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Modeling the effects of light sources on the growth of algae

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Abstract

Algae are fast growing microorganisms and beneficial in many ways, especially concerning food supplement, alternative energy, and wastewater treatment. Naturally, they need a light:dark regime for productive photosynthesis. To have more insight into how light affects their growth, we investigate the effect of light sources (fluorescent and LED) on algae growth both experimentally and computationally via modeling. It was found that growth in the fluorescent light source is relatively better than in other sources. Computational data analyses and detailed discussions are presented. Lastly, a more generalized growth model of microalgae for incorporation of other factors and variables is necessary for more realistic modeling of real-world systems.

Keywords: Modeling; Algae; Light; Algae growth

1 Introduction

The problem of worldwide food shortage and malnutrition has brought us the intention of algae production as an alternative food supply because of their richness in proteins and vitamins including B1, B2, B6, and B12. Algae are also used as the main food supply for rotifers and the supplementary food for larvae of marine fish [1]. Furthermore, lipid from algae can be extracted and converted into biodiesel fuel [2]. In addition, water treatment as a by-product of algae production has shown a potential result of reducing the COD and BOD with 93–97% and 93% efficiency, respectively. Finally, algae contain a chemical substance "Chlorella Growth Factor (COF)" which has the anti-cancer property.

Specifically, microalgae cultivation in a controlled environment using artificial light, for energy efficiency, has been a well-discussed subject [3]. It was reported that under the red LED light it has an optimal condition for the growth of *C. vulgaris* in the experiment prepared in flask volume 1 L. It was discovered that the intensity of light affects the growth rate of algae, and the type of light source plays an important role in the growth of algae [4]. Shu et al. [5] also found that the algae cultivated under the LED light condition have a different growth rate compared to the algae under fluorescent light condition. The previous study has shown that growing microalgae under red wavelength has higher growth rate than under white, yellow, purple, blue, and green, respectively. Red light is the optimal wavelength to grow *C. Vulgaris* [3, 6]. *C. Vulgaris* under red LED light reaches the highest

biogas production compared to yellow, blue, and white LEDs [7]. *C. Vulgaris* under red LED light produced the highest number of cells and the highest weight [8].

To understand better the previously mentioned results, we thus propose here to apply mathematical modeling to tackle the problem. The mathematical models can be used to describe and study the complex situation of real phenomena. Apart from that, there are the models used to study various aspects of the biological system such as metabolism, genetics, and the interaction of the gene–environment. For these reasons, the aim of this research is to experimentally and computationally study the growth of algae under various types of light sources. Still, a more generalized growth model of microalgae for incorporation of other factors and variables is necessary for more realistic modeling of real-world systems.

2 Materials and methods

2.1 Microalgal strain and culture medium

The microalgal strain of *Chlorella vulgaris* TISTR 8580 used in this study was obtained from Thailand Institute of Scientific and Technological Research. Then, it was purified by isolation techniques on Tris-Acetate-Phosphate (TAP) agar [9]. The algal stock was kept in TAP agar slant under 3000 lux daylight fluorescent lamp, light/dark photoperiod of 12 hr:12 hr, at $28 \pm 2^{\circ}$C and it was subcultured every two weeks. The TAP medium was used immediately after preparation for the next experiments [10].

2.2 The growth of *C. vulgaris* TISTR8580 under the three light sources (red LED, white LED, and fluorescence)

Starter cultures of *C. vulgaris* TISTR8580 were prepared by transferring algal colonies on TAP agar slant into 800 ml of TAP medium in 1000 ml sterilized glass bottles. They were incubated under 3000 lux daylight fluorescent lamp, light/dark photoperiod of 12 hr:12 hr, at $28 \pm 2^{\circ}$C and continuously aerated with filtered air at the rate of 0.4 vvm (volume of air per volume of culture per minute). Cell density was counted daily by haemacytometer until log phase of the growth curve was obtained with the cell density of 1×10^6 cell/ml. It was inoculated into each test bottle containing 800 ml TAP medium. There were three sets of treatment experiments consisting of red LED, white LED, and fluorescence respectively. The cultivation was maintained at temperature $28 \pm 2^{\circ}$C, light intensity 4000 lux during 12:12 light-dark cycles, air flow rate through a filter at 0.4 vvm. As shown in Fig. 1, algal growth was monitored by cell counts daily with haemacytometer [10] during a twelve-day experiment. For consistency check, each experimental setup was repeated three times.

3 Mathematical modeling

In this part, we will try to represent the model of the algae growth during the entire cultivation based on the mathematical logistic equation. The mathematical model is preferred to the experimental data as a method to avoid the fluctuation of experimental factors as well as benefits of extracting other information. The key equation is expressed by

$$\frac{dN}{dt} = r\left(1 - \frac{N}{K}\right)N,$$

where

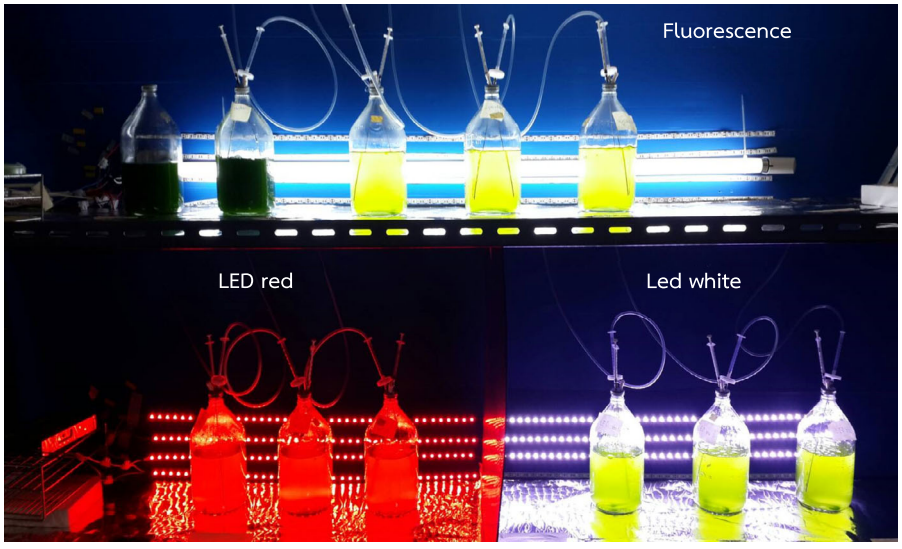

Figure 1 Cultivation condition of *Chlorella vulgaris* TISTR8580 under three light sources

Table 1 The experimental data of algae cultivation under different lighting conditions

Lighting condition	r (Mcells/day)	K (Mcells/ml)
Red LED	2.20	76
White LED	2.75	66
Fluorescent	2.55	79

- N is the population of algae as a function of time t. In the work, we assume N to be the cell population contained in a fixed volume 1 ml of medium. The population is numerically described in Mcells per ml;
- K is carrying capacity or steady-state maximum population allowance;
- r is the population growth rate in the absence of intra-specific competition or the Malthusian parameter.

The next task is to see if we can find such parameters in the equation to give the merit of validity. The procedure is as follows:

1. The growth rate is determined from numerical finite differentiation as the value of differentiation.
2. The value of K is estimated for each wavelength of light source, from the steady-state of the population.
3. The value of r is then estimated from the phase transition, where $\frac{dN}{dt}$ is determined numerically, and the estimated value of K from the previous results is used to solve the unknown parameter r.
4. The numerical result is then compared with the experimental data, and all the parameters are then repeated to minimize the difference. This is used as an indicator to determine the validity of the procedure as well as the fitness and consistency of the model to the experimental results.

Table 1 shows the results of the procedure above applied to the experimental data of algae cultivation on different lighting conditions.

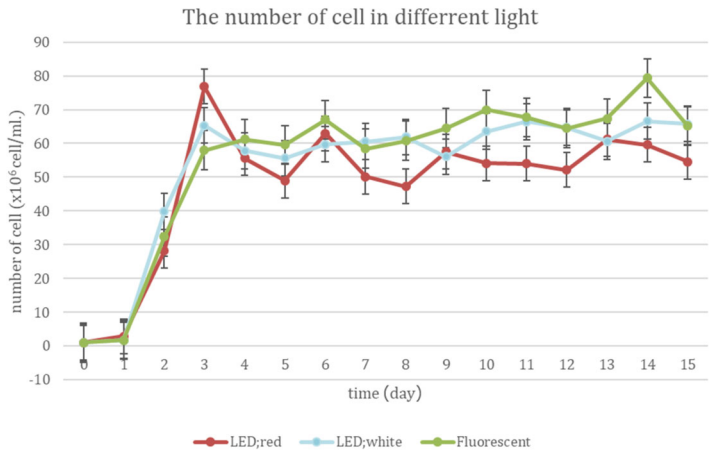

Figure 2 The graph between the density of *C. vulgaris* cell and time using different light sources, 4000 lux, 12hr:12hr light/dark cycle, 0.4 vvm air flow rate, with temperature $28 \pm 2°C$

4 Results and data analyses, discussion and conclusion

The main experimental and computational results are shown in Fig. 2. It illustrates the number of *C. vulgaris* cells at different times and conditions. The growth of *C. vulgaris* TISTR8580 from algae cells cultured under the different light sources, including the white LED light, the red LED light, and the fluorescence light, is studied. Every condition has a light intensity at 4000 lux. Also, the ratio of the given light during the night and the day period is 12:12 hours, the experiments are in cultured agar TAP medium 800 ml. Moreover, the air is given through the filter by flow rate 0.4 vvm, the initial cells density is 10^6 cell/ml, and the culture temperature at $28 \pm 2°C$.

From the experiments, it was found that the algae are in a state of lag phase during day 0 and day 1. In this period, the algae are adapting to the new environment and the population remains constant. However, during day 2 to day 3, the cell density increases dramatically, as compared to day 1. This reflects the typical nature of the exponential growth phase, namely the fast-growing phase. After day 4 to the last day of the experiment, the algae are in a state of stationary phase in which the algae population is consistently at maximum. It was experimentally found that the white LED light source gives the highest population density on day 14 at 66.63×10^6 cell/ml. Algae under a fluorescent light source with the white light had the highest density on day 14 at 79.33×10^6 cell/ml. The algae under the red LED light source gives the highest density on day 3 at 76.83×10^6 cell/ml. Although the cell density of the algae under the red LED light is more than that under white LED light, during the stationary on day 3, the density of algae cell under red LED light is decreased more than that in the case of the white LED light on day 4.

Computationally, data analyses from the mathematical model suggest that white LED condition yields the highest value of r, which in turn indicates that the growth rate during the exponential phase is highest. This implies that to accelerate the growth of algae cultivation the white LED lighting condition should be considered the most preferable choice. However, when comparing the value of K of each condition, the result is not obviously evident. As the value of K implies the probable maximum population during the steady phase, from Table 1, the value of K of each condition is within a narrow band ranging from 66 to 79 Mcells/ml. The value of K from fluorescent lighting is slightly higher than

that from the red LED lighting condition, or is considered more or less the same, while the value of K from the white LED lighting condition is significantly the lowest.

With the numerical analysis from this set of data, it suggests a vital strategy from the economic point of view. Not a single type of light source could produce both the highest growth and the highest steady population. It is in fact advised that as far as the production and time constrained are concerned, during the lag phase using white LED lighting will give rise to the high growth rate. However, once the exponent phase has passed, the production management should switch the light source to the fluorescent light condition to increase the yield further. Determination of the lighting switch is not a crucial factor, as it is shown from the graph that the exponential phase reaches its peak within three days and it does not need precise control.

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