A Cost Analysis of Microalgal Biomass and Biodiesel Production in Open Raceways Treating Municipal Wastewater and under Optimum Light Wavelength

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Introduction

The development of renewable and alternative energy has begun to attract attention as a solution to solve the two-prong problem of exhaustion of fossil fuels and greenhouse gas emissions. Although bioenergy as an alternative solution from sources such as woody biomass and crops has reached commercialization, several issues including large inefficiencies in terms of photosynthetic conversion and food versus fuel debate have kept these technologies from mass proliferation [25, 29]. On the contrary, biodiesel production using microalgae is superior in productivity per unit area, possesses higher photosynthetic efficiency, and does not compete with food crop cultivation. Besides this, microalgae are supposedly in a better position for the production of biodiesel because of their considerably higher lipid content than other biomass, depending on species [6, 10]. Moreover, biomass after lipid extraction can

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be valorized for a variety of applications, including livestock feed, medicines and health supplements, natural pigments, and single cell proteins [32].

On the contrary, mass culture of microalgae requires a large amount of water and nutrients, resulting in increasing production costs [18]. If organic wastewater can be used for cultivation of algae, it serves as a good alternative to reduce costs as well as helps in wastewater treatment, as nutrients such as nitrogen and phosphate, causative chemicals of eutrophication, are concomitantly eliminated by algal uptake [4, 13, 26]. Moreover, microalgae-based wastewater treatment presents several advantages over traditional technologies because of their ability to grow both phototrophically and mixotrophically, and in association with other microorganisms [9]. Thus, in a microalgal dominated consortium, mechanical aeration may not be required, resulting in energy savings [14].

Table 1. Characteristics of wastewater used as a nutrient source for the growth of microalgae.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>36.0</td>
</tr>
<tr>
<td>NH$_4^+$</td>
<td>29.1</td>
</tr>
<tr>
<td>NO$_3^-$</td>
<td>ND</td>
</tr>
<tr>
<td>TP</td>
<td>4.0</td>
</tr>
<tr>
<td>COD</td>
<td>81.45</td>
</tr>
<tr>
<td>Zn</td>
<td>0.008</td>
</tr>
<tr>
<td>Cl</td>
<td>123.0</td>
</tr>
<tr>
<td>Fe</td>
<td>0.18</td>
</tr>
<tr>
<td>Mn</td>
<td>0.118</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>37.0</td>
</tr>
<tr>
<td>Al</td>
<td>ND</td>
</tr>
<tr>
<td>Cr$^{6+}$</td>
<td>ND</td>
</tr>
<tr>
<td>As</td>
<td>ND</td>
</tr>
<tr>
<td>Se</td>
<td>ND</td>
</tr>
<tr>
<td>Hg</td>
<td>ND</td>
</tr>
<tr>
<td>CN</td>
<td>ND</td>
</tr>
<tr>
<td>Cr</td>
<td>ND</td>
</tr>
<tr>
<td>Cd</td>
<td>ND</td>
</tr>
<tr>
<td>Phenol</td>
<td>ND</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>ND</td>
</tr>
<tr>
<td>Benzene</td>
<td>ND</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.008</td>
</tr>
<tr>
<td>Ethyl benzene</td>
<td>ND</td>
</tr>
<tr>
<td>Xylene</td>
<td>ND</td>
</tr>
<tr>
<td>1,1-Dichloroethylene</td>
<td>ND</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>ND</td>
</tr>
</tbody>
</table>

ND denotes not detected.

Although wastewater supplements algae with nutrients and lesser amounts of utilizable organic carbon, there are several factors that limit algal growth. Light is one of the primary factors that affect microalgal photosynthesis, especially in open pond cultivation. Chlorophyll plays an important role in photosynthesis and most microalgae usually possess chlorophyll $a$ and $b$. The pigments have two absorption peaks, one in the blue and one in the red part of the visible spectrum [24]. For this reason, a change in light wavelength to increase the growth of microalgae has been deliberated using the light-emitting diode (LED) [33]. *Spirulina platensis* showed twice the growth rate in the red wavelength than in white light [30]. In addition, studies report that the other green microalgae showed up to 50% more growth and lipid productivity in blue wavelength [7, 15, 22]. In this study, we combine two approaches, use of untreated wastewater and different wavelength filters, to cultivate microalgae in the laboratory and fit the experimental results in a model to compare the costs with control cultures. Although the effects of use of wastewater and monochromatic wavelengths have been studied at the laboratory scale [21, 33], we evaluate the actual benefits that could be obtained by using these supposedly low-cost options. Our study demonstrates that these improvements in the existing system would not only increase microalgal productivity but also reduce cost of production by 73% as well as ease the cost of wastewater treatment through conventional aerobic methods [14].

Materials and Methods

Microalgae Strain and Culture Medium

In this study, we selected three strains of green microalgae that grew well in undiluted wastewater. *Chlorella* sp. JK2 and *Scenedesmus* sp. JK10 strains were isolated from municipal wastewater, whereas *Chlorella vulgaris* AG10032 was obtained from the Biological Resource Center of the Korea Research Institute of Bioscience and Biotechnology. Municipal wastewater was obtained from the primary settling basin of the Daejeon municipal wastewater treatment plant and the characteristics of the same have been described in Table 1. The wastewater was filtered by using a 0.2 µm membrane filter to remove microorganisms and suspended solids before use and characterized according to standard methods [1].

Batch Experiment – Effects of Light Wavelength

To evaluate the effect of light wavelength on wastewater treatment and microalgal growth, cellophane papers (blue, green, red, and white) with 0.3 mm thickness (Woo-Sung MF, Korea) were used as light filters to obtain the respective wavelengths (Fig. 1A). Precultured *Chlorella* sp. JK2, *Scenedesmus* sp. JK10, and *C. vulgaris* AG10032 were inoculated with initial cell concentrations
of 8 × 10⁴ cells in a 1 L media bottle (Duran, Germany) with a working volume of 800 ml and constantly stirred at 150 rpm. Inorganic carbon for growth of microalgae was supplied at 0.5vvm (aeration volume/medium volume/minute) using an air pump. Batch tests were performed for 16 days at 25 ± 1 °C with continuous illumination using fluorescent light of 50 µmol/m²/s when light was passed through the specific filters.

**Determination of Chlorophyll a and Dry Cell Weight**

The dry weight of the algal cells was measured by filtering an aliquot of the culture suspension through preweighed GF/C filters (Whatman, UK). After rinsing with distilled water, the filters were dried at 105°C for 1 h, and reweighed. Chlorophyll a concentration was determined by a spectrophotometric method described previously [12].

**Chemical Analysis**

All samples were filtered through 0.2 µm pore size membranes (Sartorius, Germany) before the analysis, as the presence of suspended particles would not only lead to contamination but also yield erroneous results during algal biomass determination. The chemical oxygen demand (COD) was measured according to standard methods [1]. Total nitrogen (TN, dissolved) content was measured by the chromotropic acid method [1]. Total ammonium nitrate (dissolved) was measured by reacting ammonia with hypochlorite and salicylate ions to form the salicylic acid analog of indophenol. Total phosphorus (TP, dissolved) was measured by the persulfate acid digestion method for wastewater [1].

**Lipid Content**

The total lipids were extracted by mixing chloroform–methanol (1:1 (v/v)) with the samples in a proportion of 1:1 using a slightly modified version of Bligh and Dyer’s method [3]. The mixtures were transferred into a separatory funnel and shaken for 5 min. The lipid fraction was then separated from the separatory funnel and the solvent evaporated using a rotary evaporator. The weight of the crude lipid obtained from each sample was measured using an electronic scale [20].

**Fatty Acid Composition Analysis**

A fatty acid composition analysis was performed using a gas chromatograph (Shimadzu GC-2010, Japan). Fifty milligram samples were placed into capped test tubes, saponified with 1 ml of a saturated KOH-CH₃OH solution at 75°C for 10 min, and then submitted to methanolysis with 5% HCl in methanol at 75°C for another 10 min. Thereafter, the phase containing the fatty acids was separated by adding 2 ml of distilled water and then recovered. The components were identified by comparing their retention times and fragmentation patterns with those for standards [33]. Six fatty acids (C16:1, C17:0, C18:0, C18:1, C18:2, and C18:3) were used as the standard materials [20].

**Cost Analysis**

We evaluated the cost of producing microalgal biomass based on the laboratory results obtained in this study, which were then extrapolated from the control condition to industrial scale computed through previous studies. The cost analysis model used by Slade and Bauen [28] was adopted to fit our experimental results. Three scenarios envisaged included a control condition (worst case scenario) where industrial water is supplemented with nutrients and CO₂, both of which add to the cost (Scenario 1) [28], algae growing in municipal wastewater (Scenario 2), and algae growing in wastewater fitted with wavelength-filtered greenhouse (Scenario 3). All the scenarios assumed a 40 ha land area for the raceway pond system. The cost modeling approach included only the cultivation and harvesting process steps, and cost is represented in cost per kilogram of biomass, cost per liter of biodiesel. Cost of biodiesel was estimated as per a previous study [6]. The cost of wastewater was assumed to be zero, as algae effectively treat this wastewater and the treated water does not possess any disposal issues [14]. All scenarios do not include any land cost. The HRT of the raceway pond and the biomass...
concentration in the control condition were also based on previous studies [6, 28]. It was also assumed that use of wastewater would not increase biomass productivity, although in wastewater, algae essentially switch to mixotrophic cultivation [14]. For all the cases, after the dewatering process, the liquid medium was recycled to raceway ponds to compensate for evaporation, as a standard practice.

Results and Discussion

Different Light Wavelengths Using Light Filters

The use of LEDs with selective wavelength in open pond cultivation and photobioreactors (PBRs) is unviable, and as biodiesel is a relatively low-value product, their use in a mass cultivation system would be limited. Hence, in this study, we used cellophane filter, which would also be used on greenhouses during open pond or PBR cultivation, and observed the light emission spectrum of each filter using a high-resolution spectrometer (CAS 140CT, Germany) before the actual experimental run. The output spectrum of the fluorescent lamps using light filters without normalization is presented in Fig. 1B. Four different light filters were used (red, green, blue, and transparent), and their transmission spectrum was measured. Transparent cellophane filter was used as a control group. Blue, green, and red color filters show dominant wavelength at 480, 554, and 622 nm, respectively, and hence were used as filters indicative of the respective wavelengths for microalgal cultivation using wastewater.

Nutrients Removal

Nutrient removal efficiency in terms of total nitrogen, total ammonia, and total phosphorus under different wavelengths were studied (Fig. 2). Although all microalgae grown under different wavelengths removed the nutrients efficiently after the end of the batch study period of 16 days, there was a distinct trend in each wavelength.

Fig. 2. Total nitrogen and ammonium nitrate concentration in cultures of Chlorella sp. JK2 (A and D), Scenedesmus sp. JK10 (B and E), and C. vulgaris AG10032 (C and F) under red, green, blue, and white light over 16 days period.

■: Red light filter; ●: Green light filter; □: Blue light filter; ○: Control using transparent light filter.
After a 6-day incubation period, *Chlorella* sp. JK2 showed nitrogen removal efficiencies as much as 80.75%, 51.50%, 41.31%, and 20.36% under blue, red, transparent, and green filter, respectively (Fig. 2A). This trend was also observed in *Scenedesmus* sp. JK10. Nitrogen removal efficiencies of *Scenedesmus* sp. JK10 were 88.64%, 57.86%, 56.17%, and 48.61% under blue, red, transparent, and green filter, respectively (Fig. 2B). Nitrogen removal efficiencies of *C. vulgaris* AG10032 were 72.11%, 41.78%, 38.11%, and 16.33% under blue, red, transparent, and green wavelength filter, respectively (Fig. 2C).

$\text{NH}_3$-N removal efficiencies of the *Chlorella* sp. JK2 after an incubation period of 6 days were 88.66%, 52.96%, 42.96%, and 17.87% under blue, red, transparent, and green filter, respectively (Fig. 2D). $\text{NH}_3$-N removal efficiencies of *Scenedesmus* sp. JK10 were 94.50%, 58.42%, 56.70%, and 50.52% under blue, red, transparent, and green filter, respectively (Fig. 2E). $\text{NH}_3$-N removal efficiencies of *C. vulgaris* AG10032 were 75.60%, 44.67%, 41.58%, and 14.09% under blue, red, transparent, and green filter, respectively (Fig. 2F).

Total phosphorus removal efficiencies showed a similar trend compared with nitrogen removal (Fig. 3). Total phosphorus removal efficiencies of the *Chlorella* sp. JK2 after 6 days incubation showed as much as 72.50%, 45.00%, 32.50%, and 33.75% under blue, red, transparent, and green filter, respectively (Fig. 3A). Total phosphorus removal efficiencies of *Scenedesmus* sp. JK10 were 87.25%, 52.50%, 45.00%, and 35.0% under blue, red, transparent, and green wavelength filter, respectively (Fig. 3B). Total phosphorus removal efficiencies of *C. vulgaris* AG10032 were 57.50%, 47.50%, 37.50%, and 35.00% under blue, red, transparent, and green wavelength filter, respectively (Fig. 3C).

Every species showed faster nutrient removal under blue wavelength and the lowest removal under green wavelength. Nutrient removal efficiencies of red and transparent wavelengths showed a similar pattern, but was significantly less than in blue wavelength. In particular, under blue wavelength, nutrient concentrations decreased within 8 days of cultivation, while under the other wavelength within 10 days. These results are consistent with the growth of microalgae.

**COD Removal**

COD removal efficiencies of the *Chlorella* sp. JK2 after 6-day incubation were 59.48%, 33.70%, 27.56%, and 15.28% under blue, red, transparent, and green, respectively (Fig. 4A), whereas those of *Scenedesmus* sp. JK10 were 66.23%, 40.70%, 38.36%, and 26.09% (Fig. 4B) and for *C. vulgaris* AG10032 the removal efficiencies were 52.11%, 28.79%, 26.33%, and 15.25%, respectively (Fig. 4C). From these results, blue wavelength seems best suited for removal of COD. Meanwhile, in most of the treatments, COD increased slightly after incubation for 10 days. The most likely reason for the increase of COD is the release of organic
carbon by microalgae. Previous studies have demonstrated that microalgae release small photosynthetic organic molecules such as glycolic acid, especially during the stationary phase, in autotrophic growth [31]. In Figs. 2 and 3, most of nutrients were exhausted after 10 days. From this point on, microalgae may start autotrophic growth, and it seems that organic carbons were secreted by microalgae corresponding to this period.

**Biomass Production**

In 50 μmol/m²/s light conditions, the dry cell weight of Chlorella sp. JK2 cultured for 14 days was 0.240, 0.093, 0.370, and 0.313 g/l under red, green, blue, and transparent filter, respectively (Fig. 5A). The dry cell weight of
Scenedesmus sp. JK10 cultured for 14 days was 0.263, 0.163, 0.293, and 0.260 g/l, while that for Chlorella sp. JK2 was 0.347, 0.100, 0.413, and 0.277 g/l under red, green, blue, and transparent filter, respectively (Figs. 5B and 5C). Under blue wavelength, Chlorella sp. JK2 showed the highest growth rate (Table S1). On the other hand, the lowest growth rate was under green wavelength (Fig. 5A). The order of high growth rates was blue, red, transparent, and green. Scenedesmus sp. JK10 also showed the highest growth rate under blue wavelength and the lowest growth rate under green wavelength (Fig. 5B). However, unlike Chlorella sp. JK2, Scenedesmus sp. JK10 showed a higher growth rate in the control condition than in red wavelength. C. vulgaris AG10032 showed a similar growth rate to that of Chlorella sp. JK2. Chlorophyll $a$ results also showed a similar trend of increase under blue wavelength (Fig. S1).

It has been reported that Scenedesmus sp. showed 45% increase in growth under the red and blue wavelengths [15] and Nannochloropsis sp. demonstrated increased growth of about 20% under blue wavelength [7]. The biomass productivity of C. vulgaris increased about 50% under blue wavelength compared with control [22]. Studies suggest that microalgae also takeup nutrient more effectively in blue wavelength [17]. Similarly, most studies reported a reduction in growth rate under green wavelength [15, 34]. The beginning of the photosynthesis process is the absorption of photons by the photosynthetic apparatus. The photosynthetic apparatus is composed of the reaction center, core antenna, and peripheral antenna. In particular, the core antenna contains photosynthetic pigments such as chlorophylls and they absorb light in different wavelengths [19]. Chlorophyll $a$ absorbs in the vicinity of 435 and 676 nm, and chlorophyll $b$ absorbs near 475 and 650 nm [2]. In other words, the blue and red wavelengths are the most absorbed than any other wavelengths during algal photosynthesis. On the other hand, chlorophyll $a$ and $b$ do not nearly absorb green light spectrum (520~570 nm), hence the green part of the spectrum has little or no impact on photosynthesis [19, 24].

From Fig. 1, it can be ascertained that the green light filter used in this experiment shows the strongest peak in 545 nm and weak intensity in the other parts of the spectrum that correspond to the absorption region of chlorophyll $a$ and $b$. For this reason, light passed through a green filter used as the light source reduces microalgal photosynthetic efficiency. According to a scheme of photosynthesis, the energy required to fix one carbon atom through photosynthesis can be calculated [11]. In the case of the middle wavelength range such as green wavelength, at least eight photons are required. One photon of blue wavelength has about 15.5% higher energy than green wavelength. Overall, photons in the blue wavelength region are more efficient in terms of photosynthesis [7]. Moreover, when blue wavelength is used, lesser light intensities suffice for microalgal growth because of their higher energy levels. Hence, blue wavelength results in higher photosynthetic efficiency, resulting in increased absorption of nutrients from wastewater. Hence, both the nutrients and COD removal rate of all microalgae under blue wavelength are superior.

**Lipid Content and FAME Composition**

The lipid content of Chlorella sp. JK2 was 25.23%, 27.05%, 22.21%, and 24.21% under red, green, blue, and transparent wavelength filter, respectively (Fig. S2A). Lipid content did not change significantly across wavelengths (~10% change), albeit there was a mild reduction under blue wavelength. The lipid content of Scenedesmus sp. JK10 was 15.82%, 26.09%, 22.90%, and 21.58% under red, green, blue, and transparent wavelength, respectively (Fig. S2B). Scenedesmus sp. JK10 also showed slightly higher lipid content in the green wavelength compared with blue and transparent filters. However, in the red wavelength, the lipid content was significantly reduced compared with control. The lipid content of C. vulgaris AG10032 was 26.29%, 30.25%, 24.30%, and 18.78% under red, green, blue, and transparent wavelength, respectively (Fig. S2C). C. vulgaris AG10032 showed an increase in the lipid content in all wavelengths when compared with control. However, the lipid productivity of all strains was enhanced in blue wavelength and was lowest in green wavelength, allowing us to conclude that blue wavelength would be a better choice for enhancing both biomass and lipid productivities for biodiesel production (Table S1).

The lipids extracted from Chlorella sp. JK2, Scenedesmus sp. JK10, and C. vulgaris AG10032 were converted to fatty acid methyl ester (FAME) and their compositions are summarized in Fig. S3. The FAME composition change under different wavelength conditions was not significant. However, stearate (C18:0), which was not observed in the control group of all algal strains, was present in red and blue wavelength conditions although in smaller percentage when compared with other fatty acids. In addition, polyunsaturated fatty acids (PUFAs) tended to decrease slightly under red and blue wavelength conditions compared with the control group, and the major percentage of fatty acids belonged to C16-C18, which is considered to be suitable for biodiesel production [16].
Cost Analysis

As described in the Materials and Methods section, three scenarios were considered in the cost analysis. All scenarios considered cultivation of microalgae in raceway ponds. Scenario 1 represented a worst case, wherein algae was grown in industrial freshwater supplemented with nutrients using fertilizers besides carbon dioxide supply, aptly increasing the variable costs (Table S2). Scenario 2 considered cultivation of algae in wastewater, thereby decreasing water costs, treatment costs for wastewater (not considered), CO\(_2\) costs (as organic carbon is present in the wastewater), and nutrient costs. This resulted in a decrease in biomass production costs by about 63% in Scenario 2 compared with Scenario 1 (Tables 2 and S3).

In the third scenario, in addition to use of wastewater, wavelength filters were used by constructing greenhouses that filtered a particular wavelength, resulting in increased biomass productivities observed in experimental data and extrapolated in the model. This increase in biomass productivities yielded the highest cost reduction of about 73%, even though the overall capital costs would increase because of greenhouse construction (Tables 2 and S3).

Table 2. Overview of key cost analysis model parameters and cost of producing biomass and biodiesel under three different scenarios.

<table>
<thead>
<tr>
<th>Key parameters &amp; costs</th>
<th>Units</th>
<th>Scenario #1 (Control, worst case scenario)</th>
<th>Scenario #2 (Use of wastewater)</th>
<th>Scenario #3 (This study, use of wastewater &amp; blue wavelength)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total biomass production</td>
<td>Mg.ha(^{-1}).year(^{-1})</td>
<td>31.5</td>
<td>31.5</td>
<td>63.0</td>
</tr>
<tr>
<td>Total CO(_2) consumption</td>
<td>Mg.ha(^{-1}).year(^{-1})</td>
<td>288.225</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fertilizers use (mass fertilizer per mass algae)</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Water cost</td>
<td>$.kg(^{-1})</td>
<td>0.0002</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO(_2) cost</td>
<td>$.kg(^{-1})</td>
<td>0.14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nutrients cost</td>
<td>$.kg(^{-1})</td>
<td>0.55</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total fix capital per annum</td>
<td>$.year(^{-1})</td>
<td>837,840.0</td>
<td>745,237.0</td>
<td>1,330,078.0</td>
</tr>
<tr>
<td>Total direct production costs</td>
<td>$.year(^{-1})</td>
<td>2,582,786.0</td>
<td>512,578.0</td>
<td>512,578.0</td>
</tr>
<tr>
<td>Total production costs</td>
<td>$.year(^{-1})</td>
<td>3,420,626.0</td>
<td>1,257,816.0</td>
<td>1,842,656.0</td>
</tr>
<tr>
<td>Unit cost of producing biomass</td>
<td>$.kg(^{-1})</td>
<td>2.71</td>
<td>1.00</td>
<td>0.73</td>
</tr>
<tr>
<td>Unit cost of producing oil</td>
<td>$.L(^{-1})</td>
<td>7.78</td>
<td>2.86</td>
<td>2.10</td>
</tr>
</tbody>
</table>

The cost of microalgal production projected in various studies conducted during 1996–2013 has varied considerably. In 1996, the United States Department of Energy’s aquatic species program evaluated that microalgal production costs would be conservatively about 1.6$ L\(^{-1}\) (in terms of 2009 dollar rates) [8, 27]. Net present value analysis for 2014 shows that under various scenarios, algal oil would cost in the range of 0.62–0.9$ L\(^{-1}\), which is extremely optimistic [8]. A recent study equates the cost of producing biomass under optimal irradiance, photosynthetic efficiency, free nutrient, and carbon dioxide input costs to 0.85$ kg\(^{-1}\) [23], which is comparable to the present study (0.73$ kg\(^{-1}\)). The most recent study on life cycle assessment of microalgal production for biofuels in open ponds arrives at 2.26$ kg\(^{-1}\) for the base case and 0.50$ kg\(^{-1}\) for the projected case, which includes higher productivity assumptions and zero CO\(_2\) and nutrient costs, as assumed to be supplemented with freely available wastewater and CO\(_2\). In the case of PBRs, the cost arrived at in both cases is 12.6 and 4.8$ kg\(^{-1}\), respectively [28].

Costs computed in this study are comparable to the latest studies; however, this study uses much less algal productivity and lipid content assumptions [5]. Hence, the cost of biodiesel production computed by this study is substantially high in the base scenario, as the values are
conservative and realistic. This study, nevertheless, proves that the use of wastewater and light filters decreases the cost of producing biomass significantly by 63% and 73%, respectively. Considering these are conservative estimates, the overall cost reduction would be much higher.

In conclusion, in this study we confirm that the use of blue wavelength filters would positively influence microalgal growth and nutrients removal from wastewater in all the strains used in this study, and among the strains, Scenedesmus sp. JK10 showed the highest nutrient removal efficiency. A cost analysis of the use of wastewater and wavelength filters for microalgal growth in commercial scale raceway ponds reveals a remarkable decrease in biomass production costs (~73%), which would eventually reduce the cost of valuable bioproducts, especially biodiesel, as lipid productivity under blue wavelength filter was twice that of the control culture (white light).

Acknowledgments

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