Renewable and Sustainable Energy Reviews 94 (2018) 49–68

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Production of biofuels from microalgae - A review on cultivation, harvesting, lipid extraction, and numerous applications of microalgae

Manoj Kumar Enamala[a], Swapnika Enamala[b], Murthy Chavali[c], Jagadish Donepudi[d], Rajasri Yadavalli[e], Bhulakshmi Kolapalli[a], Tirumala Vasu Aradhyula[f], Jeevitha Velpuri[g], Chandrasekhar Kuppam[h,*]

[a] Acharya Nagarjuna University, Guntur, Andhra Pradesh, India
[b] GSL Medical College, Rajahmundry, Andhra Pradesh, India
[c] MCETRC, 20-26-136, Chiravuru, Tenali, 522201 Guntur, Andhra Pradesh, India
[d] Mechanical Engineering Department, Narasaraopeta Engineering College, Narasaraopet, Guntur, Andhra Pradesh, India
[e] Sreenidhi Institute of Science and Technology, Yamnampet, Ghatkesar, Telangana, India
[f] Department of Mechanical Engineering, National Chung Cheng University, Taiwan
[g] Environmental Science and Technology, JNTUH, Hyderabad, Telangana, India
[h] Green Processing, Bioremediation and Alternative Energies Research Group, Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam

ARTICLE INFO

Keywords:
Bioenergy
Algae biomass
Harvesting procedures
Lipid
Biodiesel
Third generation biofuel

ABSTRACT

The concern regarding alternate sources of energy is mounting day-by-day due to the effect of pollution that is damaging the environment. Algae are a diverse group of aquatic organisms have an efficiency and ability in mitigating carbon dioxide emissions and produce oil with a high productivity which has a lot of potential applications in producing biofuel, otherwise known as the third-generation biofuel. These third generation biofuels are the best alternative to the present situation since they have the perspective to eliminate most of the ecological problems created by the use of conventional fossil fuels. These organisms are responsible for closely 50% of the photosynthesis process taking place on the planet and are distributed predominantly in many of the aquatic systems. The huge interest in utilizing these organisms as a potential source of energy lies in converting the primary as well as secondary metabolites into useful products. Algae are considered to be the most prominent resource for the upcoming generations as the most suitable and sustainable feedstock. The key process limitations in microalgal biofuel production are inexpensive and effective harvesting of biomass and extraction of lipids. The major objective of this article is to provide a comprehensive review on various methods of both biomass harvesting and lipid extraction from microalgae available, so far, besides to discuss their advantages and disadvantages. This article also deals with various conditions that are favourable for lipid accumulation as well as the yield from different species.

1. Introduction

The energy crisis is increasing globally due to the heavy industrial development and exponentially growing population. Sources like petrol, diesel, natural gas, coal which were considered to be the basic sources for fuelling the life are getting exhausted due to extensive usage [1,2]. Moreover, these fossil fuels release a lot of toxic and harmful gases into the atmosphere and pollute the environment which is the major disadvantage [3,4]. The greenhouse gas (GHG) levels in the environment have increased at an alarming rate in the post-industrialization era by 25% of the total [5]. Natural causes, as well as human activities, have been mentioned as the major causes of this rise in temperature leading to global warming [1]. The major contributors include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other fluoro-hydrocarbons. Among them, the major pollutant which damages the environment is CO_2 [1,6]. The above-mentioned gasses are

Abbreviations: GHG, Greenhouse gas; N_2O, Nitrous oxide; TCA, Tricarboxylic acid; ETC, Electron transport chain; ATP, Adenosine triphosphate; Glu-6-P, Glucose-6-phosphate; PPP, Pentose phosphate pathway; NH_4^+, Ammonium; NH_3, Ammonia; O-U, Ornithine-urea; WC, Water column; WB, Water bodies; $NaSO_4$, Sodium sulphate; DIC, Dissolved inorganic carbon; $FeCl_3$, Ferric chloride; Fe_2SO_{43}, Ferric sulphate; $CaOH_2$, Calcium hydroxide; $MgOH_2$, Magnesium hydroxide; R-NH_2, Amine groups; Al_2SO_{43}, Aluminium sulphate; bio-CH_4, Bio-methane; bio-H_2, Biohydrogen; FA, Fatty acids

* Corresponding author.
E-mail address: chandrasekhar.kuppam@tdt.edu.vn (C. Kuppam).

https://doi.org/10.1016/j.rser.2018.05.012
Received 9 May 2017; Received in revised form 12 May 2018; Accepted 13 May 2018
1364-0321/

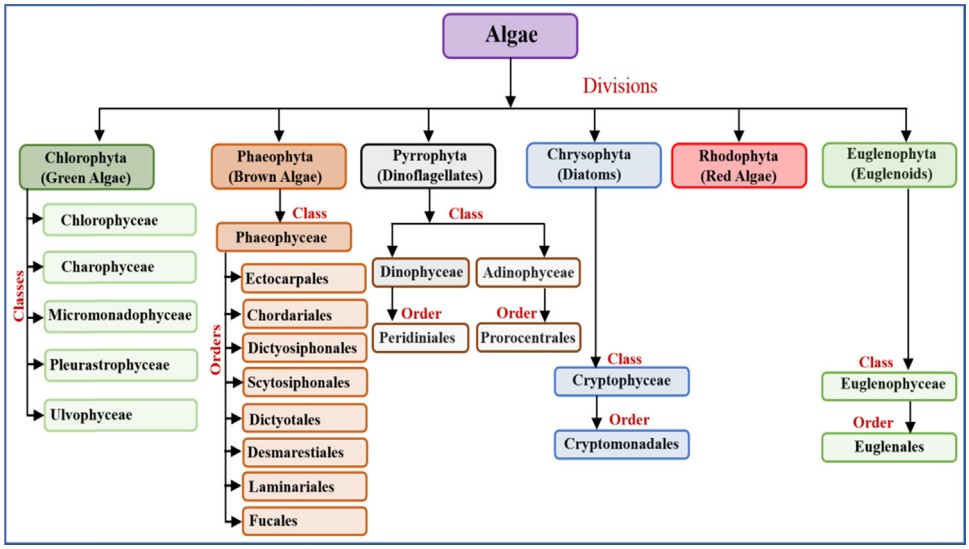

Fig. 1. Classification of algae explained in a simple way.

present in the atmosphere at a normal rate but due to the emissions from the vehicles, their concentration has increased over the past few decades [7]. Owing to all this, there has been a change in climatic conditions over the globe, which has become a topic of debate [8]. At this time, replacing fossil fuels with other alternative sources especially those that benefit the environment is the best solution [1,4]. These microalgae sources act as solar driven energy cell factories and are capable of converting CO_2 to oxygen (O_2) and thus reducing the toxic substances and chemicals in the environment. Hence these organisms are very promising in this aspect [9].

The working machinery of these organisms is the same as that of the plants, as both are photosynthetic. These utilize the sunlight from the atmosphere for the photosynthesis process and other essential nutrients from the surroundings for their growth [10]. There are also many food crops available which are used for the production of fuel apart from algae. Much of the study is being carried out on industrial production of biodiesel from plant sources. Apart from soya bean oil, jatropha, left-over cooking oil, canola, corn, and animal fats etc., are also being tried as fuel sources [11]. However, these sources must also meet the requirement for the food for human beings. Upon extensive usage of these sources for oil production, there may arise a scarcity in providing food for human beings [11]. Production of biofuels from the plant sources was criticized by many scientific communities as well as local farmers and the general public since the growth of these plants needs an extensive usage of land, leading to a crisis in food grain production.

The biofuels are divided into three generations depending on the source from which they are obtained [12].

- First generation biofuels derived from plant sources.
- Second generation biofuels derived from agricultural wastes, lumber wastes etc.
- Third generation biofuels derived from microalgae.

Researchers have turned their interest towards fuel production from one of the oldest living creatures on the earth, microalgae. These are utilized not only in producing fuels but also in capturing the CO_2 from the atmosphere which helps in cleaning the environment and producing better air to breathe [13,14]. There are two different classes of algae known as macroalgae and microalgae. These photosynthetic organisms are mainly found in aquatic habitats both freshwater and marine. These are microscopic and have very amazing and fascinating structures [15].

The reasons for algae being the preferred source over plant sources

(a) The microalgae have a high efficiency for photosynthesis with an adaptability to a wide range of light and temperature variations [16].
(b) The microalgae can grow in water with different levels of nutrients and can adjust to the change in the growth characteristics and nutrient uptake ability [16].

These organisms have a larger surface to volume ratio, which enables them to grow very efficiently. Fixation of CO_2 at different water levels is achieved very easily. But the major challenge would be the cultivation of microalgae on a large-scale, harvesting and finally converting into useful fuels which are beneficial for the human society and as well have an economic impact [12].

In this review article, we have discussed the state-of-the-art in biofuel production from microalgae. The distinctiveness of this review is in its coverage of numerous harvesting procedures, extraction methods and parameters which are involved in growth and the lipid extraction techniques. In this paper, we have given a tabular column and illustrated various conditions that favor lipid accumulation as well as the yield from different species. We also discuss various maximum growth rate values, lipid percentage accumulated in their cells of individual species, numerous methods regarding biofuel and co-products recovery, carbon dioxide mitigation and wastewater treatment.

1.1. General characteristics of algae

The green algae and the cyanobacteria together called the blue-green algae consist of a huge group of photosynthetic organisms, the most efficient organisms reported to date. Unlike other microorganisms, these have abundant chlorophyll inside the cells, with a well-defined nucleus, cell wall, and pigments [8].

1.2. Forms of algae

The various forms of algae which exist are:

- Colonial, Capsoid, Coccoid, Palmelloid, Filamentous, Parenchymatous.

The cell walls of diatoms comprise polymerized silica known as a