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REVIEW

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Nutrients and bioactive potentials of edible green and red seaweed in Korea

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Abstract

Background: Traditionally, East-Asians (Korea, Japan, and China) utilize seaweeds as a food source and ingredient in traditional medicine. Korea is one of the biggest seaweed producer and consumer in the global trade. Especially, side dishes made from seaweeds are very popular in the traditional Korean cuisines. Seaweeds are popular as fresh vegetable salads and soup or eaten as snacks.

Main body: Seaweeds are rich in essential nutrients, minerals, and vitamins as well as a promising source of novel bioactive compounds. The compounds (polysaccharides, polyphenols, and sterols) present in the edible Korean seaweeds possess important bioactive properties such as antioxidant, anti-inflammation, anticancer, anti-diabetic, and anticoagulant properties. Thus, the long-term consumption of seaweed has a potential to reduce the risk of cancer, diabetes, obesity, and inflammation-related complications. However, seaweed consumption is limited to the small population around the globe. Thus, it is important to increase the awareness of the health benefits of seaweeds consumption among the general population.

Short conclusion: In the present study, we discussed some popular green and red edible Korean seaweeds and their health-promoting properties. This study might be useful to increase the public awareness of the consumption of seaweed as a food source.

Keywords: Edible seaweed, Bioactive, Functional foods

Background

Seaweeds have been used as human food since ancient times. The use of seaweeds as a food traced back to the fourth century in Japan and sixth century in China. Especially, those people who lived near the coastal area preferred to consume seaweeds as a main or side dish, or as a soup (Kılınc et al. 2013). Usually, Europeans consume less amount of seaweeds compared to the Asians due to the regulations and the food habits of Europeans. However, during the last few decades, consumption of seaweed in European countries gradually increased with the identification of invaluable health effects associated with seaweeds (Mabeau and Fleurence 1993). In addition to the nutritious value, seaweeds are a rich source of structurally diverse bioactive components such as phlorotannins, sulfated polysaccharides, and pigments. Each and every year, thousands of scientific reports are published about the bioactive properties and the potential health benefits associated with the edible seaweeds. As a result of this public awareness, demand for seaweeds and their commercial products slightly increased in the global trade (Sanjeewa et al. 2017).

Korea is one of the important edible seaweed producers in the global market. Harvesting from the wild and cultivation (mariculture, land-based culture, and farming) are the major seaweed production methods. According to the FAO databases, in 2014, Korea alone commercially cultivated around 397,841 tons of *Porphyra spp.*, 283,707 tons of sea mustard, 6055 tons of green laver, and 16,563 tons of other brown seaweed species (FAO 2014). Korean people usually consume seaweeds in fresh forms or dry them under the sun to make different food items and to keep a long time. In the traditional Korean cuisines, seaweeds are popular as soup (mi-yeok-guk and mom-guk), snacks (kimbugak), vegetable, pickle, and salad or used to prepare gim-bap. Gim-bap is a mixture of gim (dried seaweed) and steamed white rice, which contains a mixture of vegetables and meat types. Gim-bap is a popular food item in Korea as a side dish and simple lunch. Most of the Korean people usually consume dried and fresh gim as their side dish (Kim et al.

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2015a, b, Fleurence and Levine 2016). However, the popularity of seaweeds as processed food items or as functional materials is low in Europe and South Asia. Therefore, in the present section, special attention is given to collect the literature about edible green and red seaweeds present in Korea. In addition, the bioactive properties reported from edible Korean green and red seaweeds are also discussed in the present review.

Main text

Green seaweeds

Capsosiphon fulvescens (mae-saeng-i)

Capsosiphon fulvescens is an edible green seaweed in Korea. *C. fulvescens* is abundant in the southern coast of Korea as well as throughout the world. Traditionally, *C. fulvescens* is used as an ingredient in functional foods for centuries in Korea (Sharma and Rhyu 2014). Specifically, these seaweeds are used to treat stomach disorders and hangovers (Go et al. 2011). In general, mae-saeng-i contains around 55% polysaccharides, 30% proteins, 13% ash, and 1% lipids from its dry weight. In addition, mae-saeng-i is a good source of essential macro and micro minerals such as Fe, Se, Ca, Mg, Na, K, and P. Specifically, mae-saeng-i contains large amounts of Fe and Se compared to the other edible green seaweeds. In addition, polysaccharides presented in *C. fulvescens* build up with fructose, galactose, glucose, maltose, and sucrose (Park 2005, Yang et al. 2005). *C. fulvescens* is a popular side dish in Korean cuisines due to the unique flavor and soft texture as well as its health-enhancing properties, such as anticoagulant, anticancer, anti-inflammatory, and immuno-modulatory properties (Hwang et al. 2008; Kim et al., 2013b, c). Boiling *C. fulvescens* with oysters to prepare soup and/or steaming *C. fulvescens* with rice to prepare gul-guk-bap are two popular food items prepared from mae-saeng-i. In addition to the fresh seaweed, powdered *C. fulvescens* is also popular in Korean local markets due to the diverse food applications of mae-saeng-i powder such as soup and juice porridge.

Caulerpa lentillifera (ba-da-po-do)

Caulerpa lentillifera is a green seaweed which is naturally distributed in the tropical regions. *C. lentillifera* is commercially cultivated in East-Asian countries to be utilized as food for farm animals and humans (Kim KO 2015). In addition to the food applications, *C. lentillifera* is used to treat wastewater accumulate in shrimp farms (Apiratikul et al. 2011). *C. lentillifera* is usually consumed as a fresh salad or as a salt-preserved form in Korea, Japan, and the Philippines. According to the previous studies, the dried biomass of *C. lentillifera* contains around 10% protein, 16.76% polyunsaturated fatty acids, 1% lipids, 38.6% carbohydrates, and 37% ash from its dry weight. Moreover, *C. lentillifera* is rich in essential minerals (Na, K, Ca, and Mg), omega-3 fatty acids, dietary fibers, and vitamins (A and C) (Matanjun et al. 2009, Sharma and Rhyu 2014). Traditionally, *C. lentillifera* extracts are used to treat high blood pressure, rheumatism, and diabetes, as well as to treat bacterial and fungal infections (Sharma et al. 2015). Recently, a number of studies demonstrated that *C. lentillifera* extracts have a potential to develop as a drug or functional material to treat cancers and diabetes mellitus (Nguyen et al. 2011; Sharma and Rhyu 2014).

Enteromorpha linza (ip-parae)

Enteromorpha linza is a broad paddle-shaped green seaweed commonly seen in the coasts of Korea and Japan as well as in European and Mediterranean coastal areas. *E. linza* prefers to grow on rocky surfaces and rapidly colonizes on the bare surfaces, and it also can grow on compacted mud banks or even sandy shores (Cho et al., 2011b, b; Patra and Baek 2016). *E. linza* has long been used as a food source in traditional Korean cuisines, which is used to prepare soup and seasoned cooked vegetables or consume after mixing with vegetables and spices. Recently, Patra and Baek (2016) reported the essential oil presented in *E. linza* has a potential to inhabit the foodborne pathogens (*Bacillus cereus* and *Staphylococcus aureus*). In addition to antimicrobial properties, polysaccharides separated from *E. linza* are found to possess interesting bioactive properties such as blood lipid reduction and anti-inflammatory, antioxidant, and anticancer properties (Zhang et al. 2011).

Enteromorpha prolifera (gasi-parae)

E. prolifera is an abundant fouling green seaweed in Asian countries such as Korea, China, and Japan, which prefers to grow from the intertidal to the upper subtidal zones (Cho et al., 2011b, b). Traditionally, Korean people use gasi-parae to prepare salads or preserve as a soup after boiling in hot water. In addition, *E. prolifera* is used as an ingredient in meals and cookies or as essences (Aguilera-Morales and Casas-Valdez, 2005). The southern coast of Korea is a popular region for commercial cultivation of the *Enteromorpha* species (Huh et al. 2004). *E. prolifera* is a rich source of essential nutrients; the dried gasi-parae contains around 9~14% protein and 32~36% ash. In addition, it contains n-3 and n-6 fatty acids, 10.4 and 10.9 g/100 g of total fatty acids, respectively (Aguilera-Morales and Casas-Valdez, 2005). The studies carried out with extracts and compounds collected from *E. prolifera* which was found to possess a range of bioactive properties such as antioxidant, blood lipid reduction, anticancer, immune modulatory, and anti-inflammatory properties (Shi et al. 2017).

Ulva pertusa (goo-meong-gal-parae)

Ulva pertusa is a common edible seaweed distributed in the coastal waters (mid-littoral to shallow sublittoral zone) of Korea, China, and Japan (Song et al. 2010). In general, the production rate of *U. pertusa* was reported as 7 kg/m^2 (wet weight) (Kwon et al. 2017). In addition to the high growth rate and bioavailability, *U. pertusa* is rich in vitamins, trace elements, and dietary fibers and is also considered as a low-calorie food. Moreover, *U. pertusa* has been used as an ingredient in the traditional medicine for urinary diseases, sunstroke, and hyperlipidemia (Qi et al. 2006), in addition to the food value, which is useful to reduce eutrophication in mariculture waters and increase the survival rate productivity and feeding efficiency of the cultured shellfish species, such as shrimps and prawns (Jin and Dong 2003).

Codium fragile (cheong-gak)

Codium fragile is an edible green seaweed of family Codiaceae. *C. fragile* is abundant on the coasts of Korea, China, Japan, and some coastal areas of Northern Europe. Traditionally, Korean people use *C. fragile* as a food ingredient which has been used in traditional medicine to treat dysuria, dropsy, and enterobiasis. Other than the food and traditional medicinal applications, secondary metabolites present in *C. fragile* are found to possess interesting bioactive properties such as antioxidant, anticancer, anti-angiogenic, and anti-inflammatory properties (Lee et al. 2017).

Red seaweeds

The main application of red seaweed is as a source of hydrocolloids. Agar and carrageenans are two well-known hydrocolloids separated from red seaweed which are used in diverse medicinal and food applications. Thus, the demand for hydrocolloid-based industries has been expanding rapidly during the past few decades (Meinita et al. 2017). In addition to the commercial applications, traditionally, Korean people consume some red seaweed species in fresh forms and after processing them into different types of foods such as soup, cookies, or snacks.

Porphyra spp. (gim)

Laver is one of the popular edible red seaweed among the people living in countries like Korea, China, and Japan (Lee et al., 2016a, b). Modern commercial cultivation of laver species arose during the 1960s with the identification of the Conchocelis phase of *Porphyra*, which allowed artificial seeding and maximizing production in the artificial environmental conditions (Shaw and Liu 2000). Gim is rich in proteins, vitamins (A, B, and C), and minerals (iron, zinc, copper, manganese, and selenium) as well as contains a low amount of simple sugars compared to the other edible seaweeds (Shaw and Liu 2000, Fleurence and Levine 2016). *Porphyra tenera* and *P. yezoensis* are commonly used to produce commercial food products such as dried seasoned laver and roasted laver for sushi (Park et al. 2014). The dried and roasted laver are popular food products in the Korean food market as well as in the international market due to the high nutritional value, texture, compactness, and pleasant taste of processed *Porphyra spp.* (Park et al. 2014; Cho et al. 2015). Usually, mlavers are consumed as dried seaweed. Kim-bu-gak (snack) and gim-bap are popular food products in the Korean food market produced from laver (Oh and Choi 2015).

Gelidium amansii (wu-mu-ga-sa-ri)

Gelidium amansii is a popular edible red seaweed, which is commonly used as a food ingredient in Korea, Taiwan, China, and Japan. Specifically, agar jelly made from hot-water extracts of *G. amansii* is a popular food item in Taiwan and Japan (Yang et al. 2017). This red seaweed is a rich source of carbohydrates, especially galactose (23%) and glucose (20%) (Wi et al. 2009). *G. amansii* is considered as a cheap source of agar. Thus, this red seaweed is commonly cultivated for agar production (Kang et al. 2013). Previous studies carried out with *G. amansii* demonstrated the supplementation with *G. amansii* in high-cholesterol and high-fat diets has a potential to reduce liver and plasma lipid levels in diabetic rats (Yang et al. 2017).

Gracilaria verrucosa (go-si-rae-gi)

Gracilaria verrucosa is a popular edible red seaweed in Korea. *G. verrucosa* is commercially cultivated in Asian countries to obtain food-grade agar for different industrial applications. In addition to the agar production, *G. verrucosa* is a popular raw material in the bio-ethanol industry due to its high level of ethanol extraction efficiency. Galactose and glucose are the principal monosaccharide types obtained from *G. verrucosa* for bio-ethanol production (Meinita et al. 2017; Nguyen et al. 2017). In addition to the food applications, a number of studies reported the secondary metabolites presented in *G. verrucosa* have a potential to develop as functional materials (Dang et al. 2008).

Gracilariopsis chorda (gae-ko-silaegi)

Gracilariopsis chorda is a perennial red seaweed, which is popular for its wide medicinal benefits and which is also utilized as a food ingredient in Korea (Mohibbullah et al. 2016). In addition to Korea, *G. chorda* is utilized as a raw material for produce agar in France, Indonesia, Mexico, Morocco, Portugal, and Spain. Usually, *G. chorda* biomass contains large amounts of carbohydrate [34.4% (g g^{-1} DW)]. In contrast to the food value of *G. chorda*, a number of studies reported *G. chorda* is a potential candidate for bioethanol production due to its high growth rate and bio-availability (Meinita et al. 2013).

Gloiopeltis tenax (pul-ga-sa-ri)

Gloiopeltis tenax is an important red seaweed which belongs to the phylum *Rhodophyta* and the class *Florideophyeeae*. *G. tenax* is an economically important edible red seaweed which has been traditionally used as food and as a sizing material in the silk industry (Chen et al. 2011; Zheng et al. 2012). In addition to the food applications, *G. tenax* is traditionally used in the treatment of diarrhea and colitis (Zheng et al. 2012).

Bioactive effects reported from green and red seaweeds

Antioxidant properties

Free radicals are produced during the metabolism as a result of the mitochondrial metabolism, inflammatory responses, phagocytosis, and physical exercises. The production of free radicals accelerates with the external factors such as smoking, radiation, drugs, and pesticides (Carocho and Ferreira 2013). Continuous overproduction of free radicals in biological systems is capable of damaging all classes of chemicals (proteins, amino acids, nucleic acids, and carbohydrates) in the biological materials. Thus, it is important to avoid oxidative stress in the biological systems to protect organisms from oxidative damage (Kang et al., 2015b). According to the previous reports, green and red seaweed used in traditional Korean cuisines are found to possess interesting antioxidant properties. Herein, we discussed some antioxidant properties reported from edible red and green seaweed used in traditional Korean dishes.

Kim et al. (2015a) attempted to study the antioxidant activity of a protein purified from *C. fulvescens*. According to the authors, the 33-kDa-weight protein had better radical scavenging activity against hydroxyl radical, 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), hydrogen peroxide (H_2O_2), and superoxide anion. In addition, the authors found that the isolated protein has a potential to inhibit the H_2O_2-mediated ROS production in HepG2 cells at concentration of 0.01~10 μg/mL. Cho et al. (2011a) studied the antioxidant properties of extract and fractions separated from *E. prolifera*. In this study, the authors reported that the ethanol extract of *E. prolifera* had profound DPPH and hydroxyl radical scavenging activity as well as reducing power compared to the commercial antioxidants such as BHA and α-tocopherol. In addition, the authors reported that, the antioxidant effects of *E. prolifera* extracts and fractions had correlation with total phenolic contents in each extract. Nguyen et al. (2011) also attempted to evaluate the DPPH, H_2O_2, and ferrous ion chelating capacity of ethanolic extracts separated from dry *C. lentillifera* using two drying methods including thermal drying and freeze-drying. According to the authors, freeze-dried seaweed had better antioxidant capacity (0~100 ppm) as well as high total phenolic contents compared to the thermal drying method. Kim (2010) studied the total phenolic contents and antioxidant activities of *U. pinnatifida* and *C. fulvescens* under different drying conditions. According to the results, radical scavenging activity and phlorotannin contents were higher in the extracts separated by the vacuum drying method compared to the hot air drying method. According to the results, the antioxidant properties of seaweeds might depend on the processing method. Zheng et al. (2012) evaluated antioxidant properties of extract separated from *G. tenaxi* using the supercritical carbon dioxide fluid extraction technique. According to the results, the extract had strong DPPH, lipid peroxidation inhibition capacity, and hydroxyl radical-scavenging activity compared to the commercial antioxidant butylated hydroxytoluene (BHT). Seo et al. (2012) attempted to evaluate the effect of *G. amansii* on lipid accumulation and ROS production in 3T3-L1 cells. In this study, the authors found that 80% methanolic extract of *G. amansii* (1~100 μg/mL) has a potential to downregulate the ROS production of 3T3-L1 preadipocytes by reducing mRNA levels of a nicotinamide adenine dinucleotide phosphate hydrogen oxidase 4 and upregulating the expression levels of anti-oxidant proteins such as superoxide dismutases, glutathione peroxidase, and glutathione reductase. Mohibbullah et al. (2015) studied the neuroprotective effect of ethanol extract from *G. chorda* using hypoxia/reoxygenation-induced oxidative stress in cultured hippocampal neurons. According to the results, out of 23 seaweeds examined, *G. chorda* had the best neuroprotection at 15 μg/mL, followed by *U. pinnatifida*. In addition, the authors suggested that the active compound in *G. chorda* is arachidonic acid, which is responsible for neuroprotection against hypoxia/reoxygenation-induced oxidative stress.

In addition to the crude organic solvent extracts, Zhang et al. (2013b) studied antioxidant properties of water-soluble and alkali-soluble polysaccharides separated from *E. linza*. According to the authors, the superoxide radical scavenging effect of two polysaccharides was ranged between 10.4 and 15.6 μg/mL (EC_{50}). In addition to these significant findings, Wang et al. (2013a) reported that the low-molecular-weight polysaccharides separated from *E. linza* have potential radical scavenging properties against superoxide and hydroxyl radicals. Zhang et al. (2014) also reported that a low-molecular-weight polysaccharide isolated from *E. linza* has a potential to be used as an ingredient in food and pharmaceutical industries due to its strong superoxide ($EC_{50} = 5.44$ μg/mL) and hydroxyl radical ($EC_{50} = 920$ ng/mL) scavenging properties. Xu et al. (2015) reported that a 45.4-kDa polysaccharide purified from *E. prolifera* has better radical scavenging properties such as DPPH, hydroxyl, and superoxide anion radicals. Qi and Sun (2015) attempted to evaluate the antioxidant properties of a polysaccharide collected from *U. pertusa* in the liver of hyperlipidemic rats. According to the results, doses of 125 and 250 mg/kg had better superoxide dismutase activity as well as glutathione peroxidase than the hyperlipidemic rats. Recently, Kim et al. (2017) reported the crude protein separated from *C. fulvescens* has a potential to protect hippocampal neurons against ethanol-induced oxidative stress in Sprague-Dawley rats (male/250~300 g) by upregulating the mature brain-derived neurotrophic factor as well as protecting against chronic ethanol-exposed endoplasmic reticulum (ER) stress in rats (10~20 mg/kg). Recently, Lee et al. (2017) reported that polysaccharides separated from *P. yezoensis* by microwave-assisted rapid enzyme digest system have a potential to be developed as functional material due to its strong antioxidant properties. According to the results, low-molecular-weight polysaccharide is found to possess strong alkyl radical scavenging activity with IC_{50} of 114.4 μg/mL.

Anticancer properties

Cancer is a major health care problem in many parts of the world and was reported to cause 8.8 million deaths in 2015. According to the previous studies, metabolites present in seaweed are capable of suppressing the cancer cells and the further development of cancer (Kim et al. 2013a, b, c). Thus, promotion of seaweed consumption might be a possible approach to reduce cancer risk (Sanjeewa et al. 2017). In this section, we discussed some outcomes of anticancer studies carried out with green and red Korean edible seaweeds.

Cho et al. (1997) attempted to evaluate anticancer and anti-mutagenic properties of the nine Korean seaweeds (sea lettuce, sea tangle, chlorella, sea mustard, sporophyll of sea mustard, seaweed papulosa, fusiforme, purple laver, and Ceylon moss) using 20% methanolic extracts on human colon cancer (HT-29) cells and *Salmonella typhimurium* TA100 cells. According to the authors, all seaweed extracts had promising anti-mutagenic activity against aflatoxin B_1 and N-methyl-N′-nitro-N-nitrosoguanidine in *S. typhimurium* TA100. In addition, sporophyll of sea mustard, sea tangle, and sea mustard extracts had anticancer activity on AGS human gastric adenocarcinoma cells and HT-29 human colon carcinoma cells at the 0.2 mg/mL concentration. Maeda et al. (2012b) attempted to study anticancer effects of β-1,3-xylooligosaccharide prepared from *C. lentillifera* on human breast cancer (MCF-7) cells. In this study, the authors found that 1,3-xylooligosaccharides have a potential to inhibit the proliferation of MCF-7 cells via inducing condensation of chromatin and altering the apoptosis protein expression levels in 1,3-xylooligosaccharide-exposed MCF-7 cells (downregulated expression of PARP and upregulated expression of caspase-3/7). The Wnt signals are usually associated with the development of organs, cell proliferation, morphology, and motility within vertebrates. However, unusual activation of Wnt proteins in cancer cells is responsible for the upregulated proliferation and survival rates associated with cancer cells. Therefore, inhibition or downregulation of Wnt signal-associated proteins is considered as a key approach in anticancer drugs (Kim et al. 2013b). Kim et al. (2013b) attempted to evaluate anticancer properties of glycoprotein isolated from *C. fulvescens*. According to the authors, glycoprotein inhibited the upregulated expressions of Wnt-1 signal-associated proteins as well as cell cycle-related proteins Cyclin D and cell cycle progress in gastric cancer cells (5~20 μg/mL). Deregulated levels of apoptosis in cancer cells are considered as a major barrier to effective elimination of cancer cells. Thus, the compounds that have a potential to restore apoptosis have a great potential to develop as anticancer drugs (Sanjeewa et al. 2017). Choi et al. (2014) attempted to evaluate the anticancer properties of methyl alcohol extract separated from *E. linza* on human leukemia cells (U937). In this study, the authors demonstrated the extract has a potential to induce apoptosis in U937 cell via upregulated expression of death receptors 4 and 5 and downregulated expression of anti-apoptotic proteins such as Bcl-2 and Bcl-xL and IAP family proteins (50~300 μg/mL). In addition, Kwon and Nam (2007) reported a polysaccharide isolated from *C. fulvescens* has a potential to inhibit the proliferation and cell cycle progression of gastric cancer cells via upregulating caspase-3 activation and downregulating Bcl-2 expression in polysaccharide-exposed cancer cells. Recently, Kim et al. (2015b) studied the anticancer properties of ethanol extracts of *P. tenera* on oral cancer cells (YD-10B). According to the results, exposure of YD-10B cells to the *P. tenera* extracts (50–200 μg/mL) for 24 or 48 h induces the apoptosis cell death in YD-10B cells via upregulating cytochrome *c* and downregulating the expression levels of procaspase 3/9 and Bcl-2 proteins in YD-10B cells. In addition to these significant results, Zhang et al. (2016) studied the anti-mutagenic effects of polysaccharides separated from *E. linza* on *Allium sativum* root cells induced by ultraviolet and sulfur dioxide. According to the results, *E. linza* polysaccharides had antigenotoxic and anti-mutagenic activity on *A. sativum* root cells. However, since *A. sativum* is a higher plant, it is important to carry out future studies with human or mammal cells in order to develop drugs or functional materials from these polysaccharides.

Anti-inflammation and immunomodulatory properties

Inflammation is a protective response, which plays an important role in host defense mechanisms. Inflammatory responses are useful to stimulate tissue regeneration and defeat pathogens (Pesic and Greten 2016), while uncontrolled and continuous inflammatory responses are linked to tissue destruction, carcinogenesis, obesity, and obesity-associated insulin resistance (Kundu and Surh 2008, Jais and Bruning 2017). Thus, compounds with inhibitory effects on inflammatory mediators have a potential to develop as functional materials or drugs to treat inflammation-associated diseases. In this section, we discussed anti-inflammatory properties reported from some Korean edible seaweeds.

Recently, Ali et al. (2016) reported 3-hydroxy-4,7-megastigmadien-9-one isolated from *U. pertusa* has a potential to inhibit lipopolysaccharide (LPS)-induced inflammatory responses in bone marrow-derived dendritic cells via inhibiting NF-κB and MAPK-associated proteins. According to the results, the isolated compound had strong inhibition effect on pro-inflammatory mediators such as interleukin (IL)-12 p40 ($IC_{50} = 7.85 \pm 0.32$ μM) and IL-6 cytokine ($IC_{50} = 7.86 \pm 0.18$ μM) but not TNF-α. However, in an another study, Ali et al. (2017) reported that 3-hydroxy-4,7-megastigmadien-9-one isolated from *U. pertusa* has considerably high TNF-α inhibition effect on LPS-induced bone marrow-derived dendritic cells ($IC_{50} = 7.56 \pm 0.21$ μM). In addition, the authors reported that the inhibition of the transcriptional activity of AP-1 and NF-κB is also responsible for inhibiting LPS-induced inflammation in dendritic cells. Manzoor et al. (2016) attempted to study the inhibitory effect of 4-hydroxy-2,3-dimethyl-2-nonen-4-olide isolated from *U. pertusa* in CpG-stimulated bone marrow-derived dendritic cells. According to the results, CpG DNA-stimulated bone marrow-derived dendritic cells had strong inhibition of interleukin (IL)-12 p40 and IL-6 production with IC_{50} values ranging from 7.57 ± 0.2~10.83 ± 0.3 μM respectively. Recently, Lee et al. (2017) attempted to evaluate anti-inflammatory properties of hot water extract separated from *C. fragile* on LPS-stimulated RAW264.7 cells and carrageenan-induced male Sprague-Dawley rats (300~330 g, 10 weeks old). According to the results, *C. fragile* extracts inhibited LPS-induced inflammatory responses in macrophage cells at the concentrations ranging between 50 and 200 μg/mL. In addition, oral administration of seaweed extract (50~200 mg/kg body weight) suppressed carrageenan-induced paw edema thickness (6~50%) in rat model.

In addition to the anti-inflammatory properties, some studies reported that the extracts separated from Korean edible green and red seaweed have a potential to act as immunomodulatory agents. In this subchapter, immunomodulatory properties reported from Korean edible seaweeds are briefly introduced. Karnjanapratum et al. (2012) attempted to evaluate the immunomodulatory properties of sulfated polysaccharides isolated from *C. fulvescens* using in vitro RAW 264.7 cells. According to the results, exposure of *C. fulvescens* polysaccharides to RAW 264.7 cells triggers the production of NO, PGE_2, and cytokines significantly compared to the control treatment (6.25~25 μg/mL). Maeda et al. (2012a) also reported the purified sulfated polysaccharide obtained from *C. lentillifera* has a potential to act as an immunomodulatory agent. According to the authors, the isolated polysaccharide increased the NO production from RAW 264.7 cells via upregulated activation of NF-κB and MAPK-associated inflammatory proteins at the concentration of 1~4 μg/mL.

Anti-diabetic and anti-obesity properties

Diabetes is one of the most prevalent and chronic metabolic diseases, which alerts the glucose metabolism with abnormally high plasma glucose levels (Leung et al. 2017). Obesity is a metabolic disorder which can define as increased body weight caused by excessive fat accumulation. Obesity presents a risk to health with an increase in health care problems and reduced life expectancy by inducing the risk for the pathogenesis of other chronic disease conditions such as diabetes and cardiovascular and renal diseases (Lee et al., 2016a; Leung et al. 2017). Recently, the studies carried out with Korean edible seaweeds have demonstrated the metabolites present in those seaweeds contain promising anti-diabetic and anti-obesity properties. In the present section, we discussed some anti-diabetic and anti-obesity properties reported from Korean edible seaweeds.

Previously, Zhang et al. (2013a) compared the α-glucosidase inhibitory effects of five polysaccharide fractions purified from *E. linza* along with acarbose, commercial α-glucosidase inhibitor. According to the results, purified polysaccharides inhibited the α-glucosidase with IC_{50} 0.38~0.58 mg/mL. However, in the same study, the authors found that IC_{50} of acarbose on α-glucosidase was 0.46 mg/mL. Sharma and Rhyu (2014) reported the extract separated from *C. lentillifera* has a potential to increase the insulin secretion from rat insulinoma cells and stimulate the glucose uptake in 3T3-L1 adipocytes. In addition, the authors reported that *C. lentillifera* (5~25 μg/mL) extract preserved functional β-cell mass from cytokine-induced injury and downregulated the inflammatory response by inhibiting NO and iNOS production from cytokine-exposed cells. Woo et al. (2013) reported that 80% ethanolic extract separated from *G. verrucosa* has a potential to increase glucose uptake in 3T3-L1 adipocytes without showing any cytotoxic effect on 3T3-L1 adipocytes. Moreover, the authors suggest that AMPK signal pathway might be responsible for the anti-adipogenic and anti-diabetic effects of *G. verrucosa* extract in 3T3-L1cells.

Malfunctions of the AMPK and PI3K/AKT associated signal pathways in insulin-sensitive tissues have been identified as one major cause for accumulation of blood glucose level. Recently, Sharma et al. (2015) attempted to evaluate the effects of 70% ethanolic extract separated from *C. lentillifera* (CLE) on AMPK- and PI3K/AKT-associated protein expression levels in C57BL/KsJ-db/db mice. According to the result, CLE (250 and 500 mg/kg) upregulated the glucose uptake of db/db mice via stimulating the PI3K/AKT signaling pathway without altering the mice weight or dietary intake. Han et al. (2016) also reported that whole wheat bread prepared using *C. fulvescens* has a potential to reduce the plasma glucose and lipid levels in Sprague-Dawley rats. Recently, Kang et al. (2016) evaluated the in vitro and in vivo anti-diabetic effect of 70% ethanol extract from *G. amansii* (GAE). According to the authors, under in vitro conditions, GAE suppressed differentiation of 3T3-L1 adipocyte through downregulation of adipogenesis and lipogenesis. In addition to this significant finding, in vivo results suggest that GAE has a potential to decrease the body weight gain and adipose cell size in high-fat diet-induced obesity in mice. Tang et al. (2013) reported that a partially purified polysaccharide separated from *E. prolifera* has a potential to reduce blood lipid and oxidative stress in high-fat diet-induced mice fed high-fat diet. According to the authors, oral administration of separated polysaccharide (300 mg/kg body weight) significantly increased the activities of endogenous antioxidant enzymes such as superoxide dismutase, glutathione peroxidase, and catalase.

Antimicrobial properties

In the food processing and other food-related industries, special attention is given to avoid microbial infections. Thus, food poisoning, food spoilage, and other food-related infections have become an important topic of concern in the food processing and other food-related industries. To avoid food contaminations and increase the shelf life, a large number of synthetic food preservatives has been developed. However, market demand for food products with synthetic food preservatives and antimicrobial agents continuously get reduced due to the adverse side effects associated with those food preservatives (Patra and Baek 2016). During the last few decades, a number of food preservatives developed from the natural origins. The present section briefly discussed about antimicrobial activities reported from Korean edible seaweeds.

Recently, Shao et al. (2017) reported that polysaccharides obtained from *E. prolifera* have a potential to act as an antimicrobial compound against *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Salmonella spp*. According to the results, the inhibition zone diameters were ranged between 8.90 and 14 mm (200 μL of 16 mg/mL drop). In addition, the authors reported that minimum inhibition concentration of tested polysaccharides were ranged between 1 and 4 mg/mL against aforementioned bacterial strains. Patra et al. (2015) attempted to evaluate the antibacterial properties of an essential oil separated from *E. linza* against *E. coli* and *S. typhimurium.* In this study, the authors found that the minimum inhibitory effect of isolated oils against *Escherichia coli* and *S. typhimurium* was 12.5 and 25 mg/mL, respectively (Patra et al. 2015). Patra and Baek (2016) studied the inhibitory effects of foodborne pathogens using the essential oil from *E. linza*. According to the authors, the extracted oils have a potential to inhibit growth of *Bacillus cereus* (12.3–12.7 mm inhibition zone) and *S. aureus* (12.7–13.3 mm inhibition zone), two important foodborne pathogens. *Prevotella intermedia* and *Porphyromonas gingivalis* are two gram-negative periodontal pathogens responsible for pathogenesis of periodontitis in a chronic inflammatory disease. Park et al. (2013) attempted to study the antimicrobial activities of stearidonic and gamma-linolenic acids separated from *E. linza* against aforementioned bacterial pathogens. According to the results, minimal inhibitory concentration values of stearidonic and gamma-linolenic acids were 39.06 μg/mL against *P. intermedia* and 9.76 μg/mL against *P. gingivalis*. In addition, Zheng et al. (2012) reported that the extracts collected from *G. tenax* have moderate inhibitory effects on foodborne pathogens such as *S. aureus*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, and *Escherichia coli*. According to the results, minimum inhibitory concentration of extracts ranged between 3.9 mg/ and 15.6 mg/mL under tested conditions against aforementioned bacterial species.

Anticoagulant properties

Heparin is a sulfated polysaccharide, which has been identified as a strong anticoagulant compound. Heparin is used as a commercial anticoagulant drug for the treatment and prevention of thromboembolic diseases for more than seven decades (Jin et al. 1997; Walenga and Bick 1998; Pushpamali et al. 2008). However, due to the adverse side effects associated with heparin (alopecia, allergic reactions, thrombocytopenia, eosinophilia, heparin-induced thrombocytopenia, heparin-associated osteoporosis, and skin reactions), requirement for some effective alternatives for heparin increased (Walenga and Bick 1998). In this section, we briefly discussed about potentials of secondary metabolites present in Korean edible seaweeds to develop as anticoagulant agents.

Qi et al. (2013) reported that two water-soluble sulfated polysaccharides separated from *E. linza* have a potential to prolong the activated partial thromboplastin time (APTT) and thrombin time (TT) in human plasma. In addition, Wang et al. (2013b) studied the anticoagulant properties of low-molecular-weight polysaccharide prepared from *E. linza*. According to the authors, anticoagulant activities of all the samples were increased with the degree of sulfation and had considerable good anticoagulant activity compared to the heparin, a commercial anticoagulant. Synytsya et al. (2015) attempted to evaluate the anticoagulant activity of a sulfated polysaccharide separated from *C. fulvescens*. The authors reported that the polysaccharide (4-linked l-rhamnose-3-sulphate and d-xylose residues carrying monomeric d-glucuronic acid or d-glucuronic acid-3-sulphate on O-2 of some l-rhamnose-3-sulphate units as the side chains) has potential anticoagulant properties. According to the authors, the isolated polysaccharide had significant in vitro anticoagulant activities under tested conditions. Moreover, the isolated polysaccharide significantly prolonged the APTT and TT at the concentrations between 0.01 and 0.2 mg/mL. Kang et al. (2015a) studied the anticoagulant properties of ulvease, a new fibrinolytic protease, separated from *U. pertusa*. According to the results, ulvease possesses direct-acting fibrinolytic and plasminogen-activating activities which have a potential to act on fibrin clot more efficiently than plasmin and/or u-PA. Specifically in this study, the authors found that ulvease hydrolyzed the Aα- and Bβ-chains of fibrinogen, but ulvease does not hydrolyze the γ-chain of fibrinogen.

Conclusions

As a source of food and medicine, seaweeds have a long history in Korea. Korea is one of the biggest consumers and producers of edible seaweeds. Traditionally, Korean

Table 1 Edible red and green Korean seaweeds with reference to their reported bioactive compounds and food applications

Name	Applications	Bioactive properties	References
Capsosiphon fulvescens	Soup, stomach disorders, and hangovers	Antioxidant	Kim, 2010, Kim et al., 2015a , and Kim et al. 2017
		Anticancer	Kwon and Nam 2007
		Immunomodulation	Karnjanapratum et al. 2012
		Anti-diabetic	Han et al. 2016
		Anticoagulant	Synytsya et al. 2015
Caulerpa lentillifera	High blood pressure, rheumatism, diabetes, and bacterial and fungal infections	Antioxidant	Nguyen et al. 2011
		Anticancer	Maeda et al., 2012b
		Immunomodulation	Maeda et al., 2012a
		Anti-diabetic	Sharma and Rhyu 2014 and Sharma et al. 2015
Enteromorpha linza	Soup, seasoned cooked vegetables	Antioxidant	Zhang et al., 2013a and Wang et al., 2013a, b
		Anticancer	Choi et al. 2014 and Zhang et al. 2016
		Anti-diabetic	Zhang et al., 2013a
		Antimicrobial	Patra et al. 2015
Enteromorpha prolifera	Ingredient in meals and cookies or as an essence	Antioxidant	Xu et al. 2015
		Anti-diabetic	Tang et al. 2013
		Antimicrobial	Shao et al. 2017
Ulva pertusa	Urinary diseases, sunstroke, and hyperlipidemia	Antioxidant	Qi and Sun 2015
		Anti-inflammatory	Ali et al. 2016, Ali et al. 2017, and Manzoor et al. 2016
		Anticoagulant	Kang et al., 2015a
Codium fragile	To treat dysuria, dropsy, and enterobiasis	Anti-inflammation	Lee et al. 2017
Porphyra spp.	Snacks, rice wraps	Antioxidant	Lee et al., 2016b
		Anticancer	Kim et al., 2015b
Gelidium amansii	Agar jelly	Antioxidant	Seo et al. 2012
		Antimicrobial	Kang et al. 2016
Gracilaria verrucosa	Agar jelly	Antioxidant	Heo et al. 2006
		Anti-diabetic	Woo et al. 2013
Gracilariopsis chorda	Agar	Antioxidant	Mohibbullah et al. 2015
Gloiopeltis tenax	Agar, to treat diarrhea and colitis.	Antioxidant and Antimicrobial	Zheng et al. 2012 Zheng et al. 2012
Grateloupia filicina	Agar, traditional food in the Kangwando area of Korea	Antioxidant	Athukorala et al. 2003 and Athukorala et al. 2005

people incorporate seaweeds in to their diets as salads, cookies, or soup. The dried seaweeds are used as ingredients in many food applications such as gim-bap, condiments, or snacks to eat together with tea. Besides the food value of Korean edible seaweeds, accumulating evidences suggest that the secondary metabolites present in those edible seaweeds have a potential to develop as functional materials due to their promising bioactive properties (Table 1). Due to the interesting bioactive properties, seaweed-associated products seem to become one of the pioneer profit-earning businesses in the global trade. However, consumption of seaweeds is still not in the satisfactory level specially in European and Asian countries due to less awareness of health benefits associated with edible seaweeds. In this study, we discussed some food application, bioactive properties, and some bioactive compounds reported from green and red edible seaweeds. Therefore, the content of this article might be useful to increase consumption of seaweeds as well as utilization of seaweed materials as functional ingredients.

Abbreviations
DPPH: 2,2-Diphenyl-1-picrylhydrazyl radical; H_2O_2: Hydrogen peroxide; IL: Interleukin; iNOS: Inducible nitric oxide synthase; LPS: Lipopolysaccharide; MAPK: Mitogen-activated protein kinases; NF-κB: Nuclear factor κB; NO: Nitric oxide; PGE2: Prostaglandins; ROS: Reactive oxygen species

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KKAS and YJJ designed this study and drafted the manuscript. KKAS, LWW, and YJJ conceived and designed the study and also revised the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Not applicable.

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