PROSPECTS AND HEALTH PROMOTING EFFECTS OF BROWN ALGAL-DERIVED NATURAL PIGMENTS

Prospek dan Manfaat Kesehatan dari Pigmen Alami Rumput Laut Coklat

Ratih Pangestuti[1*] and Singgih Wibowo[2]

[1] Research Center for Oceanography, Indonesian Institute of Sciences, Jakarta 14430, Indonesia
[2] Research and Development Center for Marine and Fisheries Product Processing Biotechnology, Jl. K.S. Tubun Petamburan VI Jakarta Pusat 10260 Indonesia
*Corresponding author: pangesturth@yahoo.com

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Abstract

Recently, a great deal of interest has been developed to isolate novel bioactive compounds from marine resources. Among marine resources, marine brown algae are considered valuable sources of structurally diverse bioactive compounds such as chlorophylls and carotenoids. Chlorophyll has been known for its antioxidant activity; meanwhile carotenoid is well known for its anticancer and anti-obesity properties. Therefore, marine brown algal-derived natural pigments have great potential for further development of valuable products in nutraceutical, and pharmaceutical areas. This contribution presents an overview of potential health benefits properties, and prospects of natural pigments derived from marine brown algae.

Keywords: Marine brown algae, natural pigments, nutraceutical, pharmaceutical

Abstrak

Beragam biota laut telah banyak diteliti, dieksplorasi dan dikembangkan untuk digunakan sebagai sumber bahan baku obat di industri farmasi. Diantara biota laut, rumput laut coklat merupakan sumber daya yang kaya akan beragam senyawa aktif, seperti klorofil dan karotenoid. Aktivitas antioksidan klorofil telah lama diketahui, sementara karotenoid terkenal akan aktivitas anti-kanker, dan anti-obesitas. Oleh karena itu, pigmen alami dari rumput laut coklat sangat potensial untuk dikembangkan sebagai produk yang penting dalam bidang nutraseutikal, dan farmaseutikal. Review ini menyajikan ikhtisar tentang manfaat kesehatan, dan prospek dari pigmen alami yang berasal dari rumput laut coklat.

Kata Kunci: rumput laut coklat, pigmen alami, nutraseutikal, farmaseutikal

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INTRODUCTION

Indonesia is the largest archipelagic country in the world, stretches from the Indian Ocean to the Pacific Ocean and straddles the equator for a distance of 2.500 km from the north to south. Due to the large number of islands; the Indonesian coastal zone spreads along 81.000 km which make it the second longest coastline in the world after Canada. The Indian and Pacific Ocean have affected the diversity of marine organisms in Indonesia. In addition, long and nutritious coastal area in Indonesia is suitable and potential environment for marine algae to grow. Earliest report on marine algae in Indonesia is obtained based on the Sibolga Expediton (1899-1900), which record more than 700 species of marine algae. Recently, more than 1000 species of Indonesia marine algae were reported including new species and new record (Pangestuti & Limantara, 2010).

Marine algae, particularly brown algae are potential sources of structurally diverse bioactive compounds. Brown algae are good sources of nutrients and one particular interesting feature is their richness in natural pigments (Pangestuti & Kim, 2011a; Pangestuti & Kim, 2011b). Natural pigments are pigments made by living organisms. Natural pigments are found extensively in the nature from the simplest prokaryotic throughout the kingdom of fungi, plants, and animals (Mortensen, 2006). Marine brown algae; however, are potential sources of non-animal natural pigments. Basic classes of natural pigments found in brown algae are chlorophylls, and carotenoids (Figure 1) (Kim & Pangestuti, 2011). Table 1 showed fucoxanthin (natural pigments-derived from brown algae) contents (mg/g) in several brown algae species from Indonesia which potential to be developed in the near future.

Chlorophylls are greenish lipid-soluble natural pigments which contain porphyrin ring and found in

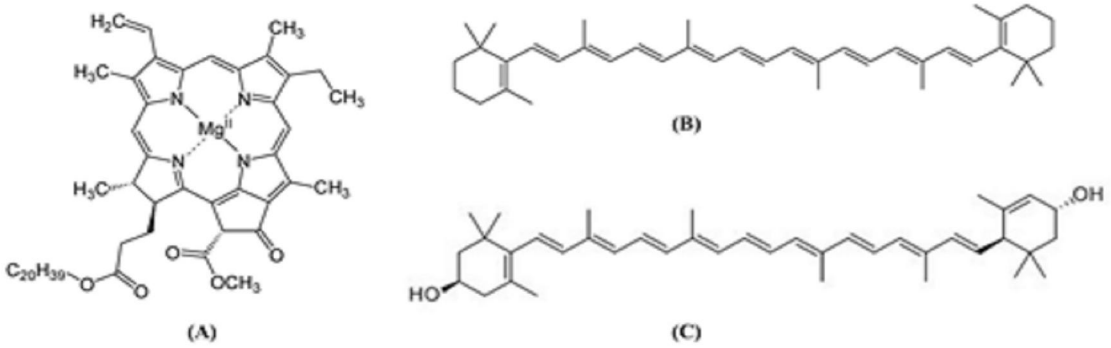

Figure 1. Examples of natural pigments found in marine algae. Chlorophyll a (A); carotene (B); and xanthophyll (C).

Table 1. Fucoxanthin content in several brown algae species originated from Indonesia

Brown algae species	Fucoxanthin content (mg/g)	References
Padina australis	0.43 ± 0.07	(Jaswir et al., 2011)
Sargassum binderi	0.73 ± 0.39	(Noviendri et al., 2011)
Sargassum duplicatum	1.01 ± 0.10	(Noviendri et al., 2011)
Turbinaria conoides	0.21 ± 0.01	(Zailanie & Purnomo, 2011)
Sargassum filipendula	0.19 ± 0.01	(Zailanie & Purnomo, 2011)
Sargassum cinereum	0.16 ± 0.01	(Zailanie & Purnomo, 2011)
Sargassum echinocarpum	0.16 ± 0.01	(Zailanie & Purnomo, 2011)
Turbinaria turbinata	0.59 ± 0.08	(Jaswir et al., 2013)
Sargassum plagyophyllum	0.71 ± 0.01	(Jaswir et al., 2013)

all algae, higher plants and Cyanobacteria. Structurally, chlorophylls are substituted tetrapyrrole with a centrally bound magnesium atom; the porphyrin tetrapyrrole is further esterified to a diterpene alcohol, phytol, to form chlorophyll (Ferruzzi & Blakeslee, 2007). Up to now, information on the bioavailability of chlorophyll derivatives is limited partially due to the general assumption that chlorophylls are unabsorbable by humans. However, considering the abundance of chlorophyll in brown algae, the diversity of derivatives formed through marine algae processing and preparation, dietary exposure to these natural pigments can be significant. In addition, sensitivity of chlorophylls to extremes pH and temperature allows the formation of several distinct chlorophyll derivatives through processing of marine algae tissue and human digestion (Ferruzzi & Blakeslee, 2007).

Carotenoids are lipid soluble, yellow orange red pigments found in plants and some animals. Animals however, cannot synthesize carotenoids. Hence, the presence of carotenoids is due to dietary intake (Mortensen, 2006). Carotenoids are linear polyenes that function as light energy harvesters and antioxidants that inactivate reactive oxygen species (ROS) formed by exposure to light and air (Ioannou & Roussis, 2009). Carotenoids are considered as accessory pigments; since they augment the light-harvesting properties of algae by passing on light excitation to chlorophyll (Larkum & Kühl, 2005). Carotenoids can be classified into two types: carotenes, which are unsaturated hydrocarbons; and xanthophylls, which present one or more functional groups containing oxygen (Batista *et al.*, 2006). One very visible carotenoid in brown algae is fucoxanthin; the brown pigment which colors kelps and other brown algae as well as the diatoms. Fucoxanthin is one of the most abundant carotenoids contributing around 10% estimated total production of carotenoids in nature

(Heo & Jeon, 2009). It has unique structures including an unusual allenic bond and a 5,6-monoepoxide in its molecule. For different brown algal strains, the compositions and profile of fucoxanthin were found to be different (Terasaki et al., 2009). In human body, fucoxanthin absorption strongly depends on a number of factors which are not entirely understood. Many factors may impact fucoxanthin absorption, including the amount and type of dietary lipids consumed, the stability of the matrix to which the carotenoid was bound, and additional dietary factors such dietary fiber (Bohn, 2008).

HEALTH PROMOTING EFFECTS OF MARINE BROWN ALGAL-DERIVED NATURAL PIGMENTS

Antioxidant Activity

Antioxidants may have a positive effect on human health as they protect human body against damage by ROS, which attack macromolecules such as membrane lipids, proteins and DNA, lead to many health disorders such as cancer, diabetes mellitus, neurodegenerative and inflammatory diseases with severe tissue injuries (Rahman, 2007). Marine algal-derived natural pigments are not only function as colorants, but they also contribute to the antioxidant activity of marine algae. It has been demonstrated that marine algae have potential antioxidant activity and various classes of pigments have been shown as potent antioxidants. Antioxidant activity of natural pigments depends on their structural features such as porphyrin ring, phythyl chain and extended system of conjugated double bonds (Le Tutour et al., 1998). Le Tutour et al. (1998) reported that chlorophyll a and related compounds derived from brown algae possess antioxidant activities in methyl linolenate systems. Another research demonstrated that chlorophyll a exhibits antioxidant activity in the dark, and importantly, porphyrin ring are an essential structure for this activity. More recently, it has been indicated that chlorophyll a reacts with peroxyl radicals ($RO_2^{\cdot}$) to form charge transfer complex where the π-cation radical of chlorophyll a is connected to the negative charged of peroxyl radical (Cahyana et al., 1993). The charge transfer complex reacts with another peroxyl radical leading to inactivate products. Chlorophyll derivatives which lack a central Mg^{2+} and phytyl chain have shown more potent antioxidant activity than chlorophyll (Cahyana et al., 1993). Another research group has prepared different chlorophyll derivatives and investigated their antioxidant activities (Lanfer-Marquez et al., 2005). Among the natural pigments assayed, chlorophyll b derivatives showed stronger antioxidant activity than chlorophyll a derivatives, suggesting that the presence of aldehyde group (–CHO) in place of methyl group provides a better antioxidant activity; however, the investigation of the mechanism involved needs to be investigated.

Yan et al. (1999) identified that fucoxanthin is the major antioxidant of *Hijikia fusiformis*. Although it has been previously reported that carotenoids such as zeaxanthin, β-carotene and lutein did not show DPPH scavenging activity, Yan et al. (1999) showed that fucoxanthin has a strong radical scavenging activity. The potential involvement of fucoxanthin in radical scavenging activity may correlate to the presence of unusual double allenic bonds at C-7' position (Yan et al., 1999). These findings were confirmed in a recent study by Sachindra et al. (2007) which isolated fucoxanthin from *Undaria pinnatifida* and prepared two fucoxanthin metabolites, fucoxanthinol and halocynthiaxanthin. The antioxidant activities of those three carotenoids were assessed by DPPH, hydroxyl radical scavenging activity and singlet oxygen quenching activity. The order of scavenging activity of each carotenoid followed a pattern of fucoxanthin > fucoxanthinol > halocynthiaxanthin (Sachindra et al., 2007). The major structural differences in these three carotenoids are the presence of an allenic bond in fucoxanthin and fucoxanthinol, suggesting that the allenic bond is responsible for the higher scavenging activity of fucoxanthin and fucoxanthinol. Chemical structures of fucoxanthin fucoxanthinol and halocynthiaxanthin are presented in Figure 2.

In addition, Sasaki et al. (2008) demonstrated that fucoxanthin when added to ground chicken meat at a content level of 200 mg/kg reduced the formation of secondary oxidation products including TBA reactive substances in the same level as α-tocopherol (Sasaki et al., 2008). Oral administration of fucoxanthin has been reported to improve plasma antioxidant status and meat color in broiler chicks (Sasaki et al., 2010). Moreover, fucoxanthin obtained from *Padina tetrastromatic* has shown higher potential to be used as antioxidant than β-carotene in modulating antioxidant enzyme in plasma and liver of retinol deficiency rat (Sangeetha et al., 2009). However, the exact mechanisms of action how fucoxanthin exerts antioxidative effect in rat induced by retinol deficiency are not yet completely understood. In addition, cytoprotective effect of fucoxanthin against ROS formation induced by H_2O_2 has been observed *in vitro* (Heo & Jeon, 2009). Several studies have indicated that the number of hydroxyl groups on the ring structure of fucoxanthin is correlated with the effects of ROS suppression.

Anti-Obesity Activity

Obesity is a medical condition in which excess body fat has accumulated to the extent that

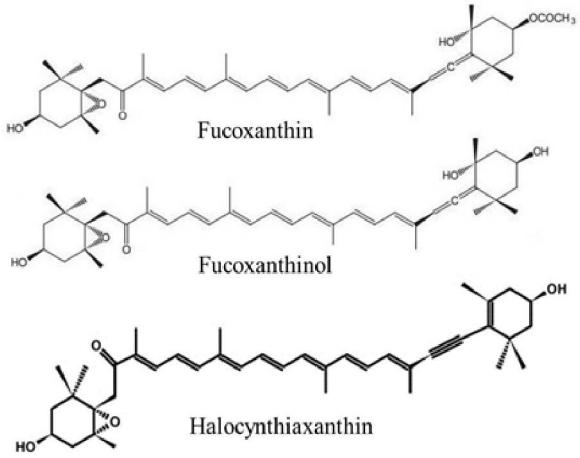

Figure 2. Chemical structures of fucoxanthin, fucoxanthinol and halocynthiaxanthin.

it may have an adverse effect on health, leading to reduced life expectancy and increased health problems. It is one of the greatest public health challenges in the first half of this century. A number of studies indicated that obesity is associated with type 2 diabetes mellitus, cardiovascular disease, certain forms of cancer and sleep-breathing disorder (Kopelman, 2000). Moreover, there was a dramatic increase in obesity in many industrialized and developing countries, which cause a worrying health trend (Kearney, 2010). Therefore, the necessity for discovering alternative sources of anti-obesity agents has been risen with interesting demand for safe and natural ones.

Excessive growths of adipose tissue in obesity are caused from adipocyte hypertrophy and the recruitment of new adipocytes from precursor cells. Therefore, regulation of adipogenesis appears to be a potential treatment for obesity. Fucoxanthin and fucoxanthinol isolated from *Undaria pinnatifida* have been reported to inhibit differentiation of 3T3-L1 preadipocytes into adipocytes (Hayato et al., 2006). The inhibitory effect of fucoxanthin and fucoxanthinol on adipocyte differentiation might be mediated through the down-regulation of adipogenic transcription factors, such as peroxisome proliferator-activated receptor-c. Structure suppressive effect on adipocyte differentiation has also been reported. Carotenoids with keto group, epoxy group, hydroxycarotenoid, epoxyhydroxycarotenoid and keto-hydroxycarotenoid did not show suppressive effect on adipocyte differentiation. Meanwhile treatment with fucoxanthin and neoxanthin showed significant suppressive effect suggesting that allenic bond is crucial factor for the anti-obesity effect. The result of Hayato *et al.* studies leads to the hypothesis that other carotenoid with an allenic group and additional hydroxyl group in the end may also effective in suppressing adipocyte differentiation.

Anti-Cancer Activity

Formation of cancer cells in human body can be directly induced by free radicals and natural anticancer drugs as chemopreventive agents have gained a positive popularity for cancer treatment. Hence, radical scavenging compounds such as natural pigments from marine algae can be used indirectly to reduce cancer formation in human body. Marine algal-derived pigments are known to be important free radical scavenger and antioxidants for the prevention of oxidative damage, which is an important contributor in carcinogenesis. During cancer multi-stage cascade, normal cells undergo initiation, promotion and progression processes. Most natural anticancer compounds are able to manipulate the growth of cancer cells with no or minor side effects. Therefore, identification of novel effective cancer chemopreventive agents has become an important worldwide strategy in cancer prevention.

Exciting research studies have been published regarding carotenoids and its anticancer qualities. Ishikawa et al. (2008) showed anti-adult T-cell leukemia effects of fucoxanthin and its deacetylated metabolite fucoxanthinol. The inhibitory activities of fucoxanthin and fucoxanthinol were stronger than those of β-carotene and astaxanthin (Ishikawa et al., 2008). A recent study from Japan demonstrates that anticancer activity of fucoxanthin goes way beyond its ability to induce apoptosis. Apoptosis inducing effect of fucoxanthin on human leukemia cells (HL-60) has also been reported (Kotake-Nara et al., 2005). The apoptosis induction was associated with activation of caspase-3, -8 and -9 which can be thought as central

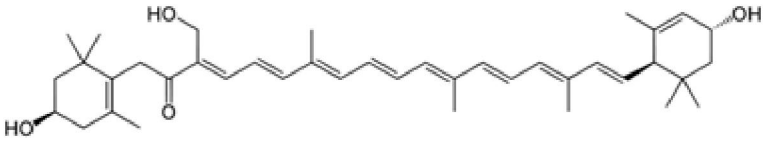

Figure 3. Chemical structure of siponaxanthin.

executioner of the apoptotic pathway. More recently, Ganesan et al. (2011) reported that siphonaxanthin (Figure 3) derived from *Codium fragile* is more potent growth-inhibitor against HL-60 cells than fucoxanthin. The structural differences between these two carotenoids are fucoxanthin contains epoxide and an allenic bond in its structure, whereas siphonaxanthin does not contain those functional groups. However, siphonaxanthin has an additional hydroxyl group on the 19th carbon atom. Since esterified form of siphonaxanthin showed lower inhibitory effect, suggesting that the presence of that hydroxyl group are contributed significantly to the inhibitory effect of siphonaxanthin (Ganesan et al., 2011).

Meanwhile, anti-proliferative effect and apoptosis induction by fucoxanthin in human colon cancer cells (Caco-2, HT-29 and DLD-1) have also been reported. Fucoxanthin remarkably reduced the viability of human colon cancer cell lines and treatment with fucoxanthin induced DNA fragmentation. Exposure to fucoxanthin decreased the level of apoptosis suppressing protein (Bcl-2), suggesting that anticancer mechanism of fucoxanthin was mediated through apoptosis mechanism (Hosokawa et al., 2004). Apoptosis inducing effect of fucoxanthin in human prostate cancer cells (PC-3, DU 145, and LNCaP) and human lung cancer cells (H1299) have also been observed (Kotake-Nara et al., 2005; Jaswir et al., 2011). Although current knowledge of relationship between the structure and apoptosis activity of fucoxanthin is limited, some researchers suggest that conjugated double bonds and 5,6-monoepoxide are thought to be highly susceptible to acids, alkali and oxygen lead to their prooxidant actions which might cause apoptosis induction in the several cancer cells. More recently, Januar et al. (2012) done *in silico* study of fucoxanthin as anti-tumor agents. They reported that the most probable fucoxanthin main mechanism in apoptosis is by binding with tubulin, which causes microtubules depolimerization and cell cycle arrest (Januar et al*.,* 2012).

Anti-Inflammatory Activity

Anti-inflammatory effect of natural pigments is mainly based on modulation of macrophages function. Macrophages are the resident of immune cells in the innate immune system which plays an important role in the maintenance of homeostasis by changing their function according to the tissue. As the residence of the immune system, macrophages are a predominant source of pro-inflammatory mediators including nitric oxide (NO), prostaglandin E_2 (PGE_2), pro-inflammatory cytokines [tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and interleukin-1β (IL-1β)] and ROS (Block et al., 2007). It has been consistently demonstrated that the origin of cancer was at sites of chronic inflammation, in part based on the hypothesis that some classes of irritants, together with the tissue injury and ensuing inflammation they cause, enhance proliferation. Chronic inflammation may also play significant role in mediating neurodegenerative diseases such as Parkinson's disease (PD), Alzheimer's disease (AD), multiple sclerosis (MS) and Acquired immune deficiency syndrome (AIDS) dementia complex (Cho et al., 2006). Secondary metabolites derived from marine algae are known to have promising anti-inflammatory activities. However, the scientific analysis of marine algae-derived natural pigments anti-inflammatory activity has been poorly carried out and until now only few studies were reported. For example, pheophytin a (Figure 4) isolated from *Epiactis prolifera* has been reported to suppressed 12-O-tetradecanoylphorbol-13-acetate (TPA)-induced superoxide radical and inflammatory responses in mouse macrophages (Okai & Okai, 1997).

Fucoxanthin is recently known to be potent anti-inflammatory agents *in vitro* and *in vivo* in responses to bacterial lipopolysaccharides (Torsdottir et al., 1991). Anti-inflammatory effect of fucoxanthin is comparable with predinisolone, a commercially available steroidal anti-inflammatory drug (Shiratori et al., 2005). Heo et al. (2010) screened inhibitory effect of NO production from nine species of brown algae and confirmed that inhibition of NO production were correlates with fucoxanthin contents. In addition, they also demonstrated anti-inflammatory effect of fucoxanthin isolated from *Myagropsis myagroides* in LPS-stimulated RAW264.7 cells. Fucoxanthin treatment were able to attenuates the productions of NO and PGE_2 by inhibiting inducible NO synthase and cyclooxigenase-2 expressions (Heo et al., 2010).

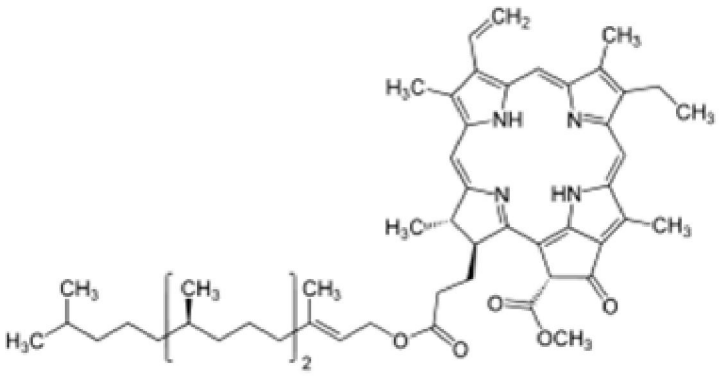

Figure 4. Chemical structure of pheophytin a.

Anti-inflammatory activities of fucoxanthin were mediated through the suppression of nuclear factor-κB (NF-κB) and the phosphorylation of mitogen activated protein kinases (MAPKs) (Pangestuti et al., 2013). Production of pro-inflammatory mediators has been continuously reported in many inflammatory tissues, along with increased expression of their mRNAs and proteins. Therefore, inhibition of pro-inflammatory mediators by marine-algal pigments suggests its potential for the treatment of inflammatory and other related diseases.

Neuroprotective activity

Neurodegenerative diseases are estimated to surpass cancer and be the second most common cause of death among elderly by 2040s (Pangestuti & Kim, 2011b). For this reason, neuroprotection has attracted a great deal of attention (Pangestuti & Kim, 2013). Neuroprotection may defined as mechanisms and strategies used in order to protect neuronal cells against injury, apoptosis, dysfunction and or degeneration in the central nervous system (CNS) by limiting neuronal dysfunction or death after CNS injury (Pangestuti et al., 2011). Many categories of natural and synthetic compounds have been reported to possess neuroprotective activities. However, these synthetic neuroprotective agents are believed to have certain side effects such as dry mouth, tiredness, drowsiness, sleepiness, anxiety or nervousness, and difficulty to balance. Several scientific studies have provided insight into neuroprotective properties of marine algal-derived natural pigments. Fucoxanthin isolated from *Hijikia fusiformis* were able to inhibited N-myc expression and cell cycle progression of GOT0 cells, a human neuroblastoma cell line (Okuzumi et al., 1990). At a concentration of 10 ìg/ml, fucoxanthin reduced the growth rate of GOT0 cells to 38%, but their exact mechanisms of action are not yet completely understood.

Ikeda et al. (2003) found that wakame was able to attenuate the development of hypertension and its related diseases in stroke-prone spontaneously hypertensive rats (SHRSP). Furthermore, they isolated fucoxanthin from wakame and showed that fucoxanthin attenuated cell damage in cortical neurons during hypoxia and oxygen reperfusion (Khodosevich & Monyer, 2010). Since ROS generation is considered to occur after hypoxia and re-oxygenation, whereby free radicals damage neurons, it may assume that neuroprotective activity of fucoxanthin mainly based on their scavenging activity. Neurite outgrowths are fundamental neuronal features which play an important role in neuronal development during embryogenesis and in the adult brain. Pheophytin a and its analog, vitamin B12 derived from *Sargassum fulvellum* has been reported to promoted neurite outgrowth in phaeochromocytoma (PC12) cells (Ina et al., 2007). Neurite outgrowth promoting activity of pheophytin a has been reported to be closely related to their low molecular weight. The rationale for this is low molecular weight pheophytin a may incorporate into the cells more efficiently and therefore promote neurite outgrowth effectively. Based on several findings it may conclude that natural pigments are valuable source of neuroprotective agents and could be introduced for the preparation of novel functional ingredients in functional foods and pharmaceuticals as a good approach for the treatment and or prevention of neurodegenerative disease.

PROBLEMS AND PROSPECTS IN DEVELOPING MARINE ALGAL-NATURAL PIGMENTS

Nowadays researchers pay a great attention in studying marine algal-derived natural pigments for human health and nutrition. However, development of marine algal-derived natural pigments as an alternative source for consumer's well-being, by being a part of food and pharmaceutical still faces several challenges.

Up to now, development of marine algal-derived natural pigments in food and pharmaceuticals is based on established observations and experiments *in vitro* or *in vivo* models; only few of marine algal-derived natural pigments effects have been examined in human subjects. Therefore, small clinical studies and further large-scale controlled studies are needed. It is also necessary to note that natural pigments have well-known disadvantages over the synthetic ones based on the low stability, and storage. Another important challenge in the development of marine algal-derived natural pigments in pharmaceuticals is that many drugs failed to provide real therapeutics in practice. Potential reasons for this failure include inappropriate use of specific phamaceutics for a given disease or stage of disease progression or the use of suboptimal dose. Hence, future studies are needed focusing on the synergistic benefits of marine algae consumption, recommended doses and timing of intake, and preparation methods for marine algal-derived natural pigments in order to maximize the desired protective effect in the prevention of diseases.

Conventional purification methods for natural pigments were silica gel chromatography. This method has advantages such as easy detection of the color of chlorophylls, carotenoids and simple scale-up. However, there are several disadvantages, such as the need for fresh brown alga tissues, large solvent volumes and time-consuming procedures, involving the discharge of potentially hazardous solvents to the environment and possibly damage the functional properties of the extracts by hydrothermal stress. Hence, novel extraction and separation techniques have recently been employed in the development of natural pigments derived from marine algae. Some of those methods are centrifugal partition chromatography, supercritical fluid extraction, and microwave-assisted extraction.

Centrifugal Partition Chromatography

Kim et al. (2011) introduced centrifugal Partition Chromatography using a two-phase solvent system made from a pair of mutually immiscible solvents: one used as the stationary phase and the other as mobile phase. As an example, for fucoxanthin purification, they used solvent partition method using a two-phase solvent system of *n*-hexane–ethyl acetate–ethanol–water (5:5:7:3, v/v/v/v). High-purity fucoxanthin were successfully isolated by this method (Kim et al., 2011).

Supercritical Fluid Extraction

Supercritical fluid extraction is an alternative separation technology. Supercritical fluid extraction is more selective for carotenes than the usual organic liquid extraction and it is preferred for handling temperature-sensitive molecules such as natural pigments. Purification of carotenoids from brown algae (*Undaria pinnatifida*) by using supercritical carbon dioxide (SCO_2) has been reported by Roh et al. (2008). They used ethanol as co-solvent with flow rate of 3.0% (v/v) as compared to SCO_2. They performed experiments in a semi-batch flow apparatus on dried samples at temperatures from 303 to 333 K and pressures from 80 to 300 bar. The brown algae yielded more carotenoids oil at higher pressure, suggesting that pressure is an important factor to extract carotenoids based on SCO_2 (Roh et al., 2008).

Microwave-Assisted Extraction

Recent research into the recovery of bioactive compounds from algae using microwave-assisted extraction techniques has reported improved yields of fucoxanthin in comparison to conventional methods. Microwave-assisted extraction is an efficient sample preparation method, which takes the advantage of microwave irradiation achieving drastically accelerated removal of a variety of compounds from solid matrices. It shows higher or equal extraction efficiencies as compared with traditional solvent extractions while allowing great reduction in time and solvent consumption. Microwave-assisted extraction is becoming a simple, economical, and proper alternative technique for extraction of natural products from brown algae (Xiao et al., 2012).

In the beginning of 2011, Indonesia produced 3 million tons of marine algae and by 2015; Indonesia hopes to replace Philippines as major marine algae producer with 10 million tons of production. However, majority of marine algae productions in Indonesia are dominated by red algae with *Eucheuma* and *Gracilaria* as the main species. Meanwhile, brown algae are still identified as under-exploited resources. Until now, coastal communities and fishermen did not realize and explore the potency of brown algae. In Indonesia, most of brown algae production is from the wild harvest. Therefore, brown algae species that has the potential to be cultured and developed for food and pharmaceutical industries need to be more explored by relevant stakeholders (i.e. policy makers, industry investors and regional and primary production communities). Moreover, strategic investment in research and development in this field, as well as capacity building for the necessary skills in brown algal-derived natural pigments industry are urgently needed. Further, brown algae either as raw materials for pigment extraction or natural pigments commodity could help to develop the blue economy concept which

supports sustainable development of Indonesia's maritime sector.

CONCLUSIONS

Marine brown algae is an alternative source for synthetic ingredients that can contribute to consumer's well-being, by being a part of new functional foods and pharmaceuticals. Strategic investment in research and development in this field, as well as capacity building for the necessary skills in brown algal-derived natural pigments industry are urgently needed. Furthermore, marine brown algae exploration could help to develop the blue economy concept which supports sustainable development of Indonesia's maritime sector.

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