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Potential of Microalgae for Biofuel and Food Production

Tan Yeong Hwang[1*], Chai Mee Kin[1], Wong Ling Shing[2]

[1]Institute of Sustainable Energy, Universiti Tenaga Nasional, Jalan Ikram-Uniten, 43000 Kajang, Selangor, Malaysia
[2]Faculty of Health and Life Science, INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia

[*]**Email**: yeonghwang_113@hotmail.com

Abstract

With the continuous increase of global population, energy and hunger are the critical crisis that humankind facing in this century. Microalgae has been proposed as the solution due to the presence of the various metabolite and their attractive features. This review summaries the potential of microalgae as the feedstock for biofuel and food production. The literature indicated that the abundance of suitable fatty acid in microalgae can be used for biodiesel production while other bio-components such as carbohydrate can be used for biogas and bioethanol production. Apart from biofuel production, presence of high-quality protein, fatty acid, polysaccharides, vitamin, minerals and other bio-components with benefit biological properties in microalgae spur it as dedicated candidates for food production. However, the microalgae derived biofuel and food are still not available at the moment. The challenges that might need to be confront prior to industrial production are also briefly discussed in this review.

Keywords

Microalgae, biofuel, food, hunger

Introduction

Overwhelming consumption of fossil fuels in the past few decades to satisfy the global energy demand and increased industrialization lead to imminent depletion of fossil fuel and hastening of climate change. While fossil fuels are formed naturally, it requires millions of years to replenish (Höök & Tang, 2013). With the rapid industrial and new growing economies such as China, India, and South East Asia, the global energy demand is estimated to continuously grow annually (BP, 2021). However, current energy production which mainly using fossil fuel will intensify greenhouse gas emission. Meanwhile, the volatility of global fossil fuels price is another energy crisis that derived from complicated factors such as pandemics, disasters and conflicts. The hiking of energy costs causes a rising of electric bill which in turn resulted in catastrophic setback to the economy of the energy-importing countries. Hence, exploring clean and renewable energy

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resources are of great importance to reduce the dependence on the fossil fuel and their impact on environment.

Besides energy crisis, hunger is another greatest issue that humankind facing in this century. In 2019, approximate 8.4% of global population have not access enough food to eat. The Covid-19 pandemic in 2020 worsen global food supply, with estimation of approximate 9.9% (700 million) of people suffering hunger problems (FAO, IFAD, UNICEF, et al., 2021). This issue will be exacerbated as it is estimated that the world population will have surged to 9 billion by 2050 along with increasing food demand. In the last few decades, agricultural land has been expanded from natural habitat and occupy more than one-third of earth surface (Benton, Bieg, Harwatt, Pudassaini, & Wellesley, 2021). Intensive agricultural activities especially expansion cropland is considered as a primary factor of deforestation, biodiversity loss and soil degradation (Benton et al., 2021; FAO, 2021; IPBES, 2018). The agriculture development is also contributed global greenhouse gases emission (Bennetzen, Smith, & Porter, 2016) and accelerate scarcity of water supply (FAO, 2021). In addition, overfishing also render dramatic change to natural ecosystem and biodiversity of ocean (Sumaila & Tai, 2020). Thus, the agriculture sector need transformation to increase food production without further taxing our Mother Nature.

Microalgae is a microscopic organism that live in diverse ecological habitats with a range of growth environment. In the last decade, numerous research proposed that microalgae have the potential as sustainable biomass resources for biofuel and food production because of their attractive features. In comparison to plant, microalgae can produce high biomass per unit of area in a few weeks. Microalgae able to utilize carbon dioxide effectively to produce various valuable metabolites through photosynthesis in non-arable land. Nevertheless, strenuous efforts are still required to push forward microalgae into mainstream production. This review discusses the potential of microalgae for biofuel and food production and the challenges that might need to be confront prior to industrial production.

Potential of microalgae for biofuel

At current age, microalgae biomass which categorized as third-generation biofuel have obtained noteworthy attention due to its attractive advantages compare to first- and second-generation biofuel. Generally, first- and second-generation biofuel which utilizing edible crop and lignocellulosic crops respectively as resources are cultivated in monoculture on a large scale. Edible and lignocellulose crops usually required several months to years to mature and to be harvested (Ferdous Alam, Er, et. al., 2015; Purcell & Ashlock, 2014), high amount of freshwater, herbicide and pesticide are required to sustain their growth. As a result, a serious debate regarding impact of first- and second-generation on food security, biodiversity loss and freshwater scarcity have been raised.

In comparison to first- and second-generation biofuel, microalgae can yield higher oil yield in significant smaller area (Table 1). Besides that, microalgae grow extremely fast and can be harvested within several weeks (Narala et al., 2016). During growing period, microalgal photosynthetic rate and carbon fixation rate are demonstrated to be higher than agricultural stock (Singh & Ahluwalia, 2013). Microalgae such as *Desmodesmus* sp. and *Chlorella* sp. can flourish in the environment rich with carbon dioxide or flue gas (Swarnalatha, Hegde, Chauhan, et al., 2015; Zhao, Su, Zhang, et. al., 2015). Hence, microalgae can also be used as a tool to sequester atmosphere carbon dioxide in tandem cultivating for biofuel production. Moreover, not all countries have ideal environment to grow agricultural feedstock for biofuel. In contrast, microalgae can be found in various habitat worldwide and tolerate different growing conditions therefore it is possible to explore the specific microalgae in local and develop biofuel production in the countries that difficult to grow agricultural feedstock for biofuels.

Table 1. Land requirement comparison on biodiesel feedstocks (Gouveia et al., 2017).

Feedstock	Oil content (%weight of biomass)	Oil yield (L/ha/year)	Biodiesel productivity (kg/ha/year)	Amount land required (m^2 year kg^{-1} biodiesel)
Soybean	15-20	56-636	47-566	18-214
Rapeseed	40-48	538-974	450-862	12-22
Jatropha	28-40	741-2151	656-1800	6-15
Palm oil	22-50	3226-6000	2700-5400	2-4
Microalgae	30	58700	51927	0.2
Microalgae	50	97800	86515	0.1
Microalgae	70	136900	121104	0.1

There is various research cultivating microalgae biomass for biodiesel production as most microalgae can accumulate high lipid content with the fatty acid profile that similar to agricultural feedstock for biodiesel (Idris et al., 2017; Menezes et al., 2016). The lipid yield and fatty acid profile are vary depending on the microalgae species (Azeez et al., 2021) and growth conditions (Mandotra, Kumar, Suseela et al., 2016). For instance, studying twelve freshwater microalgae species isolated from fish pond, Azeez et al. (2021) reported that lipid content in *Scenedesmus* sp and *Pediastrum* sp were 51.43% and 47.35% respectively which much higher than lipid content in *Ankistrodesmus* sp and *Microcystis* sp. with 11.32% and 14.93% respectively. Other microalgae species such as *Chlorella*, *Neochloris* and *Nannochloris* are also confirmed to have high lipid content with more than 30% of its dry weight (Abreu, Fernandes, Vicente, et. al., 2012; Ashour, Elshobary, El-Shenody, et al., 2019; Rodríguez-Palacio et al., 2022). Despite emphasizing the high lipid production in microalgal lipids for biodiesel, ensuring the properties of fatty acids in microalgal lipid meet biodiesel standard is also of great importance. The studies showed that under certain growth conditions, the physical properties of fatty acid produced by microalgae including *Chlorella sorokiniana*, *Chlorococcum oleofaciens*, *Chlorella minutissima* and *Nannochloris atomus* abide the biodiesel standard EN14214 and ASTM D6751 (Arora, Patel, Pruthi, et al., 2018; Bounnit et al., 2020; Qiu, Gao, Lopez, et al., 2017; Rayati, Islami, & Mehrgan, 2020).

Besides of lipids, microalgae also contain carbohydrates and protein which can be used as substrate for anaerobic digestion to produce biogas such as methane and hydrogen. In comparison to most terrestrial plant substrate, microalgae almost do not have recalcitrant lignin and cellulose, therefore microalgae biomass is more efficient in biogas production (Dębowski, Zieliński, Kisielewska, et al., 2017). Choosing suitable microalgae species is important to produce high quality and quantity of biogas (Debowski et al., 2020; Torres, Padrino, Brito, et al., 2021). For instance, 587 ml g VS^{-1} of biogas was produced using *Chlamydomonas reinhardtii* biomass whereas 287 ml g VS^{-1} of biogas was produced using *Scenedesmus obliquus* biomass under same conditions (Mussgnug, Klassen, Schlüter, et al., 2010). The composition and cell wall structure of microalgae is varied among the species, the species with high amount of composition and easily-biodegradable cell wall can be degraded effectively by microorganisms during fermentation thereby produce accentuated amount of biogas (Mussgnug et al., 2010). Pretreatment such as ultrasonic, alkaline digestion, enzymatic and ozonation have been applied to microalgae with recalcitrant cell wall in previous studies to enhance the biogas production (Córdova, Chamy, Guerrero, et al., 2018; Panyaping, Khiewwijit, & Wongpankamol, 2018; Saleem et al., 2020). However, some preatreaments are expensive and might not suitable for large-scale production.

Potential of microalgae as food

Microalgae are considered as potential candidates for food because of their aptitude to produce various types of compounds such as protein, lipid, carbohydrates and carotenoid that benefit to human health. Among the microalgae, *Chlorella* and *Spirulina* are the dominating microalgae genus that currently marketed as health food for human due to their rich nutritional value. (Raja et al., 2018).

Protein is one of the essential elements in human daily diet. Amino acids are the building block of the protein and can be categorized as essential and non-essential amino acid. Essential amino acids cannot be synthesized by human body whilst non-essential amino acid can be synthesized by human body (Kumar et al., 2019). These amino acids especially essential amino acid must be obtained from plant or animal. However, with continuous increase of food demand and negative impacts of current agricultural production to environment, alternative protein source with low cost is needed. In this scenario, several microalgae species have been reported to have high percentage of proteins compared to animal and plant. Moreover, in comparison to plant and egg, some of microalgae have higher quantities of essential amino acids (Christaki, Florou-Paneri, & Bonos, 2011). For instance, *Heterocapsa rotundata*, *Ansanella granifera*, *Alexandrium andersonii* have essential amino acid index (EAAI) that higher than EAAI of protein in egg (Lim, Jeong, Kim, & Ok, 2018). In another studies conducted by Siahbalaei, Kavoosi and Noroozi (2021), protein produced by *C. vulgaris*, *S. obliqus*, *Chlamydomonas reinhardtii*, *Haematococcus pluvialis*, *Monoraphidium dybowskii*, and *Parachlorella kessleri* were analyzed. The result indicated that these microalgae not only have all essential amino acid, the quantities of protein in these microalgae raw materials is also higher than the protein in eggs. Therefore, consuming lower amount of microalgae raw materials can provide sufficient essential amino acid for adults. It is notably to mention that these microalgae also produced other amino acids that have anti-diabetic functional properties.

Initially, microalgal fatty acid are studied for the biodiesel production. Nevertheless, numerous research indicated microalgal fatty acid have high nutritional value. The accumulation of lipid content in microalgae occurs in range between 5% to 60% of dry biomass (Sajjadi, Chen, Raman, et al., 2018). Different microalgae species and growing conditions such as nutrient availability, pH, light, salinity and temperature greatly influence types and amount lipid production (Morales, Aflalo, & Bernard, 2021). Generally, microalgae can produce a wide range of lipid and lipid-like compounds. Among these lipids, polyunsaturated fatty acid especially α-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have gained the attention for nutraceutical application. EPA and DHA are important nutrients for humans because they cannot be synthesized by human cell but they play a vital role in neurological development and prevention of chronic diseases (Barta, Coman, & Vodnar, 2021). Marine products especially marine fish oil is main dietary supply of EPA and DHA, however, current fisheries and aquaculture could not meet the global demand (Barta et al., 2021). Several microalgae taxa such as Dinophytes, Haptophytes, some Cryptophytes, Thraustochytrids, or Euglenoids are known to produce high amount of DHA whereas diatoms, Eustigmatophyte and some Haptophytes are known to synthesize high amount of EPA (Remize, Brunel, Silva, et al., 2021). Moreover, EPA and DHA from microalgae have low health risks. The research indicated that fewer or no contaminants in microalgae are detected compared to fish oil because fish are end consumer and the toxins are bioaccumulated through food web (Santigosa, Brambilla, & Milanese, 2021). In other studies conducted by Hossain et al. (2022), high DHA algae meal diet and fish oil diets could induce significant increase of immune gene expression for interleukin and superoxide dismutase in sobaity (*Sparidentex hasta*) but former diet more cost effective and provide additional nutrient such as antioxidant.

Carbohydrates are another macromolecule in microalgae which serve as structural component of cell wall and energy storage. Some microalgae such as *Dunaliella tertiolecta* are rich in carbohydrate and can accumulate up to 30-50% of its dry weight (Rizwan, Mujtaba, & Lee, 2017). The amount and composition of carbohydrate are varied with species and cultivation conditions. A large diversity of monosaccharides such as xylose, glucose, mannose and their polymers can be constituents of carbohydrates (Bernaerts et al., 2018). Numerous studies showed that microalgal polysaccharides have bioactive properties such as immunomodulatory, antiviral, antitumor, and antimicrobial activities (Casas-Arrojo, Decara, Arrojo-Agudo, et al., 2021; Hafsa et al., 2017; Yang, Wan, Wang, et al., 2019; Zhang, Liu, Ren, et al., 2019). However, the research related to suitability of microalgal carbohydrates as animal feed and human food are still insufficient.

Apart from macromolecules, microalgae also produce micronutrient including pigment, phenol, flavonoid, vitamin and minerals that have benefit effect to human health (Santhakumaran, Ayyappan, & Ray, 2020). Microalgal pigments such as astaxanthin and β-carotene showed strong antioxidant properties which prompt them as a potential candidate in pharmaceutical industry (Mulders, Lamers, Martens, et al., 2014; Stramarkou, Papadaki, Kyriakopoulou, et al., 2016). The elemental composition analysis on conducted by Lena et al. (2020) and Santhakumaran et al. (2020) showed that microalgae are good sources of minerals. Other studies also confirmed that microalgae such as *Chlorella*, *Spirulina* and *Nannochloropsis* are good sources of vitamin (Fabregas & Herrero, 1990; Ljubic, Jacobsen, Holdt, et al., 2020; Tarento et al., 2018). It is noteworthy to mention that some vitamin especially vitamin B complex cannot be synthesized from plant, therefore animal is main source for vitamin B complex. Recently, the study carried out by Edelmann et al. (2019) confirmed that *Chlorella* powder is excellent source for vitamin B complex.

Challenges and perspectives

Although the commercial potential of microalgae is well-established, the large-scale microalgae biomass production is pertaining not economically or commercially available due to the high cost of cultivation. Hence, wastewater is suggested to replace standard medium (Hernández-García et al., 2019). Considering nutrients in wastewater are always fluctuated, the microalgae cultivation with wastewater should be conducted in different concentration range of wastewater and their effects on target metabolite production should also be scrutinized. Using wastewater to cultivating microalgae for purpose of food production is remain contentious due to the presence of toxins and heavy metals (Oyebamiji, Boeing, Holguin, et al., 2019). It is also important to ensure these microalgae cultivated with wastewater are not contaminated and safe to be consumed by animal or human.

Many consumers have conservative food habits and introduction of microalgae as alternative food might not be accepted by some of them. Hence, the study of public perception on using microalgae as food and benefit of microalgae consumption is imperative to be carried out to understand the consumer perception and increase the awareness of consumer on microalgae. To increase the consumer confidence on microalgae production as food, the method of adding microalgae into existing food such as soup, noodle and bread should be developed. In this development. the effect of adding microalgae on nutritional content, sensorial and culinary properties of the food should be investigated. Besides that, the bioaccessibility and biodigestibility of nutrient from microalgae *in vitro* and *in vivo* should also be conducted (Lafarga et al., 2019; Uribe-Wandurraga, Igual, García-Segovia, et al., 2020).

Genetic engineering is a method of modifying specific genes related to target metabolism to enhance synthesis, storage and structural contents of target metabolite inside the microalgae cell. It has been proposed to improve the target metabolite productivity and economic feasibility of microalgae biomass production (Shokravi et al., 2021). The biofuel that using genetic modified microalgae are classified as fourth-generation biofuel. Although the studies have demonstrated the genetic engineering is a promising strategy to exhibit the increase of the target metabolite production, various opinions are raised on the safe utilization of genetic modified organisms. Moreover, some countries strictly regulate or prohibit genetic modified organisms for commercial purpose (Sreenikethanam, Raj, J, et al., 2022). Therefore, it is of great importance to evaluate the risks possessed by genetic modified microalgae to nature and human. Despite of focusing on modifying genetics of microalgae known genome sequence, the genomics, metabolomics and proteomics of many potential microalgae species for biofuel and food production still underexplored and yet to be studied (Kumar et al., 2020). Understanding of microalgae genomics, metabolomics and proteomics probably can provide the insight of improving target metabolite production without genetic modification.

Conclusion

As microalgae are able to synthesize various metabolites and offer many advantages over plant and animal, microalgae derived biofuel and food production possess a great potential to confront energy and hunger issues. The abundance of suitable fatty acid in microalgae can be used for biodiesel production while other bio-components such as carbohydrate can be used for biogas and bioethanol production. Apart from biofuel production, presence of high-quality protein, fatty acid, polysaccharides, vitamin, minerals and other bio-components with benefit biological properties in microalgae spur it as a dedicated candidate for food production. However, the microalgae derived biofuel and food still not available at the moment due to high cost of cultivation. Understanding microalgae metabolism and increase public perception are other hindrances that should be cleared up in the future. Once these hurdles are settled, large-scale production of microalgae biomass will not only tackle the environmental issue, but also global energy and hunger issue.

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