Algae farming in Xiapu, Fujian Province of China

Coltivazione di alga nori

Picture by The Algonauts Project

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NORI

The edible red algae Pyropia yezoensis contains many nutrients and health-promoting compounds

Review

Nori, one of the favorite food of the Japanese, is a dry foodstuff processed from the edible red algae Pyropia yezoensis with less than 3% moisture content and which has protein and dietary fiber as its major components. In addition, this seaweed contains high levels of iron, zinc, and manganese as well as high vitamin A, vitamin B12, folic acid and vitamin C. Nori is a good source of protein, similar to the protein content in beans and its interesting nutritional properties are widely studied.

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Introduction

Nori is one of the favorite food of the Japanese, enjoyed for its flavor and taste, often with Cha (green tea). This simple dry foodstuff processed from the edible red algae *Pyropia yezoensis* (the former genus name was *Porphyra*) adds variety to the daily diet and offers flavor, nutrients, and other health benefits. In Japan, the algal product is commonly found in the market not just as a topping but is also included in some traditional rolled dishes such as sushi and various kinds of wrapped rice balls. Nori is widely accepted as a good accompaniment for rice, the staple food in Japan. Here, descriptions of traditional nori foodstuffs are given.

In recent years, the total annual harvest of nori and related seaweeds has been a steady 300,000 tons, based on statistical data from Japanese fisheries (MAFF, 2017). Most of the nori is produced by aquaculture of the major species, *Pyropia yezoensis*, in shallow water. By the Edo period, the aquaculture techniques had been established, and nori came to be processed in well-dried and sometimes roasted paper-like sheets measuring 19 cm by 21 cm, or approximately 3 g per sheet, using traditional Japanese techniques for making paper by hand. Today, these processes are automated with specialized machines. The annual production of dried and roasted nori reached 7 billion sheets in 2015 (MAFF, 2017).

Various kinds of seaweed, which contain a number of polysaccharides, vitamins and minerals, are popular foodstuffs in Japan. Nori is among them, but it has a unique characteristic nutritional profile that sets it apart from other seaweeds. Even more remarkable is that it is a good source of nutrients that are rare in other vegetables and also has unique metabolites with health benefits, as discussed below.

Nutrients and flavors

Common nori is a dried product with less than 3% moisture content and which has protein and dietary fiber as its major components, as shown in Figure 1. It is low fat (3.7%) and is low in digest-

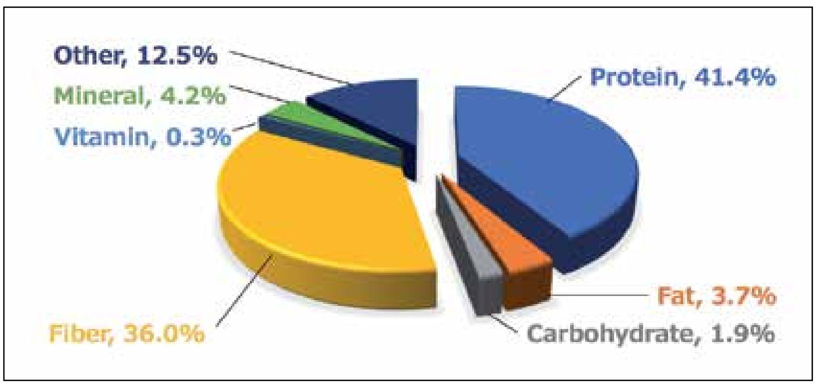

Figure 1. Nutritional Composition of Nori

ible carbohydrates (1.9%). Nori is a good source of protein, similar to the protein content in beans. Further, based on the food composition table (MEXT, 2015), nori has features that are different from other seaweeds (wakame, konbu, hijiki and hitoegusa) or other dried food materials (soybean, tomato and strawberry), as shown in Table 1. The dietary fiber content of most seaweed is approximately 30%; however, the protein content of nori, at 41.4%, is nearly three times that of other seaweeds. Analysis of the fatty acid (FA) composition (MEXT, 2015) reveals that eicosapentaenoic acid (EPA, or icosapentaenoic acid, 20:5n-3) is the major FA in dried nori (1200 mg/100 g). It has been demonstrated that some edible seaweeds, especially *Porphyra* sp., contain high levels of EPA (Dawczynski, 2007). An analytical study about nori from different growing conditions elucidated that nori has a metabolic pathway, which commonly found in animals, from linolenic acid to IPA (Kayama, 1985).

In addition, nori contains high levels of iron, zinc, and manganese (Esashi, 1993; Mišurcová, 2001) as well as high vitamin A (shown as beta-carotene equivalent), vitamin B_{12}, folic acid, and vitamin C content as compared to other foodstuffs (Figure 2). Nori's vitamin B_{12} (VB12) content is equal to that found in animal sources such as liver paste. The bioavailability of VB12 from powder has been confirmed in previous animal experiments (Takenaka, 2001) and clinical trials have confirmed the bioavailability and effectiveness of VB12 in numerous nori products. In a study by Suzuki (1995), the addition of 2 to 4 g per day of nori powder to the brown rice-based diets of six young vegans aged 7 to 14 years was effective in preventing a VB12 deficiency. All this indicates that nori contains ingredients that are nutritionally beneficial.

Nori is an important Japanese food, not only for providing nourishment but also adding flavor to meals, which enhances interest in food and increases appetite, therefore promoting good eating habits.

However, identification and analysis of nutritional components of nori have been difficult, and flavor components of nori have not been perfectly elucidated, but previous reports have revealed some costituents. For instance, it has been reported that pyrazine, gamma butyrolactone and several types of hydrogen sulfide (including dimethyl sulfide and methyl mercaptan) are important in creating the flavor of roasted nori products (Osumi, 1990; Kasahara, 1975, 1986). The tastes

	General composition						Distinct Minerals					Distinct Vitamins			
	energy (kcal)	moisture (g)	protein (g)	lipid (g)	carbo-hydrate (g)	ash (g)	Na (mg)	K (mg)	Ca (mg)	Fe (mg)	Zn (mg)	βC-EQ (μg)	VB12 (μg)	folic acid (μg)	VC (mg)
Dried seaweeds															
Nori (roasted)	188	2.3	41.4	3.7	44.3	8.3	530	2400	280	11.4	3.6	27000	57.6	1900	210
Konbu	145	9.5	8.2	1.2	61.5	19.6	2800	6100	710	3.9	0.8	1100	0	260	25
Wakame	117	12.7	13.6	1.6	41.3	30.8	6600	5200	780	2.6	0.9	7800	0.2	440	27
Hijiki	145	6.5	9.2	3.2	56.0	25.2	1800	6400	1000	58.2	1.0	4400	0	93	0
HItoegusa	130	16.0	16.6	1.0	46.3	20.1	4500	810	920	3.4	0.6	8600	0.3	280	38
Dried foodstuffs															
Soy bean	422	12.4	33.8	19.7	29.5	4.7	1	1900	180	6.8	3.1	7	0	260	3
Tomato	292	9.5	14.2	2.1	67.3	6.9	120	3200	110	4.2	1.9	2600	0	120	15
dry Strawberry	302	15.4	0.5	0.2	82.8	1.0	260	15	140	0.4	0.1	28	0	4	0

Table 1. Nutritional composition of dried seaweeds and foodstuffs

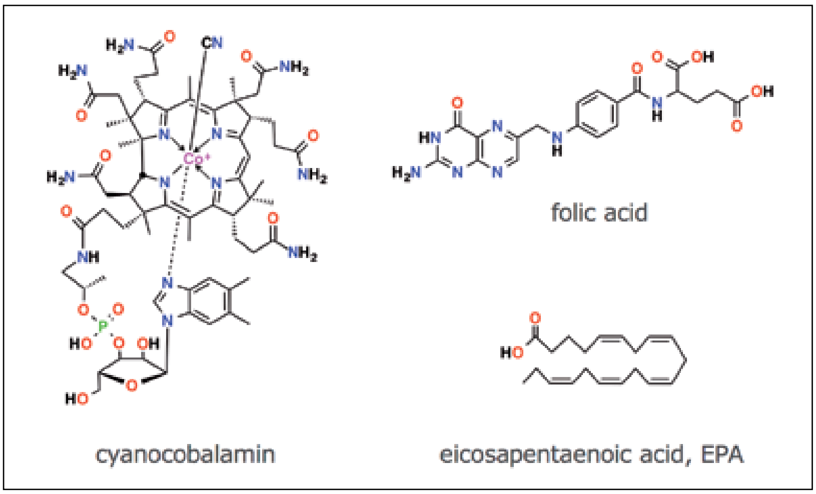

Figure 2. Characteristic nutrients of nori

of foods are also provided by the water-soluble and low-molecular compounds that are extractable from the foodstuff. In this sense, nori contains abundant amino acids such as glutamic acid, aspartic acid, alanine and taurine, along with nucleic acids such as adenyl acid and inosine acid. These components have a sweet and/or umami taste, but their levels vary according not only to the environmental growing conditions and season but also according to the processing and storage conditions of nori products (Harada, 1990). Recently, active deaminase has been purified from dried nori products, and the properties were elucidated (Nakashima, 2000). The deaminase converts from adenyl acid, which is eluted from nori to inosine acid, which is an umami component, under the optimal conditions of 7.0 to 8.0 pH at 30–50 °C in the presence of water and Ca^{2+}. The enzyme has desiccation tolerance, so it also contributes to enhancing the taste of nori when it is chewed. In this way, nori adds a pleasurable smell and taste to daily food intake.

Health-promoting compounds

Various types of seaweeds are known to be rich sources of nutrients with low calories that provide a number of health-promoting benefits. Nori also gives us an effective means for balancing our physiological condition through its unique compounds, given the recent discoveries that more ingredients found in foods than previously thought exhibit physiological regulating activities. Some of these components are found in nori, as introduced below.

Porphyran

Dietary fibers found in seaweeds can be classified into several types according to structure and activity which are closely connected to the taxonomic group

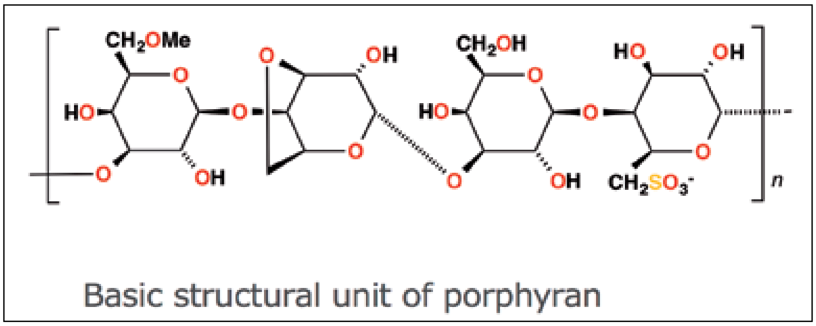

Figure 3. Basic structural unit of porphyran

of the algae (Kim, 2011). In the case of red algae, some kinds of galactan, such as agarose, carrageenan, funoran and porphyran are commonly found. In particular, porphyran is observed as a major polysaccharide in nori. The linear polysaccharide is composed of L-galactose (Gal) and D-galactose, with variations, including 6-O-methyl-D-Gal, 6-O-sulfate-L-Gal and 3,6-anhydro-L-Gal (Morrice, 1983) (Figure 3). The molecular size and sulfation rates of porphyran in nori are subject to environmental factors (Hama, 1998). It is easily dissolved in water and shows high viscosity, but does not turn into a gel.

A wide range of physiological activities of porphyran have been reported, including antioxidative activity (Zhang, 2004), anti-inflammatory activity (Isaka, 2015), inhibitory activity against α-amylase (Goni *et al.*, 2000), antidiabetic activity in KKAy mice (Kitano *et al.*, 2012), suppressive effects on serum cholesterol levels in rat (Tsuge *et al.*, 2004), anti-tumor activity (Noda *et al.*, 1989), apoptosis-inducing activity (Kwon, 2006), anti-allergic activity in mice (Ishihara, 2005) and much more.

The sulfated polysaccharide that can be prepared in large quantities from nori is expected to be used for various product applications.

Mycosporine-like amino acids

Mycosporine-like amino acids (MAA) are derivatives of mycosporine (Favre-Bonvin, 1976) that contain a cyclohexenimine or cyclohexenone ring linked to an amino acid or its metabolites (Figure 4).

The compounds have strong absorption, maxima in the range of 310 to 360 nm, and are widely present in marine plants and animals (Dunlap, 1998). These products are considered to be natural protectors against UV radiation and related lesions. Further research has shown that these products are supplied only by algae, and the marine animals have acquired them through the food chain or symbiotic relationships. Other various actions of MAA that have been reported include antioxidative activities *in vitro* (Tao, 2008), growth-inducing activity against fibrocytes of human origin (Oyamada, 2008), and UV-protecting activities in fish eyes (Dunlap, 1989). Applications in mammals are also being studied, and UV-protecting activities have been shown in externally applied MAA on mice skin (Coba, 2009). There is not currently enough data on *in vivo* functionality of MAA after oral administration to mammals.

Among marine algae, the red algae group is known to be one of the major producers of MAA (Karsten, 1998). Nori contains three major MAAs, mycosporine-glycine, shinorine and porphyra-334 (Yoshida, 1970), according to pioneering research (Ito, 1977; Takano, 1979). Today, extracts containing these MAAs are used in commercial production of sunscreen and health food products.

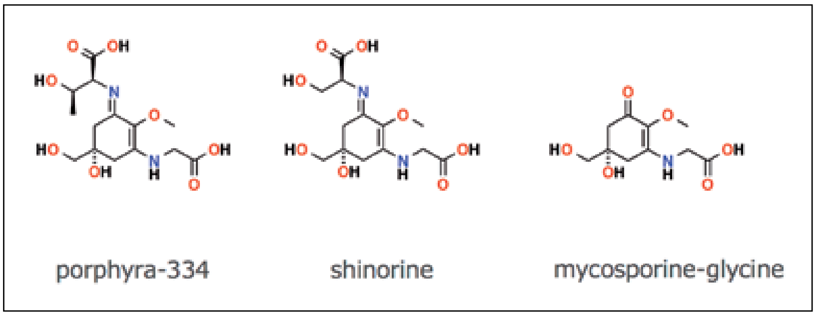

Figure 4. Micosporine-like amino acids

Galactosyl glycerols

Galactosyl glycerols (GG) such as floridoside and isofloridoside are the major products relating to osmotic modulation in most red algae (Reed, 1985) (Figure 5). The genus *Pyropia* also contains floridoside and isofloridoside, with the isofloridoside coexisting in two enantiomeric forms: D-isofloridoside (1-O-a-D-galactopyranosyl-D-glycerol) and L-isofloridoside (1-O-a-D-galactopyranosyl-L-glycerol) (Meng, 1987). Each isomer has been identified with NMR techniques (Bondu, 2008), making comparison possible through instrumental analysis to measure the content of these galactosides in nori according to environmental and seasonal conditions (Karsten, 1999).
Recently, the compounds have been found to have bifidogenic growth stimulator activity, and they are the focus of research as a new prebiotic material. GG-rich mixtures of three isomers have been purified from a 75% MeOH extract of nori to perform animal experiments, and dietary GG was shown to selectively increase the cecal *Bifidobacterium* count in rats (Ishihara, 2010). Other indices of prebiotics, such as pH of cecal content, organic acid concentrations, and fecal weight, have also supported its prebiotic activity.

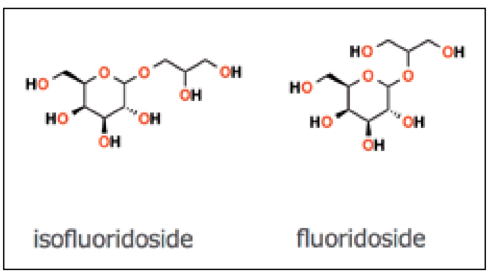

Figure 5. Galactosyl glycerols

Imidazole dipeptides

Anserine and carnosine are known as imidazole dipeptides (Figure 6), which are metabolites consisting of two amino acids, histidine and beta alanine. They are commonly found in fish such as tuna, bonita, salmon and others, and also in white meat such as chicken, goose, and turkey. However, only a few kinds of plants contain these peptides. Tamura *et al.* (1998) have found these dipeptides to act as strong antioxidants in the basic amino acid containing fraction prepared from EtOH extract of nori. The concentrations were calculated as 2.20 mg anserine and 1.60 mg carnosine in 1 g of dried nori, which compares with typical concentrations in chicken (3.57 mg and 1.30 mg/g, respectively) and fresh tuna (9.40 mg and 0.48 mg/g, respectively) (Hiraoka, 2011). These peptides show antioxidant activity in various *in vitro* assays (Kohen, 1988) and lowered uric acid levels in rats (Chen, 2004). In one study, anserine given at 25 mg per day for 4 weeks improved hyperuricemia in people who need to control uric acid levels (Kubomura, 2009), indicating that an appropriate daily intake of these dipeptides may increase the possibility of preventing hyperuricemia and protect against oxidative stress.

Other components

Among other applications, nori has also been used as a source of organic pigments after semi-purification or as supplement tablets after enzyme treatment.
Dried nori as a food product is nearly black in color, but the red alga *P. yezoensis* contains pigments of chlorophyll (green), carotenoid (orange), phycoerythrobilin (red) and phycocyanobilin (blue).
The bilin pigments having linear tetrapyrrole moiety, constituting phycoerythrin and phycocyanin, respectively, to bind to specific apoproteins. Increasing water activity during storage of nori accelerates the hydrolysis of chlorophyll and phycocyanobilin, finally inducing the color change to reddish black. Alternatively, increasing roasting treatments to bring out flavor denatures heat-labile phycoerythrin, finally inducing a color change to clear greenish black (Fujiwara, 1961).
All of these pigments have shown strong antioxidative activity *in vitro* and *in vivo* (Yabuta, 2010; Soni, 2009). In the mammal intestine, bilin pigments are easily absorbed into the bloodstream after digestion of the apoproteins by intestinal enzymes. Therefore, these large pigment molecules also appear to exhibit antioxidative activity *in vivo*.
Nori as a protein source can be utilized for protease treatment or fermentation to create new active components. There have been some trials applying fermentation techniques with nori pow-

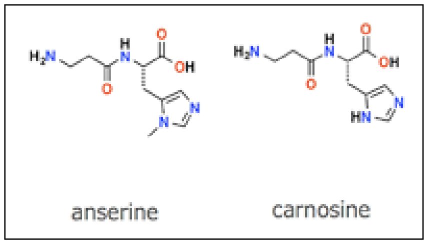

Figure 6. Imidazole dipeptides

der wherein lactic acid fermentation of nori produced gamma amino butyric acid (GABA) that had a suppressive action on blood pressure (Tsuchiya, 2007). Other research groups have reported inhibitory oligopeptides against angiotensin converting enzyme (ACE) after pepsin treatment and semi-purification of nori powder (Suetsuna, 1998). These activities and mechanisms have been confirmed in experiments using SHR rats and in human clinical trials (Saito, 2005). The nori oligopeptides have been applied to foods for specified health uses (FOSHU) product approved by the consumer affairs agency in the Japanese market since 2005. The major active peptide identified in these products from digestive nori material is Ala-Lys-Tyr-Ser-Tyr.

Conclusion

This paper has given a brief overview of nori. It is not just a traditional edible seaweed in Japan, but rather, it is also a superfood with a lot of potential for promoting good health. Various unique nutrients and health-promoting ingredients have been found in this food product. Aside from providing energy, this foodstuff enhances appetite and improves health through daily eating habits in Japan. The knowledge gained through continuous research into seaweeds and their components will enable development of new ingredients, food materials and uses of them all over the world.

Seaweeds are an important part of the traditional Japanese food culture in promoting good health. We hope that this relationship will continue for a long time into the future.

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