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Marine brown algae: A conundrum answer for sustainable biofuels production

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ABSTRACT

Meeting renewable fuels goals requires development of a large sustainable biomass resources, massive brown algae could be a potential contributor towards this goal. To date, very little information has been known for brown algal resource. This review provides overall perspective on feature and applications required for an initial assessment of the development of brown algae as a sustainable biofuels resource. The contribution presents fundamental theme of brown algae and its various applications for biofuels production. Although brown algae present one of the best available options as a sustainable biomass, the drawbacks to the economically viable production of biofuels must be solved. One of the most economic approaches for biofuels production may be the combined producing bio-active materials where multiple biofuels are produced from one biomass resource. The integrated biorefinery platform could be proposed to accomplish the biofuels of brown algae more profitable in the near future.

Contents

1. Introduction

Global climate change and energy security have been driving the seeking for environmentally sustainable, economically viable, and nonfossil energy resources. Terrestrial plants and marine algae have regarded as potential contributors towards the energy goals coupled with the realization of carbon dioxide reduction. They survive through the process of photosynthesis to convert solar energy into the chemical energy that is stored as biomass [1,2]. Under normal conditions, marine algae use solar energy and fix

Abbreviations: M, mannuronic acid; G, guluronic acid; DEHU, 4-deoxy-L-erythro-5-hexoseulose uronate; AD, anaerobic digestion; VS, volatile solid; HTL, hydrothermal liquefaction; VFA, volatile fatty acid; DOE, department of energy; EG, ethylene glycol

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carbon dioxide from the atmosphere for assimilation in the mainly form of carbohydrates and lipids, which can be exploited for biofuels production [3,4].

Marine algae (e.g., macroalgae and microalgae) include a wide variety of photosynthetic organisms living in many diverse environments and present in all existing ecosystems on earth [3]. They have been widely regarded as well-being foods, bio-active resources, and animal feeds or fertilizer [5] in human life. Meeting renewable energy goals requires development of a large sustainable resources, attention is focusing to the use of marine algae to supplement terrestrial plants with many advantages for renewable energy applications; their growth rate with high productivity, high photosynthetic efficiency, great potential for carbon dioxide fixation [3], low percentage of lignin, and high content in carbohydrates [4,6] which could be converted to various liquid and gas fuels.

Macroalgae, commonly referred to as seaweeds, are classified as green-, red-, and brown-algae evolutionarily diverse and abundant in the world's oceans and coastal waters. Brown algae are usually large macroalgae and have relatively high photon conversion efficiency which can thus rapidly synthesize biomass through assimilating abundant resources in nature. Since the areal productivity of brown algae is significantly higher than those green- or red-algae, brown algae are having a great attention to develop the sustainable biofuels production.

To date, a few reviews have been devoted to the topics on the potentials of macroalgae as a feedstock for biofuels production [4,6]. Although early effort established the feasibility of liquid biofuels (e.g., bioethanol, bio-oils, and volatile fatty acids) from brown algae has been tried [2,7,8], very little information has been focused on the sole brown algae with overall progress and economically viable strategy for development of a sustainable biofuels resource. Therefore, this review provides overall perspective on features and applications needed for an initial assessment of the development of brown algae as sustainable biofuels resources. Also, the future solution to overcome the drawbacks of the economically viable biofuels production from brown algae would be discussed.

2. Fundamental theme of brown algae

Brown algae or brown seaweeds represent a diverse group of eukaryotic, photosynthetic marine organisms distinguished most prominently by having chloroplasts surrounded by four membranes, suggesting an origin from a symbiotic relationship between a basal eukaryote and another eukaryotic organism [9]. Morphologically, brown algae are comprised of a long blade or lamina, the stipe, and holdfast for anchoring the entire structure to hard substrates in marine environment [10]. Most brown algae contain the pigment fucoxanthin, which is responsible for the distinctive greenish-brown color. The organisms absorb medium wavelength green light which enables them to live event at 30–50 m depths of nearshore coastal waters with suitable substrate for attachment. The basal metabolism of a prototypic brown alga to project the maximum energy yield of a culture given the incident solar energy is equipped with crassulacean acid metabolism (CAM) using light-independent carbon fixation (LICF) [11]. Since CAM plants minimize photorespiration, LICF could be regarded a compensating mechanism necessary to keep physiological performance of brown algae during severs photodamage and water-shortage environments [12]. The rates of LICF in brown algae shows a tendency of higher values (up to 9.6 μmol ^{14}C g^{-1} FW h^{-1}) than terrestrial plants, accounting for up to 48% of the photosynthetic fixation [13]. These pre-existing results suggest that the maximum energy yield of brown algae ($>45\%$) over a growing season can be greater than those of most terrestrial plants (e.g., 30–35% for energy crops and 20–25% for lignocellulosic biomass) as a result of their high biomass productivity [14]. The photosynthates (carbon-containing products of photosynthesis) of brown algae would not be glucose and starch as general plants, but rather glucose and mannitol are polymerized together as laminarin [9]. Also, alginate is major structural polysaccharide in the cell wall of brown algae with fucoidan and cellulose instead of lignin and cellulose as terrestrial plants [15]. These unique carbohydrates of brown algae vary according to mainly species, location, salinity and season.

Brown algae place in the division *Heterokontophyta* under phylum *Ochrophyla* with class *Phaeophyceae* [10] divided in 19 orders, 265 genera, and over 1800 species [16–18]. The representative "Kelps" are large brown algae in the order *Saccharina* with 30 different genera [16–18]. Naturally, brown algae are abundant in nearshore coastal waters with suitable substrate for attachment with in low temperatures between 6 and 14 °C (43 and 67 °F) [9]. Since immersed in water, brown algae acquire nutrients from photosynthesis and by absorbing dissolved nutrient from the surrounding water [10], they can save energy for having a high productivity. The productivity of uncultured large brown algae (e.g., *Saccharina*, *Undaria*, *Sargassum*, and *Ecklonia*) has been reported in the wide range of 3.3 to 11.3 t dry wt/ha/y114r in the nearshore farms [18,19].

Although these values indicate the high growth rate of brown algae however higher areal productivity would be required from the advanced techniques of cultivation to supply sustainable biomass as a biofuels feedstock. The potential to increase the available brown algal biomass through selective breeding programs and the fact the yields can be greatly enhanced by providing the optimum nutrients in the growing regions. For example, *Saccharina japonica* has been cultured at 25 t dry wt/ha/yr in China and at 31 t dry wt/ha/yr in Japan under experimental conditions [20,21]. There has also been significant technology transfer and macroalgal cultivation is now well tried and tested in Europe. *Saccharina latissima* has been cultivated at 15 t dry wt/ha/yr in Scotland [20,21]. The results indicate that the selections of the species and site are corresponded to the improvement of areal productivity of brown algae.

3. Biomass production of brown algae as a biofuels feedstock

Brown algae are extensively farmed in East-North Asia (e.g., China, Japan, and Korea; monsoon climate) for a commercial market as both food products and for their biochemical constituents [21]. At present, aquatic cultured production of brown algae has focused mainly on the genus *Saccharina* and *Undaria* which represented 32.6 and 9.8% of world macroalgae production (15.8 million wet tones), respectively [6,22]. The genus *Saccharina* representing the common name "Kelp or Giant Kelp" is economically important to be characterized by long, leathery laminae and relatively large size (may reach lengths of 80 m and grown as much as 50 cm/day) [3]. The greater proportion of commercial cultivation is for alginate, iodine, and mannitol, which are used in a range of industrial applications in commercial markets of foods or feedstock for polysaccharide and hydrocolloid extraction [23]. The genus *Undaria* also has economic market benefits as a food crop and medical nutrients (e.g., high levels of essential minerals, eicosapentaenoic acid as an omega-3 fatty acids, and fucoxanthin) [24]. These two genera have widely cultivated in the eastern north Asia which contributed over 90% of the worldwide production [6,22]. Currently, attention is turning to the use of marine biomass to supplement biofuels feedstock therefore brown algae are under the consideration as a candidate biomass resource.