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Research paper

Effect of CO_2 aeration on cultivation of microalgae in luminescent photobioreactors

Seyedeh Fatemeh Mohsenpour, Nik Willoughby*

Department of Chemical Engineering, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK

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ABSTRACT

This photobioreactor study investigated the influence of CO_2 aeration on biomass production, carbon dioxide fixation rate, pH, cell's essential elements such as carbon, nitrogen, and hydrogen, as well as lipid content, whilst under a range of luminescence-modified lighting conditions. The effect of aeration with pure air (comprising 0.03% CO_2) on the CO_2 fixation rate was insignificant compared to the higher concentrations used. Results showed that, with the exception of blue PBR, increasing CO_2 concentrations in the air stream enhanced the fixation rate of CO_2 in *C. vulgaris*. Cyanobacteria cells showed significant tolerance to 15% CO_2.

The results obtained demonstrated that the combination of blue light and 15% CO_2 provided a condition in which higher rates of lipid accumulation was induced in both algal strains. The highest lipid content observed at this condition was 36.6% obtained in *G. membrancea*. Aeration with 15% CO_2 enhanced lipid production of *G. membranacea*, to at least twice the amount produced at 5% CO_2 in all photobioreactors. The most significant difference between the 5% and 15% CO_2 aeration conditions was observed in the yellow PBR, in which the lipid content was enhanced up to six times.

1. Introduction

Several studies have investigated the potential of microalgae as one of the most promising biosequestration methods [1,2]. Chisti [3] reported that higher growth rates and photosynthetic efficiency makes microalgae capable of fixating carbon dioxide 10–50 times more than terrestrial plants [4]. Microalgae biomass also brings some additional benefits from CO_2 reduction by being beneficial in various industrial products such as medications, nutritious foods, cosmetics as well as biofuels [5].

Depending on the species and cultivation conditions, microalgae can accumulate lipid and oil up to 50–70% of their dry weight [3]. The oil produced by microalgae contains the suitable fatty acids for synthesis of biodiesel [6]. Lipids are essential components in microalgae where they function as storage products, membrane components, and more importantly as sources of energy [7]. Lipid accumulation is typically induced by fluctuation of growth conditions or various types of stress and it can be expressed as variation in fatty acids compositions or total lipids. As lipid synthesis occurs with reduction of photosynthesis activity Becker [7] recommended fast algae growth under optimum conditions followed by a specific stress factor, such as nitrogen starvation, to obtain maximum lipid content.

In addition, it is well known that cultivation of microalgae under stress conditions can cause alterations in their metabolic pattern. Consequently, this environmental adaptation can affect the biomass composition [8,9]. Carbon is the most important element in microalgae cells and can make up to 50% of the dry biomass [10]. Determination of elemental carbon shows the cell's response to specific growth conditions. Furthermore, it is an indication of CO_2 sequestration rate.

Nitrogen content is another essential element in microalgae cells. Elemental nitrogen, determined by elemental analysis, has been used in other studies to provide an independent evaluation of the protein content [11]. Nitrogen content can also be related to the lipid accumulation by the cells. It is well known that extreme cultivation conditions can induce nitrogen storage in the cells as an environmental response [12]. For instance, nitrogen starvation in the culture media can reduce the rate of production of all cell components which lead to lipid accumulation as storage

* Corresponding author. Institute for Biological Chemistry, Biophysics and Bioengineering, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK.
E-mail addresses: S.Mohsenpour@hw.ac.uk (S.F. Mohsenpour), N.A.Willoughby@hw.ac.uk (N. Willoughby).

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compounds in the cell [13]. In this study, the media composition was maintained constant to observe only the influence of light quality variations. The data related to the elemental content of the cells could further assist the overall view of the performance of luminescent photobioreactors.

We previously demonstrated that the spectral conversion of light by luminescent photobioreactors enhanced biomass production in microalgae [14,15].

Furthermore, some studies have examined the use of photo-convertor material in photobioreactors for algae cultivation [16–18]. An integrated photovoltaic-photobioreactor system was reported to improve energy conversion performances by converting directly available electrical energy together with microalgae biomass [17]. Fluorescent photobioreactors were used in another study to investigate the spectral shifting UV-A radiation as a tool for improving *Chlorella* sp. Growth rate [16]. A study about solar spectral conversion examined the use of photo-luminescent convertor material for cultivation of *H. pluvialis*. The report concluded that by increasing photon flux in the active spectral band of the algal chloroplast, the CO_2 to biomass conversion and oxygen production rate was improved [19].

Various studies have focused on the ability of microalgae in carbon dioxide fixation [5,20–24]. In this study, the rate of CO_2 fixation was measured according to the carbon content of cells obtained from elemental analysis (CHN analysis). Although some research papers suggest the calculation of theoretical carbon content, the aim of this study was to compare the effects of a specific culture condition in different luminescent photobioreactors.

Therefore, the experimental carbon content is entirely suitable to identify the influence of various aeration and spectral conditions on the elemental compositions and CO_2 fixation rates. In addition, the CO_2 fixation rate is significantly dependent on biomass productivity. Consequently, an increase in productivity can improve carbon uptake by microalgae. It must be noted that this rate only represents the active phase of growth when growth is exponential and maximum productivity (P_{max}) is achieved.

2. Materials and methods

2.1. Microalgae strain and culture conditions

C. vulgaris (CCAP 211/79) was cultivated in bold basal medium with 3-fold nitrogen and vitamin (3N-BBM + V). *G. membranacea* (CCAP 1430/3) was cultivated in blue green algae medium (BG 11).

Luminescent bubble column photobioreactors (PBRs) constructed from luminescent acrylic polymers were used in this study. The emission spectrum of the light inside each PBR was different. The use of five different ranges of luminescent dyes in the PBRs along with a dye-free PBR (as control) provided the light conditions which were used previously for a comparative study [15]. The light intensity was set at 200 μmol m^{-2} s^{-1} and was measured by a PAR light meter (Skye Instruments, Quantum sensor, Powys, Wales). The emission spectrum of each luminescent photobioreactors is shown in Fig. 1.

2.2. Biomass density and productivity

The dry weight of algal biomass was measured by a gravimetric method and the data were correlated to the optical density of the samples. The following equations were obtained from the calibration graphs:

$$X_b(C.vulgaris) = 0.5942 \times OD_{680} + 0.0024 \quad (1)$$

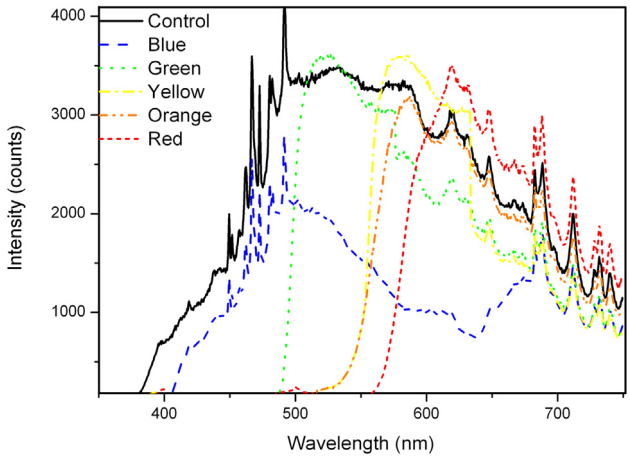

Fig. 1. Emission spectra of luminescent photobioreactors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$X_b(G.membranacea) = 0.6922 \times OD_{680} + 0.0021 \quad (2)$$

The biomass productivity rate (g L^{-1} d^{-1}) (also known as linear growth rate) was obtained during the exponential phase of growth from the growth curves and was estimated using Equation (3):

$$P = \frac{(X_t - X_0)}{(t - t_0)} \quad (3)$$

where P is the biomass productivity rate and is measured during the exponential phase of growth.

2.3. Elemental analysis

The biomass samples were weighed accurately and placed inside a small tin capsule. Total carbon, nitrogen and hydrogen content of the freeze-dried microalgae biomass was measured by elemental analysis (Exeter CE440 CHN–O/S, Control Equipment Corporation, Lowell, MA, USA). The carbon content ($Carbon_{actual}$) and Nitrogen content were then correlated to the CO_2 fixation rate and the lipid content respectively.

2.4. CO_2 fixation rate

Different concentrations of CO_2 were used for aeration of the microalgae cultures inside the photobioreactors. Pure air containing 0.03% CO_2, along 5% and 15% CO_2 aeration conditions were used to evaluate the effect of luminescent photobioreactors in improving CO_2 fixation rates. The selected aeration conditions were based on the composition of CO_2 in industrial flue gases [25,26].

According to the mass balance of microalgae, the fixation rate of carbon dioxide can be calculated. The carbon content of the algal cell is mainly derived from carbon dioxide. A mole of CO_2 has a mass of 44 g including 12 g of carbon.

Based on this information theoretical carbon dioxide consumption by each gram of microalgae can be obtained from Equation (5) as below:

$$\frac{44\ (g/mol\ CO_2)}{12\ (g/mol\ Carbon)} \times \frac{0.50\left(g\ Carbon_{theory}\right)}{1(g\ algal\ biomass)} = 1.83\ (g\ CO_2/g\ algal\ biomass) \quad (5)$$

Equation (5) shows that in theory 1 g of algal dry cell weight can