FULL LENGTH ARTICLE

Bioremediation of the textile waste effluent by *Chlorella vulgaris*

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**KEYWORDS**

Chlorella vulgaris; COD; Colour removal; Microalga; Textile waste effluent

**Abstract** The microalga biomass production from textile waste effluent is a possible solution for the environmental impact generated by the effluent discharge into water sources. The potential application of *Chlorella vulgaris* for bioremediation of textile waste effluent (WE) was investigated using 2² Central Composite Design (CCD). This work addresses the adaptation of the microalga *C. vulgaris* in textile waste effluent (WE) and the study of the best dilution of the WE for maximum biomass production and for the removal of colour and Chemical Oxygen Demand (COD) by this microalga. The cultivation of *C. vulgaris*, presented maximum cellular concentrations $C_{\text{max}}$ and maximum specific growth rates $\mu_{\text{max}}$ in the wastewater concentration of 5.0% and 17.5%, respectively. The highest colour and COD removals occurred with 17.5% of textile waste effluent. The results of *C. vulgaris* culture in the textile waste effluent demonstrated the possibility of using this microalga for the colour and COD removal and for biomass production. There was a significant negative relationship between textile waste effluent concentration and $C_{\text{max}}$ at 0.05 level of significance. However, sodium bicarbonate concentration did not significantly influence the responses of $C_{\text{max}}$ and the removal of colour and COD.

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**Introduction**

The world is facing a number of environmental challenges. Consequently, Egypt has directed significant concern to resolve the pressing environmental problems by taking several measures including ratifying various international environmental conventions and treaties that are to be harmonized into the national legislative framework. The textile industry and its waste waters have been increasing proportionally, making it one of the main sources of severe pollution problems worldwide (IPPC 2003).

Synthetic dye usage has increased in the textile and dyeing industries because of their ease and cost-effectiveness in synthesis, firmness, high stability to light, temperature, detergent and microbial attack and variety in colour compared with natural dyes (Nawar and Doma, 1989; Couto, 2009). The major
environmental problem associated with the use of dyes is their lose during dyeing process since the fixation efficiency ranges from 60 to 90% (Sugiura et al., 1999).

Fifteen percent of the total world production of dyes is lost during dyeing process and is released in the textile effluents. The release of coloured wastewaters in the ecosystem is a dramatic source of esthetic pollution, eutrophication, and perturbations including decrease in the photosynthetic activity and dissolved oxygen (DO) as well as alteration of the pH, increase in the biochemical oxygen demand (BOD) and chemical oxygen demand (COD), in aquatic life (Amin et al., 2008). Therefore, treatment of these industrial effluents is necessary prior to their final discharge to the environment. Various physical/chemical methods have been used for the removal of dyes from wastewaters (dos Santos et al., 2007; Saratale et al., 2011). These methods have some drawbacks, such as not all dyes, currently used can be degraded or removed with physical and chemical processes and sometimes the degradation products are more toxic (Abadulla et al., 2000; Nerud et al., 2001; Sharma et al., 2002). So that treatment methods must be tailored to the chemistry of the dyes (ICABRU, 2009).

Biological techniques which are cheaper and easier to operate have become the focus in recent studies of dye degradation and colorization. Microbial and enzymatic colorization and degradation of azo dyes have significant potential to address this problem due to their environmentally-friendly, inexpensive nature, and also they do not produce large quantities of sludge (Saratale et al., 2011).

Microalgae are known to remove dyes by bioadsorption, biodegradation and bioconversion. Microalgae degrade dyes for nitrogen source, by removing nitrogen, phosphorus, and carbon from water, it can help reduce eutrophication in the aquatic environment (Olguín, 2003; Ruiz et al., 2011) and, are unique in sequestering carbon dioxide, one of the main contributors to the greenhouse effect (Mata et al., 2011). Moreover, microalgae can grow at a rapid pace and, in inhospitable conditions, using water unfit for human consumption (Mata et al., 2010, 2011).

In this study, statistical experimental design was employed. These designs have many advantages and were used in many successful degradative studies (Saravanan et al., 2008). Compared to conventional one factor at a time experiments, statistical based factorial design of experiments gave more meaningful information on the effects, main and interaction, of the factor involved in the given study. Furthermore, the added advantage of reduction in the number of experiments to be performed. Employing such techniques proves more attractive for systematic investigations without compromising the accuracy of representation of the environmental system (Montgomery, 2004). On the other hand, single variable optimization methods are not only tedious, but also can lead to miss interpretation of results, especially because the interaction effects between different factors are over looked (Wenster-Botz, 2000).

Therefore, this research article aims to phytoremediate a textile waste effluent generated from Kafr Eldwar Dyeing Textile Industry, local textile dyeing industry, near Alexandria, Egypt. The present study was designed to identify microalgae strains present in the waste effluent. In addition, the ability of the dominant algal strain, Chlorella vulgaris was evaluated as an efficient phytoremediator to decolorize, detoxify and degrade this effluent. This work addresses the adaptation of the microalgae C. vulgaris in a textile waste effluent and studies the ideal wastewater dilution as well as sodium bicarbonate concentration for the maximum reduction of colour and Chemical Oxygen Demand (COD).

Materials and methods

Textile effluent characterization

The textile waste effluent (WE) was collected from the region of waste discharge at the water body as it reaches Abu-Qir bay in Alexandria, Egypt and stored under cooling to 4 ºC. Physio-chemical analyses of the water sample were carried out following the methods described by APHA (2000).

The microalgal flora in the effluent was identified following the Utermöhl’s (1958) method. The samples were immediately fixed with 4% formaldehyde for laboratory analysis and microalgae were counted and identified using 2 ml settling chambers with a Nikon TS 100 inverted microscope at 400x magnification. The dominant algal strain, Chlorella vulgaris was used throughout the study work.

The algal strain and growth conditions

The algal strain C. vulgaris was isolated and purified in axenic cultures and used throughout this study. It was cultivated as batch cultures in 1 l Erlenmeyer flasks with Bold’s Basal Medium (BBM) (Nichols, 1973) at an initial count of 4 × 10^5 cells ml^-1. For the production of biomass, exponentially growing algal culture was transferred into fresh sterile medium [10% (v/v) of inoculums]; Cultures were illuminated by tubular fluorescent lamps (PHILIPS Master TL-D 85 W/840). The light intensity at the surface of the culturing vessels was 100 µ mol photons m^-2 s^-1 with a photoperiod of 16:8 h light: dark at 25 ± 1 ºC.

The culture medium for the runs was the final textile effluent itself, which was used after dilution according to a Factorial Design. Algal cells were inoculated at a concentration of 20% (V_inoculation/V_medium) in 500 ml Erlenmeyer flasks incubated at a thermo-statically controlled environmental chamber at 25 ± 1 ºC with a luminance of 3,000 lux and with a 12 hours light/dark photoperiod (Tanticharoen et al., 1994) for 15 days. The experiment was carried out in triplicate and average values were recorded.

Factorial design

A 2^2 Central Composite Design (CCD) was used to study the influence of the wastewater concentration and sodium bicarbonate concentration on the C. vulgaris growth and the removal of wastewater pollutants. The maximum wastewater concentration for the Factorial Run Design was stipulated from the preliminary cultivation tests of the microalgae in the textile waste effluent, using as standard. Table 1 shows the real and coded values of the variables used in the 2^2 Central Composite Design (CCD). Distilled water was used for the dilutions of the waste effluent.

Monitoring of algal growth

Data of the cell density using a haemocytometer slide versus culture times were plotted and submitted to polynomial
Table 1 Physicochemical characteristics of the textile industrial effluent WE.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour intensity</td>
<td>Absorbance at 660 nm</td>
<td>0.114</td>
</tr>
<tr>
<td>pH</td>
<td>–</td>
<td>8.05</td>
</tr>
<tr>
<td>Conductivity</td>
<td>mS</td>
<td>10.23</td>
</tr>
<tr>
<td>TS</td>
<td>mg l⁻¹</td>
<td>735</td>
</tr>
<tr>
<td>TDS</td>
<td>mg l⁻¹</td>
<td>506</td>
</tr>
<tr>
<td>TSS</td>
<td>mg l⁻¹</td>
<td>229</td>
</tr>
<tr>
<td>COD</td>
<td>mgO₂ l⁻¹</td>
<td>51.2</td>
</tr>
<tr>
<td>CL%</td>
<td>%</td>
<td>0.26</td>
</tr>
<tr>
<td>SO₄</td>
<td>mg l⁻¹</td>
<td>88.67</td>
</tr>
<tr>
<td>TP</td>
<td>mg l⁻¹</td>
<td>1.51</td>
</tr>
<tr>
<td>P</td>
<td>μg l⁻¹</td>
<td>0.96</td>
</tr>
<tr>
<td>TN</td>
<td>%</td>
<td>0.105</td>
</tr>
<tr>
<td>NO₃</td>
<td>μg l⁻¹</td>
<td>0.55</td>
</tr>
<tr>
<td>NO₂</td>
<td>μg l⁻¹</td>
<td>1.95</td>
</tr>
<tr>
<td>Ca</td>
<td>mg l⁻¹</td>
<td>140.28</td>
</tr>
<tr>
<td>Mg</td>
<td>mg l⁻¹</td>
<td>159.72</td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>mg l⁻¹</td>
<td>7.05</td>
</tr>
<tr>
<td>Zn</td>
<td>mg l⁻¹</td>
<td>8.61</td>
</tr>
<tr>
<td>Cr</td>
<td>mg l⁻¹</td>
<td>6.33</td>
</tr>
<tr>
<td>Mn</td>
<td>mg l⁻¹</td>
<td>10.5</td>
</tr>
<tr>
<td>Fe</td>
<td>mg l⁻¹</td>
<td>380.4</td>
</tr>
</tbody>
</table>

Algal flora that occurred in the WE were identified. The results revealed that the species belonging to 4 families were identified during January, 2013 (Table 2, Fig. 1). The mean total phytoplankton cell abundance was 353, 552, 4 cells l⁻¹. The temporal pattern showed the presence of 26 taxa recorded that Chlorophyta made up the highest number (44.65%) and are represented by (8 genera, 14 species) Chlorella vulgaris Beyerinck, Ankistrodesmus falcatus (Corda) Raals, Ankistrodesmus setigerus (Schröder) G.S.West., Coelastrum microporum Nägeli, Crucigenia rectangularis (Nägeli) Gay, Crucigenia tetrapedia (Kirchner) Kuntze, Crucigenia quadrata Morren, Kirchnerella contort (Schmidle) Bohlin, Pediasstrum simplex Meyen, Pediasstrum tenuis (Ehrenberg) Raals, Scenedesmus bijugatus Kützing, Scenedesmus dimorphus (Turpin) Kützing, Scenedesmus quadricauda Chodat, and Tetraedron trigonum (Nägeli) Hansgirg. Followed by Bacillariophyta (39.05%), 7 genera and 10 species, including Amphora ovalis (Kützing) Kützing, Bacillaria paradoxa J.F.Gmelin, Cyclotella meneghiniana Kützing, Cyclotella glomerata B.H.Buchmann, Aulacoseira granulata (Ehrenberg) Simonsen, Navicula gracilis Lauby, Nitzschia apiculata (W.Gregory) Grunow, Nitzschia obtusa W.Smith, Nitzschia palea (Kützing) W.Smith, Nitzschia sigma (Kützing) W.Smith and Synedra utilis (Nitzsch) Ehrenberg , then Cyanophyta (12.3%); (6 genera, 9 species), Aphanoocapsa delicatissima West & G.S.West , Chroococcus dispersus (Keissler) Lemmermann, Chroococcus minutus (Kützing) Nägeli, Dactylococcopsis actedelaris Lemmermann, Merismopedia punctata Meyen, Microcystis aeruginosa (Kützing) Kützing, Oscillaria limnetica Lemmermann, Oscillaria irrigua Kützing ex Gomont and Oscillatoria tenuis C.Agardh but there was a remarkably low number of Euglenophyta (4.00%) were represented by 2 genera and 3 species that are Euglena caudata Hüblner, Phacus curvicauda Svenero and Phacus pyrum

<table>
<thead>
<tr>
<th>Group</th>
<th>Genus</th>
<th>Species</th>
<th>Cells l⁻¹</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyta</td>
<td>7</td>
<td>9</td>
<td>156,763.9</td>
<td>44.65</td>
</tr>
<tr>
<td>Bacillariophyta</td>
<td>3</td>
<td>6</td>
<td>137,102.4</td>
<td>39.05</td>
</tr>
<tr>
<td>Cyanophyta</td>
<td>6</td>
<td>9</td>
<td>456,423</td>
<td>12.3</td>
</tr>
<tr>
<td>Euglenophyta</td>
<td>2</td>
<td>2</td>
<td>140,438</td>
<td>4.00</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>26</td>
<td>353,552.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2 Taxonomic composition and proportional representation of the microalgae groups at the WE during January, 2013.
Chlorella vulgaris is the most dominant species of Chlorophyta.

Cultivation of the microalga C. vulgaris and pollutants removal

The results presented graphically in Figs. 2–4 show the growth curves of C. vulgaris obtained for each run of factorial design. The results recorded in Table 3 represents the maximum specific growth rate ($\mu_{\text{max}}$) and $C_{\text{max}}$ of the 1st to 10th runs of the factorial design for evaluating the influence of the concentrations of both wastewater and sodium bicarbonate on the growth of the microalga C. vulgaris, as well as the reduction of colour and COD. The largest SBC in 3rd run (13.5%), compared to 1st run (6.5%), caused no increasing of the values of $\mu_{\text{max}}$ and $C_{\text{max}}$. The 5th run, which was accomplished with the smallest WC (5.0%), SBC of 10.0 g l$^{-1}$, obtained the largest $C_{\text{max}}$ of 270,009 cells ml$^{-1}$.

The 2nd run (WC = 26.5%; SBC = 6.5 g l$^{-1}$), 4th run (WC = 26.5%; SBC = 13.5 g l$^{-1}$) and 6th run (WC = 30.0%; SBC = 10.0 g l$^{-1}$) presented cellular death of culture and consequently the smallest values of $C_{\text{max}}$ was 211,070 cells ml$^{-1}$.

The comparison of 7th run (WC = 17.5%; SBC = 5.0 g l$^{-1}$) and 8th run (WC = 17.5%; SBC = 15.0 g l$^{-1}$), revealed that the addition of sodium bicarbonate in the superior level resulted in obtaining higher values of $\mu_{\text{max}}$ and $C_{\text{max}}$ of 0.52 d$^{-1}$ and 218,080 cells ml$^{-1}$ for 8th run, in comparison to 0.26 d$^{-1}$ and 210,090 cells ml$^{-1}$ for 7th run.

The 9th and 10th runs, which are replicates (WC = 17.5%; SBC = 10.0 g l$^{-1}$) and 10th run (WC = 17.5%; SBC = 10.0 g l$^{-1}$), wherever the result of $\mu_{\text{max}}$ was found in run 10 (0.52 d$^{-1}$) and of $C_{\text{max}}$ in run 9 (224,030 cells ml$^{-1}$).
of the WE. The concentrations of COD recorded at the end of all runs were smaller than the initial ones, evidencing the COD removal during the time of this research study.

The results presented in Fig. 5a, b and c show the surface responses of $C_{\text{max}}$, colour and COD removal due to WC and SBC. The results indicate that the SBC concentration did not influence significantly the responses of $C_{\text{max}}$ and the removal of colour and COD. However, the linear effects of WE concentration evidenced significant influences in the answers of $C_{\text{max}}$ ($p < 0.05$). Largest $\mu_{\text{max}}$, $C_{\text{max}}$ were obtained in the small WE concentration added, in the order of 8.5%), while highest colour and COD removals were obtained in the other level of WC (17.5%). Parallel to the largest $\mu_{\text{max}}$, $C_{\text{max}}$, the maximal algal dry weight records were observed.

### Discussion

The characteristics of the WE were highly variable but comparable to those reported by a previous study (Rahman, 1993). The physicochemical characteristics of the WE were within the range of the values recorded by Lim et al. (2010) during their study on bioremediation of Malaysian textile wastewater. Copper and chromium compounds have known uses in textile manufacturing, particularly for dyeing processes (IPPC, 2003). Copper has also been previously reported in some dye plant effluents (Sharma et al., 2007). However, the constituents of the textile waste effluents differ according to the raw materials used in this industry.

The largest SBC in 3rd run, compared to 1st run containing the lowest SBC, caused the increase of the values of $\mu_{\text{max}}$ and $C_{\text{max}}$. The addition of sodium bicarbonate in the superior level during 7th run leads to obtaining higher values of $\mu_{\text{max}}$ and during 8th runs resulted in obtaining higher values of $C_{\text{max}}$. However, 5th run, which was accomplished with the smallest waste concentration and moderate SBC, obtained the maximum $C_{\text{max}}$. Using larger WE concentrations, observed in 7th and 8th runs, the control of the pH through the sodium bicarbonate buffer is necessary due to the fact that the wastewater causes a decrease of the pH in the medium, making the micro alga growth unfeasible. It can be predicted that the low WE concentration does not cause pH variations that limit the growth of the micro alga, thus the buffer effect of the bicarbonate is necessary. However, the statistical analysis revealed that the concentrations of bicarbonate did not significantly affect the variables $\mu_{\text{max}}$ and $C_{\text{max}}$.

### Table 3

<table>
<thead>
<tr>
<th>Run</th>
<th>WC (% C0)</th>
<th>SBC, g l$^{-1}$</th>
<th>Colour removal (%)</th>
<th>COD removal (%)</th>
<th>$C_{\text{max}}$ (cells ml$^{-1}$)</th>
<th>$\mu_{\text{max}}$</th>
<th>Dry wt (g l$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.5 (−1)</td>
<td>6.5 (−1)</td>
<td>74.6</td>
<td>69.25</td>
<td>260,000</td>
<td>0.89</td>
<td>1.74</td>
</tr>
<tr>
<td>2</td>
<td>26.5 (+1)</td>
<td>6.5 (−1)</td>
<td>73.7</td>
<td>65.60</td>
<td>211,070</td>
<td>0.42</td>
<td>1.88</td>
</tr>
<tr>
<td>3</td>
<td>8.5 (−1)</td>
<td>13.5 (+1)</td>
<td>72.8</td>
<td>67.50</td>
<td>252,090</td>
<td>0.87</td>
<td>1.68</td>
</tr>
<tr>
<td>4</td>
<td>26.5 (+1)</td>
<td>13.5 (+1)</td>
<td>71.16</td>
<td>51.25</td>
<td>220,002</td>
<td>0.47</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>5.0 (−α)</td>
<td>10 (0)</td>
<td>72.07</td>
<td>53.75</td>
<td>270,009</td>
<td>0.53</td>
<td>0.77</td>
</tr>
<tr>
<td>6</td>
<td>30.0 (+α)</td>
<td>10 (0)</td>
<td>74.66</td>
<td>63.13</td>
<td>220,123</td>
<td>0.56</td>
<td>0.88</td>
</tr>
<tr>
<td>7</td>
<td>17.5 (0)</td>
<td>5 (−α)</td>
<td>71.28</td>
<td>63.50</td>
<td>210,090</td>
<td>0.26</td>
<td>0.86</td>
</tr>
<tr>
<td>8</td>
<td>17.5 (0)</td>
<td>15 (+α)</td>
<td>76.32</td>
<td>49.10</td>
<td>218,080</td>
<td>0.53</td>
<td>1.55</td>
</tr>
<tr>
<td>9</td>
<td>17.5 (0)</td>
<td>10 (0)</td>
<td>75.40</td>
<td>63.75</td>
<td>224,030</td>
<td>0.52</td>
<td>1.50</td>
</tr>
<tr>
<td>10</td>
<td>17.5 (0)</td>
<td>10 (0)</td>
<td>75.68</td>
<td>69.90</td>
<td>208,011</td>
<td>0.52</td>
<td>1.49</td>
</tr>
</tbody>
</table>

The cellular deaths observed in 2nd, 4th and 6th runs may be attributed to the high WE concentration. Lim et al. (2010) studied the cultivation of *C. vulgaris*, from textile waste effluent; they stated that the dilution of the textile waste effluents is an important factor affecting the algal growth and biomass productivity. Moreover *C. vulgaris* grew in 100% waste effluent; although the final biomass attained was significantly lower ($p < 0.05$) than that grown in 20–80% textile waste concentration. However, Phang and Chua (2004) reported that *C. vulgaris* UMACC 001 was shown to be a versatile alga that is able to grow under various harsh conditions.

In this study *C. vulgaris* succeeded in decolorizing the WE during all the studied runs. In this respect, Acuner and Dilek (2004) reported that several species of *Chlorella* were capable of degrading azo dyes to their aromatic amines and to further metabolize the aromatic amines to simpler organic compounds or CO2 and thereby detoxifying them. Furthermore, El-Sheikh et al. (2009) reported the ability of *C. vulgaris* to decolorize a variety of azo dyes via algal azo dye reductase enzyme.

Gupta et al. (2006) and Ozer et al. (2006) suggested that the dye removal may be attributed to the accumulation of dye ions on the surface of algal biopolymers and further to the diffusion of the dye molecules from aqueous phase onto solid phase of the biopolymer. Moreover, Daneshvar et al. (2007) stated that colour removal by algae was due to three intrinsically different mechanisms of assimilative utilization of chromophores for the production of algal biomass, CO2 and H2O transformation of coloured molecules to non-coloured molecules, and adsorption of chromophores on algal biomass. Mohan et al. (2002) attribute the decolorization to biosorption followed by bioconversion and biocoagulation.

The final COD concentrations recorded at the end of all runs were smaller than the control value, confirming the COD removal during the time of this research study. However, it was observed that the COD removal occurred in runs, in addition to those that presented cellular death. This can be explained by the fact that Photosynthetic organisms and microalgae produce oxygen that enhances the biological degradation of the organic matter in the wastewaters (Aslan and Kapdan, 2006; Brito et al., 2007; HodaiVa et al., 2010a,b). COD removal might not have been accomplished exclusively by *C. vulgaris*; but also by other factors including the chemical oxidation caused by the aeration of the culture as well as microorganisms in the wastewater, which can promote the COD reduction of the medium according to Metcalf and Eddy (1993).
The phytoremediation of the textile industrial WE may be accomplished by phosphorous removal which could have started by two different mechanisms: by the biological assimilation during the biomass growth and by the chemical precipitation that occurred predominantly when the biomass concentration decreases, as during the decline phase or cellular death (Laliberte et al., 1997).

During the different treatments, reduced Electric Conductivity (EC) values (µS) were observed in the 1st run which are parallel to the maximum reductions in COD, colour, and the highest recorded values of $C_{max}$, $l_{max}$, and this may be due to the ability of algal species to consume the nutrients during the algal growth. In this respect, Oswald (1988) stated that total dissolved salts is one of the important factors that define the relationship of culture medium species in the cultivation of microalgae during nutrient and xenobiotic compound removal with the aid of algae-based biosorbents. This agrees with other studies using algae such as *Synechocystis* and *Phormidium* for removing colour from reactive dyes (Karacakaya et al., 2009).

The waste grown algal biomass may not be suitable for use as animal feed. However, there has been increased interest in using algae for biodiesel production (Huang et al., 2010). Moreover the amount of lipids in chlorophyta may be raised up to 45% of dry weight by stress or nutrient starvation (Hu et al., 2008). Using the current treatment design employed by the factory, the coloured wastewater is not suitable for final

![Figure 5](image-url) Interaction effect between wastewater concentration (WC) and sodium bicarbonate concentration (SBC) on $C_{max}$ (a); colour removal % (b); and COD removal % (c).
Conclusions and future directions

The microalga *C. vulgaris*, grown on the WE showed $C_{\text{max}}$ (270,009 cells ml$^{-1}$), $\mu_{\text{max}}$ (0.53 d$^{-1}$) in the smaller wastewater concentration added to the cultivation medium (5.0 and 8.5%), while larger COD removals (69.25 and 69.90%) and the largest colour removals (75.68%) were obtained using the moderate waste water concentration in the cultivation medium. Thus the cultivation of *C. vulgaris* in WE demonstrated the capability of biomass production, colour and COD removal; therefore this microalgae can be an alternative to assist in the textile culture effluent treatment, reducing the environmental impact caused by their pollutants. The algal biomass generated may be useful as feedstock, fertilizers or for biofuel production.

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References


