forsskål) Lamouroux; C. racemosa (Forsskål) J. Agardh; Caulerpa racemosa var. macrophysea (Sonder ex Kützing) Murray; C. sertularioides (Gmelin) Howe; C. taxifolia (West in Vahl) C. Agardh; Cladophora prolifera (Roth) Kützing; C. vagabunda (Linnaeus) Hoek; Codium decorticatum (Woodward) Howe; Halimeda monile (Ellis & Solander) Lamouroux; H. tuna (Ellis & Solander) Lamouroux; Penicillus dumetosus (Lamouroux) Blainville; P pyrififormis Gepp & Gepp; Udotea conglutinate (Ellis & Solander) Lamouroux; Ulva intestinalis Linnaeus [as Enteromorpha intestinalis (Linnaeus) Nees]; U. lactuca Linnaeus; U. pertusa Kjellman; U. prolifera O. F. Müller [as Enteromorpha prolifera (O. F. Müller) J. Agardh].

Food preservatives
(P) F. vesiculosus; Padina antillarum (Kützing) Piccone; P. gymnospora; Turbinaria conoides (J. Agardh) Kützing
(R) Eucheuma cottonii Weber-van Bosse; Euchema spinosum J. Agardh; Gigartina acicularis (Roth) Lamouroux; Gigartina pistillata (Gmelin) Stockhouse; Kappaphycus alvarezii (Doty) Doty ex Silva; Spatoglossum Schroederi (Gmelin) Stackhouse; Corallina elongata; H. tuna

Functional foods
(P) Desmarestia viridis (Müller) Lamouroux; Dictyopteris divaricata (Okamura) Okamura; D. membranacea (Stockhouse) Batters; Dictyota cervicornis (Kützing); D. delicatula (Lamouroux); D. men-stralis; D. mertensii (Martius) Kützing); Ecklonia cava; Ectocarpus siliculosus (Dillwyn) Lyngbye; F. vesiculosus; Halopteris scoparia (Linnaeus) Sauvageau; Himanthalia elongata (Linnaeus) Gray; Hizikia fusiformis (Harvey) Okamura; Ishige okamarae Yendo; Laminaria japonica Areschoug; Padina antillarum (Kützing) Piccone; P. tetrasymatrica Hauck; Sargassum coreanum J. Agardh; S. fli-pendula C. Agardh; S. fulvelum (Turner) C. Agardh; S. horneri (Turner) C. Agardh; S. marginatum (C. Agardh) J. Agardh; S. thunbergii (Mertens ex Roth) Kuntz; S. vulgare C. Agardh; Sargassum sp.; Scyto-siphon lomentaria (Lyngbye) Link; Spataglossum Schroederi (C. Agardh) Kützing; T. atomaria (Woodward) J. Agardh; Turbinaria conoides; Undaria pinnatifida
(R) Ahnfeltiopsis flabelliformis (Harvey) Masuda; Amphiroa cryptarthrodia var. verruculosa (Kützing) Hauck; Amphiroa sp.; Ceramium kondai Yendo; Chondria crassicaulis Harvey; C. tenuissima (With-ering) C. Agardh; Corallina elongata Ellis & Solander; Gelidium amansii (Lamouroux) Lamouroux; Gloiopeltis tenax (Turner) Decaisne; Gracilaria caudata J. Agardh; Grateloupiella elliptica Holmes; Kappaphycus alvarezii; Laurencia obtusa; Laurencia papillosa (C. Agardh) Greville; Liagora sp.; Peyssonnelia harveyana Crouan & Crouan ex J. Agardh; Porphyra sp.; Rhodothamniella floridula
(C) Caulerpa cupressoides (West) C. Agardh; C. prolifera (Forsskål) Lamouroux; C. racemosa (Forsskål) J. Agardh; C. sertularioides (Gmelin) Howe; Cladophora vagabunda (Linnaeus) Hoek; Codium fragile (Suringar) Hariot; C. isthmocladum Vickers; Ulva pertusa Kjellman; U. fasciata Delile; U. sp.

Health related functions
(P) Padina australis Hauck; Sargassum polycystum C. Agardh; Turbinaria conoides
(C) Caulerpa sertularioides (Gmelin) Howe; Halimeda macroloba Decaisne; Ulva reticulata Forsskål

Hepatoprotective properties
(P) Myagropsis myagroides (Mertens ex Turner) Fensholt; Sargassum henslowianum
(R) Callophyllis japonica Okamura C. Agardh; S. siliquastrum (Turner) C. Agardh

Hyperoxaluria inhibition
(P) F. vesiculosus

Hypertension and vascular health
(R) Ahnfeltiopsis flabelliformis (Harvey) Masuda; Bonnemaisonia hamifera Hariot; Carpospeltis affinis (Harvey) Okamura; Chondria crassicaulis Harvey; Chondrophycus undulatus (Yamada) Garbary & Harper; Chondrus crispus Stackhouse; Gelidium amansii; Gloiopeltis furcata (Postels & Buprecht) J. Agardh; Gracilaria textorii (Suringar) De Toni; G. verrucosa; Grateloupiella elliptica Holmes; G. filicina (Lamouroux) C. Agardh; G. lanceolata (Okamura) Kawaguchi; Halymena dilatata Zanardini;
Laurencia okamurae Yamada; Lithophyllum okamurai Foslie; Lomentaria catenata Harvey; Martensia denticulata Harvey; Phaeococcus sp.; Polysiphonia japonica Harvey; Porphyra tenera Kjellman; Prioniitis cornea (Okamura) Dawson; Pterocladia capillacea (Gmelin) Santelices & Hemsunders; Schizymenia dubyi (Chauvin ex Duby) J. Agardh; Scinaia okamurae (Setchell) Huismans; Sinkoraena lancifolia (Harvey) Lee, Lewis, Kraft & Lee

Inhibition of $H_2O_2$ mediated DNA damage
(P) Ecklonia cava

Medical effects
(P) Dicrateria cervicornis Kützing; D. ciliolate Sonder ex Kützing; D. crenulata J. Agardh; Lobophora variegata (Lamouroux) Womersley ex Oliveira; Padina gymnospora (Kützing); Sargassum pteropleurum Grunew; S. ramifolium Kützing; Turbinaria tricostata
(R) Acanthophora spicifera (Vahl) Bergesen; Bryothamnion triquetrum (Gmelin) Howe; Ceramium nitens (C. Agardh) J. Agardh; Chamaia salicornioides (Harvey) Lamouroux; Chondria crassicaulis (Harvey) J. Agardh; Gracilaria bursa-pastoris (Lamouroux) Nam; Digenea simplex (Wulfen) C. Agardh; Eucheuma isiforme (C. Agardh) J. Agardh; Gracilaria bursa-pastoris (Gmelin) Silva; G. caudata J. Agardh; G. cylindrica Bergesen; G. tikvahiae Mclachlan; Gracilariaopsis tenuifrons (Bird & Oliveira) Fredericq & Hammersand; Halymenia floresii (Clemente & Rubio) C. Agardh; Heterosiphonia gibbesii (Harvey) Falkenberg; Hymena spinella (C. Agardh) Kützing; Laurencia intricata Lamouroux; L. obtusa (Hudson) Lamouroux; Liagora ceranoides Lamouroux; Nemalion helminthoides (Velley) Batters
(Ac) Acetabularia senckeni Möbius; Attrainvillea longicaulis (Kützing) Murray & Boodle; Caulerpa ashmeadii Harvey; C. cupressoides (West in Vahl) C. Agardh; C. pascaloiades (Bory) Greville; C. prolifera (Forsskål) Lamouroux; C. sertulariioides (Gmelin) Howe; C. taxifolia (West in Vahl) C. Agardh; Cladophora prolifera (Roth) Kützing; C. vagabunda (Linnaeus) Hoek; Codium decorticatum (Woodward) Howe; Enteromorpha intestinalis (Linnaeus) Nees; Halimeda monile (Ellis & Solander) Lamouroux; H. tuna (Ellis & Solander) Lamouroux; Penicillus dunetosus (Lamouroux) Blainville; P. pyriformis Gepp & Gepp; Udotea conglutinate (Ellis & Solander) Lamouroux; Ulva intestinalis Linnaeus [as Enteromorpha intestinalis (Linnaeus) Nees]

Nutraceuticals
(R) Kappaphycus alvarezi; Fucus vesiculosus Linnaeus

Peroxytrinitre inhibition (pharmacological)
(P) Colpomenia bulbosa (De A. Saunders) Yamada; C. sinuosa (Mertens ex Roth) Derbès & Solier; Derbesia marina (Lyngbye) Solier; Dictyota dichotoma (Hudson) Lamouroux; Hizikia fusiformis (Harvey) Okamura; Ichige okamurai Yendo; Myelophyllum simplex (Harvey) Papenfuss; Sargassum confusum C. Agardh; S. hemiphyllum (Turner) C. Agardh; S. horneri (Turner) C. Agardh; S. thunbergii (Mertens ex Roth) Kuntz; Sargassum sp.; Scytosiphon lomentaria (Lyngbye) Link
(R) Carposetis affinis (Harvey) Okamura; C. cornea (Okamura) Okamura; Chondria crassicaulis Harvey; Chondrus ocellatus Holmes; Corallina pilulifera Postels & Ruprecht; Corallina spp.; Gelidi um amansii (Lamouroux) Lamouroux; Gigartina intermedia Suringar; Gigartina tenella Harvey; Gloioptilis furcata (Postels & Ruprecht) J. Agardh; Grateloupia turuturu Yamada; Gymnogongrus flabeliformis (Harvey) Masuda; Halymenia acuminata (Howes) J. Agardh; Lomentaria catenata Harvey; L. hakodatensis Yendo; Pachymeniopsis lanceolata (Okamura) Yamada ex Kawahata; Plocamium telfairiae (Hooker & Harvey) Harvey ex Kützing; Porphyra suborbiculata Kjellman; Symphyocladia latisscula (Harvey) Yamada
(C) Codium adhaerens C. Agardh; Enteromorpha linza (Linnaeus) J. Agardh; Ulva pertusa Kjellman

Pharmaceuticals
(P) Dictyopteris membranacea (Stackhouse) Batters; Dictyota cervicornis Kützing; D. delicatula Lamouroux;
<table>
<thead>
<tr>
<th>Species</th>
<th>Reference</th>
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<tbody>
<tr>
<td>D. menstrualis (Hoyt) Schnetter; D. mertensii (Martius) Kützing</td>
<td>Zhao et al. 2008,</td>
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<tr>
<td>Ecklonia cava; Halopetris scoparia (Linnaeus) Sauvageau; Ishige</td>
<td>Costa et al. 2010</td>
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<td>okamurae Yendo; Laminaria japonica Areschoug; Padina tetrastromat-hauck</td>
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<td>Sargassum coreanum J. Agardh; S. filipendula (C. Agardh); Sargassum</td>
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<td>fullveum (Turner) C. Agardh; S. horneri (Turner) C. Agardh; S. marginatum</td>
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<td>(C. Agardh) J. Agardh; S. thunbergii (Mertens ex Roth) Kuntz; S.</td>
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<td>vulgare C. Agardh; Spatoglossom schroederi (C. Agardh) Kützing; Taonia</td>
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<td>atomaria (Woodward) J. Agardh; Scytophion lomentaria (Lyngbye) Link;</td>
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<td>Turbinaria conoides (R) Amphiroa cryptarthroidia var. verruculosa</td>
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<td>Kötzing) Hauck; Amphiroa sp.; Corallina elongata Ellis &amp; Solander;</td>
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<td>Greville; Liagora sp.; Peyssonnelia harveyana Crouan &amp; Crouan ex J.</td>
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<td>Agardh; Rhodothamniella floridula</td>
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<td>(C) Caulerpa cupressoides (West) C. Agardh; C. prolifera (Forsskål);</td>
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<td>C. sertularioides (Gmelin) Howe; Codium isthmocladum Vickers</td>
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<tr>
<td>Promotes cellular homeostasis</td>
<td>Kang et al. 2005</td>
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<td>(R) Callophyllis japonica Okamura</td>
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<tr>
<td>Vascular chemoprotection; Improved peripheral blood circulation</td>
<td>Kang et al. 2003</td>
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<td>(P) Eisenia bicyclis (Kjellman) Setchell; Ecklonia cava; E. kurome</td>
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<td>Okamura; E. stolonifera Okamura; Hizikia fusiformis (Harvey) Okamura</td>
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