Production of Lutein-enriched Biomass by Growing Coccomyxa sp. (strain onubensis; Chlorophyta) under Spring Outdoor Conditions of Southwest Spain

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ABSTRACT

Coccomyxa sp. (strain onubensis) is an acidic environment microalga, which was grown under spring outdoor conditions of Huelva province (southwest, Spain). A 6 L pilot tubular photobioreactor was used to determine the influence of the environmental light and temperature conditions on the microalga growth and its intracellular content of carotenoids. Cloudy days supplied the adequate light intensity (maximum 1070 µmol photons m⁻² s⁻¹) and temperature (maximum 32°C) regimes for a biomass productivity of 0.28 g L⁻¹ d⁻¹ with an intracellular content of lutein (4.8 mg g⁻¹ dry weight) and eventually β-carotene (0.8 mg g⁻¹) obtained at the end of the day evening. This work supplies guidelines for a large-scale outdoor culture of Coccomyxa sp. to supply lutein-enriched biomass, with the advantage of the growth at pH 2.5, which preserves cultures from contamination.

Keywords

Coccomyxa sp.; Lutein; β-Carotene; Eukaryotic microalgae; Tubular photobioreactor.

Academic Discipline And Sub-Disciplines

Biology; Biotechnology

SUBJECT CLASSIFICATION

Biotechnology; Bioprocesses

TYPE (METHOD/APPROACH)

Outdoor bioproduction; Bioprocess engineering; High-added value compounds production

INTRODUCTION

Commercial interest of microalgae increased during the past decades due to its biomass, which is considered as a rich source of a vast group of chemicals with applications in food, nutritional, cosmetic, pharmaceutical and fuel industries [1].

The utilization of microalgae for humans is centuries old (Nostoc in Asia and Spirulina in Africa and Mexico), however, large-scale commercial production of biomass from microalgae date only from the 1950s when Chlorella and Arthrosperma began to be considered as new alternatives for foods [2,3,4]. In outdoor cultures, the availability of nutrients, light intensity and temperature are the main parameters that influence microalgal biomass production [5,6]. Light received by cells is a function of the incident light intensity on the surface of the reactor, the path length of the light from the surface to any point inside the culture, and the light attenuation produced by the cells themselves (mutual-shading effect) inside the reactor [7].

When irradiance intensity is low, the microalga photosynthetic machinery receives fewer photons than it can manage; and consequently, the growth of alga is light-limited. However, photosynthetic efficiency is usually high because the largest part of the absorbed light energy by the microalga had converted into biomass chemical energy [8]. Conversely, when irradiance intensity was high, the cultures were saturated for its photosynthetic activity; and then photooxidative damage may occur in the cells producing important degradation of photosystem II, thus, amazing cells viability. Microalgae have mechanisms to prevent photooxidation and some of them have been related with carotenoids production due to its antioxidant nature. Depending on microalga sensitivity to light, the irradiance intensity may induce the accumulation of carotenoids in the biomass [9].

Some studies have reported the influence of environmental parameters on biomass productivity from acidophilic microalgae; however, very few of them were done under outdoor conditions [10,11]. One of the main reasons that can explain this fact is because this kind of microalge apparently cannot compete for biomass production with mesophilic ones due to their low growth rate [12]. However, Coccomyxa sp. exhibits a relatively high growth rate under acidic conditions, as compared with other acidophilic microalgae; thus, it is a good candidate for outdoor cultivation with biotechnological purposes.
The effect of outdoor light intensity and temperature regimes of spring weather at Huelva province was studied on the biomass productivity and carotenoids accumulation of Coccomyxa sp. using an experimental tubular 6 L photobioreactor. The reported results provide hopes regarding the use of this microalga for large-scale production of lutein-enriched biomass.

MATERIALS AND METHODS

Microalga and growth medium

The unicellular eukaryotic microalga Coccomyxa sp. (strain onubensis) was isolated from the acidic waters of the Tinto river, which runs through a mining area in Huelva (Spain), and has very special features that include a low pH and high concentrations of heavy metals, such as iron, copper, magnesium and aluminium. The microalga has deposited in the Göttingen (Germany) stocks culture, with the number SAG 2510.

An axenic culture of this microalga has obtained by streaking it on a basal agar 1.75% (w/v) medium at pH 2.5, followed by transfer to liquid medium. According to the chemical composition of water in its natural environment, the microalga has grown at a pH of 2.5 in a modified K9 medium prepared with the following composition: 3.95 g K$_2$SO$_4$, 0.1 g KCl, 0.5 g K$_2$HPO$_4$, 0.41 g MgCl$_2$, 2.29 g KNO$_3$, 0.01 g CaCl$_2$ and 5 ml of Hutner trace elements solution. The microalgal cultures were bubbled with air containing 5% (v/v) CO$_2$. Incident light intensity on the cultures has measured at the surface of the photobioreactor using a photoradiometer Delta OHM (mod. HD9021).

Photobioreactor

The microalga has grown autotrophically in a pilot tubular photobioreactor (PBR) with a total length of 13 m made up with transparent acrylic pipes of 21 cm (inside diameter) and 25 cm (outside diameter) that included a degasser vertical column that acted to avoid dissolved oxygen accumulation in the culture and a spray cooling system to regulate temperature. In addition, the PBR has an inlet to bubble air enriched in CO$_2$. The total volume capacity of the PBR was 6 L, of which 4.5 L were within the pipes and 1.5 L within the degasser. The flow rate through the tubes was 6.0 L min$^{-1}$. A schematic diagram of the photobioreactor used in this study is shown in Figure 1.

![Photobioreactor Diagram](image-url)
Outdoor culture conditions

The regimens of incident light intensity and temperature on the microalga cultures are presented in Figures 2 and 3, respectively. Four experimental working conditions were used in these studies and they are the following:

VHLT Culture. The microalga growth proceeds under light and temperature conditions of a typical spring sunny day (late April) at the study site in Huelva province (Southwest, Spain). The cell culture endured moments of high-level of light intensity (approximately 1800 µmol photons m\(^{-2}\) s\(^{-1}\)) and maximum temperature of approximately 40ºC at the early afternoon. This culture underwent at “very high light and temperature” conditions, thus the name VHLT.

VHL Culture. The incident light intensity profile on the PBS was similar to that used for VHTL culture, but temperature has moderated with a spray cooling system, and maximum did not exceed 32ºC. This culture underwent at “very high light” conditions, thus, it has been referred to as VHL.

HL Culture. The microalga culture had submitted to the irradiance intensity and temperature change profiles typically produced during a spring cloudy day at the study site. The cell culture had exposed to a maximal light irradiance of 1070 µmol photons m\(^{-2}\) s\(^{-1}\) at the surface of the reactor, but the maximum temperature reached in the culture was 32ºC. This culture supports “high light” conditions (HL).

ML Culture. To limit the incident light intensity on the microalga cultures during the spring sunny days, the reactor was shaded with a mesh, and the algal culture was exposed to a maximal light intensity of 650 µmol photons m\(^{-2}\) s\(^{-1}\) and temperature of 36ºC. This culture supports “moderate light” conditions (ML).

Dry weight measurements and growth rate calculations

Dry weight measurements and growth rate calculations were determined as previously described [13].

Quantum yield (QY)

To evaluate the photosynthetic performance, chlorophyll fluorescence measurements have been considered as the maximum quantum yield, QY (F\(_{v}/F\(_{m}\)) of the PSII photochemistry. This parameter was determined using pulse amplitude modulation (PAM) 210, Walz, Germany), according to the method previously described [14].

Chlorophyll and carotenoids determination

Pigments were extracted using 1 mL aliquots of the cultures. The cells were spun down for 8 min at 13000 rpm, suspended in 1 mL of methanol, shaken vigorously for 1 min, and heated at 60 ºC in a water bath for 5 min. The suspension has then centrifuged for 8 min at 4400 rpm and pigments were in the supernatant. Carotenoids were separated from chlorophylls and were identified by HPLC following the method described by Young et al. [15]. An RP-18 column (TermoQuest, Thermo products, UK) was used with a mobile phase including ethyl-acetate (as solvent A) and acetonitrile and water (9:1, v/v) (solvent B). Standards (DHI, http://c14.dhigroup.com, Denmark) and their corresponding calibration curves have been used as reference to identify and quantify both lutein and β-carotene.
Measures of dissolved oxygen

Dissolved oxygen (DO) concentration in the culture is the result of an equilibrium between the oxygen-producing processes (e.g., photosynthetic activity) and oxygen-consuming processes (e.g., aerobic respiration and chemical oxidation) and the rates at which oxygen is added to, or removed from, the system by aeration or degassing, respectively. DO concentration was measured at the surface of the degasser using a portable oxymeter (Crison, OXI 45+).

Statistics

Each experiment was performed three times and the observed tendency was clear and coherent, but since outdoor conditions may slightly change from one day to another, the presented results correspond to one outdoor experiment done in a typical day conditions. Experimental results were obtained as mean ± S.D. of three parallel measures. A multifactorial analysis of the variance (ANOVA) was executed using the data obtained from each extract. Differences were considered statistically significant when \( p < 0.05 \).

RESULTS

Effect of outdoor light intensity and temperature profiles on maximum quantum yield and biomass productivity of Coccomyxa sp. cultures

Figure 4 shows the maximal \( Q_Y \) of PSII in the Coccomyxa sp. cultures under different experimental conditions used in this work. The VHTL and VHL cultures exhibited \( Q_Y \) under 0.60, with values as low as 0.50, during daytime with highest illumination, indicating that cells are under light-induced stress. On the other hand, the \( Q_Y \) values reached by HL and ML cultures are always over 0.70 and 0.60, respectively, which is compatible with non-stressed cells in the photobioreactor. The cells in these cultures exhibited healthy aspect (data not shown).

![Figure 4: Maximum quantum yield, \( Q_Y \) (Fv/Fm), of PSII in Coccomyxa sp. outdoor cultures. The initial biomass concentrations in the cultures were 0.80-0.85 g L\(^{-1}\). When indicated measurements were done through triplication using aliquots of the corresponding culture, data were given as mean values ± SD. Other experimental conditions are displayed in Figure 2.](image1)

![Figure 5: Biomass productivity of Coccomyxa sp. outdoor cultures. Data shown correspond to VHTL (white circles), VHL (white squares), HL (grey circles) and ML (dark circles) cultures. Other conditions as in Figure 4.](image2)

Figure 5 shows the diurnal relative biomass change in outdoor Coccomyxa sp. cultures. After 10 h of growth, the biomass increased by 12% (w/w) in both VHLT and VHL cultures, however, VHL culture exhibited higher biomass than VHHT culture during most part of the day, indicating that moderate temperature profile was better than high temperature regime for outdoor growth of Coccomyxa sp. The biomass productivity in HL and ML cultures differed significantly from each other during the daylight time, and a net increase of 35.0 and 15.5% (w/w), respectively, had been observed at 14:30 h local time.

Biomass productivity of Coccomyxa sp. was studied by growing the microalga for several days in HL and ML cultures (data not shown). After four days of growing, the obtained biomass productivity was 0.28 g L\(^{-1}\) d\(^{-1}\) and 0.14 g L\(^{-1}\) d\(^{-1}\), which supposes growth rate of 0.34 and 0.12 d\(^{-1}\), respectively. In HL culture, the DO (observed at the end of day solar time) increased gradually (data not shown) until 37% (v/v) with respect to the initial value.
Evolution of intracellular content of lutein in Coccomyxa sp. cultures

The effect of light and temperature on the intracellular lutein content had been studied in outdoor cultures of Coccomyxa sp. (Figure 6). At high light intensity, VHTL and VHL cultures, lutein content was below 4.0 mg g⁻¹, while in ML culture the cells showed the maximum lutein content of 5.4 mg g⁻¹ at 14:00 h local time, and HL culture showed 4.8 mg g⁻¹. However, during evening, a content of 4.8 mg lutein.g⁻¹ was obtained in both ML and HL cultures. The highest lutein/chlorophyll ratio of 0.37 was observed at the largest incident light intensity on the PBR in the VHLT culture, while a ratio of 0.25 was observed in the other cultures, all along the experiment. In addition, the intracellular β-carotene content was 1.1 mg g⁻¹ (ML culture) and 0.8 mg g⁻¹ (HL culture).

DISCUSSION

Microalgal photosynthetic performance, Qy, competes with the process of fluorescence and heat loss for excitation energy in the pigment antenna of PSII. According the Qy values obtained for Coccomyxa sp. cultures, the VHLT and VHL regimes induce an important stress in microalgal cells during daytime corresponding to highest incident light intensity. However, from 18:00 h ahead, a gradual recovery of Qy value was produced in both cultures until 0.6, which may indicate that Coccomyxa sp. cells overcome the light-induced stress. It is widely accepted that Qy value of a healthy microalga culture range between 0.70 and 0.80 [16]. Many photosynthetic organisms exhibit typical midday depression in the photosynthetic yield and they recovered well from this stress when the intensity of incident light was attenuated (Figure 4; [17]). Coccomyxa sp. grows well at a maximum temperature of 30ºC, and seems to have difficulties when temperature increases at 40 ºC, particularly if the incident light intensity on the culture is high. Conversely, some microalgae can grow well at temperature as high as 40ºC [18].

In short time (10 h) experiments, maximal biomass productivity was obtained at the early evening in HL culture (cloudy days), indicating that a maximum light irradiance of 1070 μmol photons m⁻² s⁻¹ on the PBR surface is well tolerated by the microalga (Qy = 0.68, Figure 4). These data, and those observed in VHTL and VHL cultures, suggest that incident light intensity on the surface of the culture is a critical factor for outdoor Coccomyxa sp. biomass productivity, and the cultures should be shadowed with a mesh in sunny days to preserve them from light-induced stress. In experiments extended during four days, an average of 0.28 g L⁻¹ d⁻¹ of biomass productivity of Coccomyxa sp. had been obtained in HL culture conditions strategy as compared with a productivity of 0.14 g L⁻¹ d⁻¹ corresponding to ML cultures. These data could have been improved by supplying to the culture with an organic carbon source, such as urea, in order to avoid the loss of biomass produced during the night [19]. Outdoor microalgae productivity data change significantly depending on photobioreactor type used for the culture, and data ranging between 2.70 and 0.05 g L⁻¹ d⁻¹ have been reported for Spirulina platensis and Haematococcus pluvialis, respectively, using tubular photobioreactor [20].

One of the major problems to consider for the design and operation of a closed photobioreactor is the accumulation of dissolved oxygen in the culture of microalgae [21]. In the case of Coccomyxa sp. HL culture, the photosynthetically generated oxygen during the PBR performance increased until a maximum of 37% (v/v) with respect to the initial value, but the microalga biomass production had not been negatively affected.

Lutein and β-carotene behave in Coccomyxa sp. as light harvesting pigments, in cultures with low-intensity incident light, and further, they may act as cells protectors against photooxidative damage eventually produced when cultures were submitted to high light intensity. Lutein has garnered increasing attention because its helps to prevent or diminish human age-related macular degeneration (AMD). Currently, lutein is obtained from marigold flowers, which content ranges between 0.06-1.2 % (w/w) [22]; however, reports of lutein-producing microalgae raise the question if they become an
alternative to plant flowers as natural sources of this valuable pigment [23]. Coccomyxa sp. in HL culture regime may reach the reasonable good lutein content of 4.8 mg g⁻¹ at the day evening (Figure 6) and it has the additional advantage of a biomass productivity higher than any other microalga culture. With some exceptions, the lutein content found in other microalgae used to be under 5.0 mg g⁻¹ [23].

Temperature is a more important parameter than light intensity influencing the intracellular content of β-carotene in microalgal cells [24], which is consistent with the data observed with Coccomyxa sp. Outdoor ML culture conditions (maximum temperature reached by the culture was 36°C) were the most adequate to reach optimum intracellular β-carotene content (between 0.9-1.0 mg g⁻¹). However, in HL cultures (maximum temperature reached 32°C) the β-carotene content reached at the daylight evening, was 0.8 mg g⁻¹, while the biomass production was two-fold that obtained with ML cultures, which favour the selection of cloudy days, as the best culture conditions for β-carotene production with Coccomyxa sp. The best microalga known to produce β-carotene is Dunaliella salina, with 8.3 mg L⁻¹ d⁻¹, but in this case lutein content was very low [25].

CONCLUSIONS
The findings in this work open possibilities for the production of lutein and β-carotene-rich biomass with the microalga Coccomyxa sp. in continuous outdoor cultures using a tubular photobioreactor. Spring cloudy days in Huelva province (Southwest Spain) supplied the best environmental regimes of incident light intensity on the culture and temperature profile for the growth of microalgal. However, in this area, sunny days are predominant at that time, and the outdoor PBR cultures should be shadowed with a mesh to preserve cells from photooxidative damage. Additionally, the biomass would have been harvested at the daylight evening when the intracellular lutein and β-carotene concentrations are high.

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REFERENCES


