The feasibility of biodiesel production by microalgae using industrial wastewater

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A R T I C L E   I N F O

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Microalgae
Industrial wastewater

A B S T R A C T

This study investigated nitrogen and phosphorus assimilation and lipid production of microalgae in industrial wastewater. Two native strains of freshwater microalgae were evaluated their biomass growth and lipid production in modified BBM medium. Chlamydomonas sp. TAI-2 had better biomass growth and higher lipid production than Desmodesmus sp.TAI-1. The optimal growth and lipid accumulation of Chlamydomonas sp. TAI-2 were tested under different nitrogen sources, nitrogen and CO2 concentrations and illumination period in modified BBM medium. The optimal CO2 aeration was 5% for Chlamydomonas sp. TAI-2 to achieve maximal lipid accumulation under continuous illumination. Using industrial wastewater as the medium, Chlamydomonas sp. TAI-2 could remove 100% NH4+-N (38.4 mg/L) and NO3 --N (3.1 mg/L) and 33% PO4 ++-P (44.7 mg/L) and accumulate the lipid up to 18.4%. Over 90% of total fatty acids were 14:0, 16:0, 16:1, 18:1, and 18:3 fatty acids, which could be utilized for biodiesel production.

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1. Introduction

The production of biodiesel has recently received much attention worldwide because of the world energy crisis. Microalgae, the third generation biodiesel feedstocks, are a promising candidate for biodiesel production because of their high photosynthetic efficiency compared to conventional crops (Ahmad et al., 2011). Biodiesel produced from microalgal lipid is more sustainable and environmentally friendly than petroleum-derived diesel fuels. The advantages of microalgae as feedstocks for biodiesel include they can accumulate large quantities of triacylglycerols, grow at high rates, fix CO2 from atmosphere, adapt to wide area including extreme environment and utilize nutrient from wastewater (Hu et al., 2008). Nevertheless, the microalgal biodiesel has not been widely commercialized mainly due to its high costs. Different strategies have been proposed to improve the cost-effectiveness of microalgal biofuel production. The apparent benefits of combining microalgal biodiesel production and wastewater treatment are to minimize the use of freshwater, reduce the cost of nutrient addition for microalgal cultivation and remove nitrogen and phosphorus from effluents (Li et al., 2008; Pittman et al., 2011).

Based on different microalgae and culture conditions such as temperature, nutrient and light intensity, microalgal oil content and composition are varied (Converti et al., 2009; Solovchenco et al., 2008; Li et al., 2009, 2010). The cellular lipid content in various classes of microalgae was improved significantly under stress conditions, such as nitrogen starvation, phosphate limitation and high Fe3+ concentration. (Illman et al., 2000; Khizin-Goldberg and Cohen, 2006; Liu et al., 2007). Oil content of some microalgae such as Scenedesmus sp., Chlorella sp., Neochloris oleoabundans can achieve from 20% to 50% of total cell dry weight (Gouveia and Oliveira, 2009), revealing the significant potential of biodiesel production.

Isolation and screening of native species for biodiesel production are important because they are already adapted to the local environment. Acclimation in accordance with the local environment can facilitates the microalgae growth and coming application of native species (Mansour et al., 2005). Moreover, practical use with native species can also avoid the risks of importing foreign species that might accidentally be released into the environment. In the study of Chinnasamy et al. (2010), it was indicated that 63.9% of the lipid harvested from native consortium of microalgae can be converted into biodiesel when cultivated in wastewater. The composition of wastewater discharged from industrial facility is complex. Carbon is deficient but nitrogen and phosphorus are two main components in industrial wastewater, which are capable of supporting algae growth. The aim of this study was to estimate the possibility of removing nitrogen and phosphorus from industrial wastewater and to screen a promising strain for the exploitation of renewable energy from microalgae.

2. Methods

2.1. Industrial wastewater collection

Untreated industrial wastewaters used in this study were collected from a wastewater treatment factory in the Taichung
science industrial park in Taiwan. The wastewater consists of 2.43 μS/cm conductivity, 42.2 mg O₂/L COD, 38.4 mg N/L NH₄⁺-N, 3.1 mg N/L NO₃⁻-N, 16.2 mg N/L organic N and 44.7 mg P/L PO₄³⁻-P. Wastewater samples were collected in a 20-L plastic containers and stored in a cold room at 4 °C. Wastewater samples using in the experiments were filtered through a 0.22 μm membrane in advance.

2.2. Microalgal strain, media and cultivations

*Desmodesmus* sp. TAI-1 and *Chlamydomonas* sp. TAI-2 were isolated from ponds in the middle Taiwan and grown in modified Bold’s basal medium (BBM medium) (Sterin, 1973) containing the following components (per liter) 0.25 g NaNO₃, 0.075 g MgSO₄·7H₂O, 0.025 g CaCl₂·2H₂O, 0.175 g KH₂PO₄, 0.075 g K₂HPO₄, 0.025 g NaCl, 0.0049 g FeSO₄·7H₂O, 0.01 g Na₂EDTA, 8.05 mg H₃BO₃, 1.81 mg MnCl₂·4H₂O, 0.222 mg ZnSO₄·7H₂O, 0.079 mg CuSO₄·5H₂O, 0.390 mg NaMoO₄·5H₂O and 0.0494 mg Co(NO₃)₂·6H₂O.

The microalgae were cultivated in 100 mL autoclaved BBM medium in 250 mL flasks. The flasks were incubated at room temperature with continuous illumination of 25 μmol photons m⁻²·day⁻¹ and shaken at 120 rpm on an orbital shaker.

2.3. Experimental design

The microalgae were cultivated in 300 mL autoclaved modified BBM medium in 500 mL flasks. The flasks were incubated at room temperature with continuous illumination of 25 μmol photons m⁻²·day⁻¹ and shaken at 120 rpm on an orbital shaker for 11 days to evaluate their biomass growth and lipid production under different temperature sources (nitrate, ammonium or urea).

The photobioreactor was a 6-L glass column-i-form flask with an inner diameter of approximately 13 cm and a height of approximately 41 cm (Fig. 1). The working volume was 5-L. There are eight inner diameter of approximately 13 cm and a height of approximately 41 cm (Fig. 1). The working volume was 5-L. There are eight

2.4. Analysis of lipid content and fatty acid composition

The microalgal cells were harvested from the cultural mixture by centrifugation at 8000 rpm for 15 min (Himac CR22GII, Hitachi, Japan) and the cell pellet was frozen at –20 °C. Total lipids were extracted from lyophilized biomass in CHCl₃–MeOH (2:1, v/v) by a modified method of Folch (Christie, 2003). Freeze-dried biomass was suspended in 3 mL CHCl₃–MeOH (2:1, v/v) solution, extracted by sonication for 90 min, and then collected the extract by centrifugation at 2000 rpm for 10 min. The pellet was re-extracted in 3 mL CHCl₃–MeOH solution twice. The collected extract was evaporated at 40 °C, dried at 70 °C for 2 h, and subsequently weighed after cooling to the room temperature. Lipid content of microalgae was calculated by dividing the residue weight by the freeze-dried cell weight.

Gas chromatography (HP 6890, USA) equipped with 30 m DB-WAXETR (J&W, Agilent) capillary column was used for qualitative and quantitative determination of fatty acid composition. The oven temperature program started at 190 °C, increase at 4 °C min⁻¹ until 220 °C. Carrier gas, N₂, was kept at a constant rate of 15 mL/min. Injector and detector (flame ionization) temperature were kept at 220 °C. The fatty acid methyl ester (FAME) was prepared by adding 2 mL 2 N KOH in methanol solution to the sample for saponification. Then 4 mL 2.5 N HCl in methanol solution and 1 mL BF₃ (14%, methanol solution) were added for esterification. After methylation, 1 mL saturated NaCl solution and 2 mL n-hexane were added to the vial and the top n-hexane layer was removed and placed into vials for GC analysis (Christie, 2003). The individual fatty acid compositions were identified by comparison of their retention time with those of the authentic standards (Sigma), and were quantified by comparing their peak area with that of the standard. Fatty acid composition was calculated as percentage of the total fatty acids present in the sample.

2.5. Analytical methods

The microalgal concentration was determined by measuring the optical density of algal culture at 680 nm by spectrophotometer (Hitachi, Japan), and biomass concentration was related to optical density by the equation \( y = 0.399x - 0.02 \) (R² = 0.990) for *Desmodesmus* sp. TAI-1 and \( y = 0.716x + 0.05 \) (R² = 0.992) for *Chlamydomonas* sp. TAI-2, respectively. The dry weight of algal biomass was measured using the method of suspended solid (SS) measurement.

Nitrate concentrations in the culture medium were measured by determining the absorbance at 220 nm and subsequently subtracting the double absorbance at 275 nm to avoid the dissolved organic matter interference (APHA-AWA-WEF, 2005). Phosphate and ammonium concentrations were determined colorimetrically (APHA-AWA-WEF, 2005). All the analysis were carried out with culture supernatants obtained after centrifugation at 12,000 rpm for 5 min and filtered through a 0.22 μm membrane.

pH Variation during the microalgae cultivation was measured by pH meter (WTW, Germany).

3. Results and discussion

3.1. Comparision of growth and lipid content in two microalgal strain

*Desmodesmus* sp. TAI-1 and *Chlamydomonas* sp. TAI-2 were isolated from ponds in the middle Taiwan. To compare the growth and lipid content of these two strains, the experiments were carried out in a photobioreactor with continuous illumination and 3% CO₂ aeration in the modified BBM medium. As shown in Fig. 2a, the growth of *Chlamydomonas* sp. TAI-2 was better than
Desmodesmus sp. TAI-1 under the investigated conditions. The biomass concentration produced from Chlamydomonas sp. TAI-2 was approximately 1.34 g/L at day 10, more than that produced from Desmodesmus sp. TAI-1, which was approximately 0.93 g/L.

Microalgal biomass was harvested from culture medium every two days and subjected to extraction for lipid content measurement. As shown in Fig. 2b, the biomass obtained from Chlamydomonas sp. TAI-2 has the higher lipid content than Desmodesmus sp. TAI-1 during the cultivation period. The maximum lipid content of Chlamydomonas sp. TAI-2 was 25.3% at day 10, better than the maximum lipid content of Desmodesmus sp. TAI-1, 19.7%. The lipid productivity obtained from Chlamydomonas sp. TAI-2 was 0.34 g/L, which was approximately double of that obtained from Desmodesmus sp. TAI-1, 0.18 g/L (Fig. 2c). These results suggested that Chlamydomonas sp. TAI-2 was the promising strain for biomass growth and lipid accumulation under the investigation conditions.

3.2. Effect of illumination period on growth and total lipid content of Chlamydomonas sp. TAI-2

Light and dark phases are the two phases of photosynthesis. In the light reactions the cells convert light energy into chemical energy, which is stored in high-energy compounds for dark reactions to fix CO₂ (Jacob-Lopes et al., 2009). In order to investigate the effect of illumination period on cell growth and lipid accumulation of Chlamydomonas sp. TAI-2, continuous illumination and 14:10 light and dark cycle was studied, respectively.

As shown in Table 1, the growth of Chlamydomonas sp. TAI-2 with continuous illumination was 1.3 g/L, slightly lower than that obtained from 14:10 light and dark cycle, 1.5 g/L. However, the lipid content of cells obtained from continuous illumination was 25.3%, which was approximately 1.5 times of that obtained from 14:10 light and dark cycle, 16.8%. The lipid productivity obtained from continuous illumination was 0.34 g/L, better than that obtained from 14:10 light and dark cycle, 0.25 g/L. As a result of the experiments of various illuminations, continuous illumination was chosen as the best condition with respect to lipid production and further experiments were conducted under this condition.

3.3. Effect of different nitrogen source concentrations on cell growth and lipid accumulation

The effect of nitrogen source concentrations on cell growth and lipid accumulation of Chlamydomonas sp. TAI-2 was studied in modified BBM medium containing 3 and 6 mM sodium nitrate, respectively. The biomass, lipid content and lipid productivity obtained from different sodium nitrate concentration are shown in Table 1. Li et al. (2009) demonstrated that increased sodium nitrate concentration could promote the growth of N. oleoabundans significantly when the sodium nitrate concentration was below 10 mM. In this study, the biomass of Chlamydomonas cells cultured in modified BBM medium containing 6 mM sodium nitrate was 1.8 g/L, which was approximately 1.4 times of that obtained with 3 mM sodium nitrate. In contrast to biomass, the lipid content of microalgal cells obtained with 3 mM sodium nitrate, 25.3%, was better than that obtained with 6 mM sodium nitrate, 18%. The reduction in nitrogen in the medium increases the lipid content in this microalgal strain. This result is similar to some Chlorella strains and N. oleoabundans (Illman et al., 2000; Li et al., 2009). Under nitrogen starvation, many algal species were reported to accumulate lipids (Illman et al., 2000; Solovchenco et al., 2008; Li et al., 2009). The nitrogen concentration was depleted at day 3 and day 4 when Chlamydomonas sp. TAI-2 was cultivated in medium containing 3 mM sodium nitrate and 6 mM sodium nitrate, respectively.

The lipid productivity of Chlamydomonas cells cultivated in 6 mM sodium nitrate was slightly lower than that cultivated in 3 mM sodium nitrate.

3.4. Effect of different nitrogen sources on growth and lipid accumulation

To investigate an optimal nitrogen source for cell growth and lipid accumulation of Chlamydomonas sp. TAI-2, 41.2 mg N/L of sodium nitrate, ammonium chloride and urea supplied in modified BBM medium were tested, respectively. As shown in Table 2, ammonium can support less growth of Chlamydomonas cells under starvation, and nitrogen source was approximately 0.553 g/L. However, the maximum lipid accumulation of Chlamydomonas sp. TAI-2 was studied in modified BBM medium containing 3 and 6 mM sodium nitrate, respectively. As shown in Table 2, ammonium can support less growth of Chlamydomonas cells under nitrogen starvation, many algal species were reported to accumulate lipids (Illman et al., 2000; Solovchenco et al., 2008; Li et al., 2009). The nitrogen concentration was depleted at day 3 and day 4 when Chlamydomonas sp. TAI-2 was cultivated in medium containing 3 mM sodium nitrate and 6 mM sodium nitrate.

The lipid productivity of Chlamydomonas cells cultivated in 6 mM sodium nitrate was slightly lower than that cultivated in 3 mM sodium nitrate.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tr>
<td>Biomass (g/L)</td>
</tr>
<tr>
<td>Lipid content (%)</td>
</tr>
<tr>
<td>Lipid productivity (g/L)</td>
</tr>
</tbody>
</table>

a The biomass and lipid content were measured at day 10.

b The lipid productivity was obtained at day 10.

c LDC + N: 10:14 light/dark cycle and 3 mM sodium nitrate. CL + N: continuous illumination and 3 mM sodium nitrate. CL + 2 N: continuous illumination and 6 mM sodium nitrate. All experiments were performed in 6-L photobioreactor contained 5-L modified BBM medium at room temperature with continuous illumination of 125 molm² s⁻¹ and aerated with 3% CO₂.

Fig. 2. Biomass, lipid content and lipid productivity variations of Desmodesmus sp. TAI-1 and Chlamydomonas sp. TAI-2 cultivated in BBM medium with 3% CO₂ aeration under continuous illumination during 10 days incubation.
content of *Chlamydomonas* sp. TAI-2 was 23.2% when urea was the nitrogen source (Table 2). Compared with these three nitrogen sources, the maximum lipid productivity of *Chlamydomonas* sp. TAI-2 was obtained when urea is the nitrogen source. The results showed that urea was the suitable nitrogen source for lipid production of *Chlamydomonas* sp. TAI-2 among the three tested nitrogen compounds under the tested conditions.

### 3.5. Effect of CO2 concentration on growth and total lipid content

In order to investigate the influence of CO2 concentration on microalgal growth and lipid accumulation, 3%, 5% and 10% of CO2 concentrations were studied on *Chlamydomonas* sp. TAI-2, respectively. The results were shown in Table 3. The biomass production of microalgal cells was very similar in all three cultures at approximately 1.5 g/L. However, the maximal lipid productivity (0.31 g/L) of microalgal cells was obtained in 5% CO2 aeration due to the maximal lipid content (20.9%). The optimal CO2 aeration was 5% for *Chlamydomonas* sp. TAI-2 to achieve maximal lipid accumulation under continuous illumination for 10 days.

### 3.6. Potential of *Chlamydomonas* sp. TAI-2 for combined wastewater treatment and lipid accumulation

According to the previous results, the N/P removal and lipid accumulation of the *Chlamydomonas* sp. TAI-2 was studied under continuous illumination and 5% CO2 aeration using industrial wastewater.

As shown in Fig. 3, the *Chlamydomonas* cells were able to achieve complete NH4+-N and NO3--N removal from industrial wastewater containing 38.4 mg NH4+-N/L and 3.1 mg NO3--N/L in two days. The rate of ammonium consumption was 19.2 mg NH4+-N/L/day. The removal of P was 33% from industrial wastewater containing 44.7 mg/L PO43--P in 10 days. The organic nitrogen in the wastewater could not be removed by the *Chlamydomonas* cells in the investigation condition.

In Fig. 4, the *Chlamydomonas* cells were well cultured in industrial wastewater. In generally, microalgal growth rate are lower in many industrial wastewater, due to low N and P concentration and high toxin concentrations (Pittman et al., 2011). In our study, this industrial wastewater was shown to have enough N and P to support microalgal growth, and there were no inhibitory effects of microalgal growth in this wastewater. The study of Chinnasamy et al. had shown that two freshwater microalgae *Botryococcus braunii* and *Chlorella saccharophila* were able to grow well on the untreated carpet industrial wastewater (Chinnasamy et al., 2010). The biomass of the *Chlamydomonas* cells obtained was constant after 5 days, the maximal biomass was 1.5 g/L. The maximal lipid productivity was obtained 0.28 g/L, at day 10.

The fatty acid composition of typical microalgal oil is mainly composed of a mixture of unsaturated fatty acids: palmitoleic acid (C16:1), oleic acid (C18:1), linoleic acid (C18:2) and linolenic acid (C18:3) as well as small content of saturated fatty acids: palmitic acid (C16:0) and stearic acid (C18:0) (Meng et al., 2009). The fatty acid compositions of the lipid from the *Chlamydomonas* sp. TAI-2 cultivated in industrial wastewater was determined every two days and the result was listed in Table 4. The fatty acid composition varied slightly during 10 days and the saturated fatty acids palmitic acid (C16:0), monounsaturated oleic (C18:1), and linolenic acid (C18:3) were dominant. The microalgal lipid was mainly composed of saturated fatty acid (54–79%) and the saturated fatty acids palmitic acid (16:0) presented a significant percentage (44–68%) of total lipid.

According to the quality standards of biodiesel from European Standards (EN, 2004), the linolenic acid (C18:3) content has a limit of 12% for a quality biodiesel. As shown in Table 4, the linolenic acid content of microalgal lipid was lower than 12% at day 6 and day 8. High-quality biodiesel should have similar percentage of saturated and unsaturated fatty acids to maintain high oxidative stability and low-temperature property (Knothe, 2005; Feng et al., 2011). In *Chlamydomonas* sp. TAI-2, the percentage was almost equal between saturated and unsaturated fatty acids at day 6 and day 8. Moreover, this strain had a high percentage of oleic acid (31.6%) considered to be an optimal fatty acid to exhibit a combination of oxidative stability and low-temperature property (Knothe, 2005; Feng et al., 2011). In *Chlamydomonas* sp. TAI-2, the percentage was almost equal between saturated and unsaturated fatty acids at day 6 and day 8. Moreover, this strain had a high percentage of oleic acid (31.6%) considered to be an optimal fatty acid to exhibit a combination of oxidative stability and low-temperature property (Knothe, 2005; Feng et al., 2011). In *Chlamydomonas* sp. TAI-2, the percentage was almost equal between saturated and unsaturated fatty acids at day 6 and day 8. Moreover, this strain had a high percentage of oleic acid (31.6%) considered to be an optimal fatty acid to exhibit a combination of oxidative stability and low-temperature property (Knothe, 2005; Feng et al., 2011).

### Table 3

<table>
<thead>
<tr>
<th>CO2 Concentration</th>
<th>Biomass (g/L)</th>
<th>Lipid Content (%)</th>
<th>Lipid Productivity (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% CO2</td>
<td>1.5</td>
<td>18.8</td>
<td>0.28</td>
</tr>
<tr>
<td>5% CO2</td>
<td>1.5</td>
<td>20.9</td>
<td>0.31</td>
</tr>
<tr>
<td>10% CO2</td>
<td>1.4</td>
<td>18.7</td>
<td>0.27</td>
</tr>
</tbody>
</table>

### References


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**Table 2**

<table>
<thead>
<tr>
<th>Ureaa</th>
<th>Sodium nitrateb</th>
<th>Ammonium chloridec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 mM</td>
<td>3 mM</td>
<td>3 mM</td>
</tr>
<tr>
<td>Biomass (g/L)d</td>
<td>0.492</td>
<td>0.553</td>
</tr>
<tr>
<td>Lipid content (%)d</td>
<td>23.2</td>
<td>19.7</td>
</tr>
<tr>
<td>Lipid productivity (g/L)d</td>
<td>0.14</td>
<td>0.11</td>
</tr>
</tbody>
</table>

a The biomass and lipid content were measured at day 11.
b The lipid productivity was obtained at day 11.
c All experiments were performed in 500 mL flasks contained 300 mL modified BBM medium at room temperature with continuous illumination of 25 μmol photons m–2day–1 and shaken at 120 rpm on an orbital shaker for 11 days.

d The lipid productivity was obtained at day 10.

---

**Table 4**

Biomass, lipid content and lipid productivity production by *Chlamydomonas* sp. TAI-2 at different CO2 concentrations.

<table>
<thead>
<tr>
<th>CO2 Concentration</th>
<th>Biomass (g/L)</th>
<th>Lipid Content (%)</th>
<th>Lipid Productivity (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% CO2</td>
<td>1.5</td>
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<tr>
<td>5% CO2</td>
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<tr>
<td>10% CO2</td>
<td>1.4</td>
<td>18.7</td>
<td>0.27</td>
</tr>
</tbody>
</table>

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**Fig. 3.** Nitrogen and phosphorus assimilation of *Chlamydomonas* sp. TAI-2 cultivated in the industrial wastewater with 5% CO2 aeration under continuous illumination during 10 days incubation.
achieve maximal lipid accumulation under continuous illumination. Using the industrial wastewater as the medium, *Chlamydomonas* sp. TAI-2 could remove 100% NH4\(^+\)-N and NO3\(^-\)-N and 33% PO4\(^3-\)-P and accumulate the lipid up to 18.4%. The composition of fatty acids is suitable to be utilized for biodiesel production. Therefore, the *Chlamydomonas* sp. TAI-2 is a promising microalgae to remove nitrogen and phosphorus in the industrial wastewater and subsequently to produce biodiesel.

**Acknowledgement**

This study was supported by a fund from National Science Council in Taiwan.

**References**


European Standard EN 14214 2004. Automotive fuels-fatty acid methyl esters (FAME) for diesel engines-requirements and test methods.


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**Table 4**

<table>
<thead>
<tr>
<th>Fatty acid (% of total fatty acid)</th>
<th>Time (day)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
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<tbody>
<tr>
<td>C14:0</td>
<td></td>
<td>–</td>
<td>12.1</td>
<td>4.1</td>
<td>4.3</td>
<td>4.9</td>
</tr>
<tr>
<td>C16:0</td>
<td></td>
<td>68.4</td>
<td>66.4</td>
<td>43.9</td>
<td>43.6</td>
<td>61.1</td>
</tr>
<tr>
<td>C16:1</td>
<td></td>
<td>–</td>
<td>–</td>
<td>4.6</td>
<td>3.7</td>
<td>6.2</td>
</tr>
<tr>
<td>C18:0</td>
<td></td>
<td>–</td>
<td>–</td>
<td>5.5</td>
<td>5.7</td>
<td>6.7</td>
</tr>
<tr>
<td>C18:1</td>
<td></td>
<td>–</td>
<td>–</td>
<td>31.7</td>
<td>31.6</td>
<td>–</td>
</tr>
<tr>
<td>C18:2</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>C18:3</td>
<td></td>
<td>31.6</td>
<td>21.5</td>
<td>10.2</td>
<td>11.1</td>
<td>21.1</td>
</tr>
<tr>
<td>Saturated</td>
<td></td>
<td>68.4</td>
<td>78.5</td>
<td>53.5</td>
<td>53.6</td>
<td>72.7</td>
</tr>
<tr>
<td>Unsaturated</td>
<td></td>
<td>31.6</td>
<td>21.5</td>
<td>46.5</td>
<td>46.4</td>
<td>27.3</td>
</tr>
</tbody>
</table>

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*: Not detectable.

During 10 days incubation.*

*Fig. 4. The variation of biomass, lipid content and lipid productivity of *Chlamydomonas* sp. TAI-2 cultivated in industrial wastewater with 5% CO2 aeration under continuous illumination during 10 days incubation.

4. Conclusion

The native strains, *Chlamydomonas* sp. TAI-2 had higher biomass production and lipid accumulation than *Desmodesmus* sp. TAI-1. The optimal CO2 aeration was 5% for *Chlamydomonas* sp. TAI-2 to proved if mix with other sources of algal oil (Chinnasamy et al., 2010).