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Influence of spectral light quality on the pigment concentrations and biomass productivity of *Arthrospira platensis*

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ABSTRACT

The species in the *Arthrospira* genus are cultured at a large scale throughout the world primarily for food supplements for human and animal diets. These species are valued for the rich composition of their biomass, which contains minerals, antioxidants, proteins and essential amino acids. This biomass can also be used for high-value product extraction, for example, the pigments chlorophyll *a*, β-carotene and phycocyanin as well as essential fatty acids. The use of LEDs is a solution for optimizing the productivity and biochemical composition of biomass produced by these microalgae. In this study, an innovative strategy for using LEDs was evaluated for *Arthrospira platensis* cultivation to increase its biomass productivity and high-value pigments (chlorophyll *a*, total carotenoids and phycocyanin). Microalgae suspensions were cultured in 250 mL Erlenmeyer flasks containing 120 mL of culture (George-modified Zarrouk's medium, pH 8.90) at 32 ± 1 °C with constant stirring and an initial biomass concentration of 0.03 g L^{-1}. The biomass weights from ten lighting conditions consisting of blue and red LEDs of different compositions were evaluated in relation to the algal productivity and the chlorophyll *a*, total carotenoid and phycocyanin contents. The best results were obtained using LEDs that had a 70% red and 30% blue composition and a light intensity of 100 μE m^{-2} s^{-1}, leading to an average biomass productivity of 0.148 g $L^{-1}d^{-1}$ and average concentrations of 21.35 μg mL^{-1}, 5.45 μg mL^{-1} and 167.98 μg mL^{-1} of chlorophyll *a*, carotenoids and phycocyanin, respectively, in the given culture volume.

1. Introduction

There is great demand for natural products to replace the chemical additives used in the food, pharmaceutical and cosmetics industries, which has stimulated research in the biotechnology field. The objective is to obtain natural products quickly, efficiently and independently of seasonal variations and crop regimes, which are major limiting factors in producing these compounds in higher plants. For this reason, the production of microalgal biomass has become a very promising alternative, due to its very high biomass productivities and other factors, such as the possibility of indoor cultivation. The advantages include the fact that microalgae production can be continuous and it does not follow harvest regimes; the culture medium can be reused, which reduces water consumption; CO_2 or residual organic carbon sources from industrial processes can be used as a source of carbon for growth [1]; it has higher photosynthetic efficiency than higher plants and is efficient at CO_2 fixation [2]; and the residual biomass derived from the extraction of the compounds of interest can still be used as a food supplement in feed or as fertilizer, among other possibilities. In addition, the production of commercial microalgae is already established in several countries, such as the United States, Australia, Israel, China and Chile [3].

Regarding commercial production, the primary species of microalgae grown throughout the world belong to the genera *Chlorella*, *Arthrospira*, *Dunaliella* and *Haematococcus* [3]. Among these, the species in *Arthrospira* known as *Spirulina* have the largest market, and they are currently cultivated in at least 22 countries [4]. Their production is primarily destined for the human and animal dietary supplement markets due to the high nutritional and functional value of their biomass, which is rich in minerals, antioxidants, vitamins, proteins, essential amino acids and polyunsaturated fatty acids (omega-3 and omega-6) [3]. With regard to obtaining high value-added compounds on a commercial scale, the biomass of *Arthrospira* is cultivated for the purpose of extracting phycocyanin, the only natural blue pigment used

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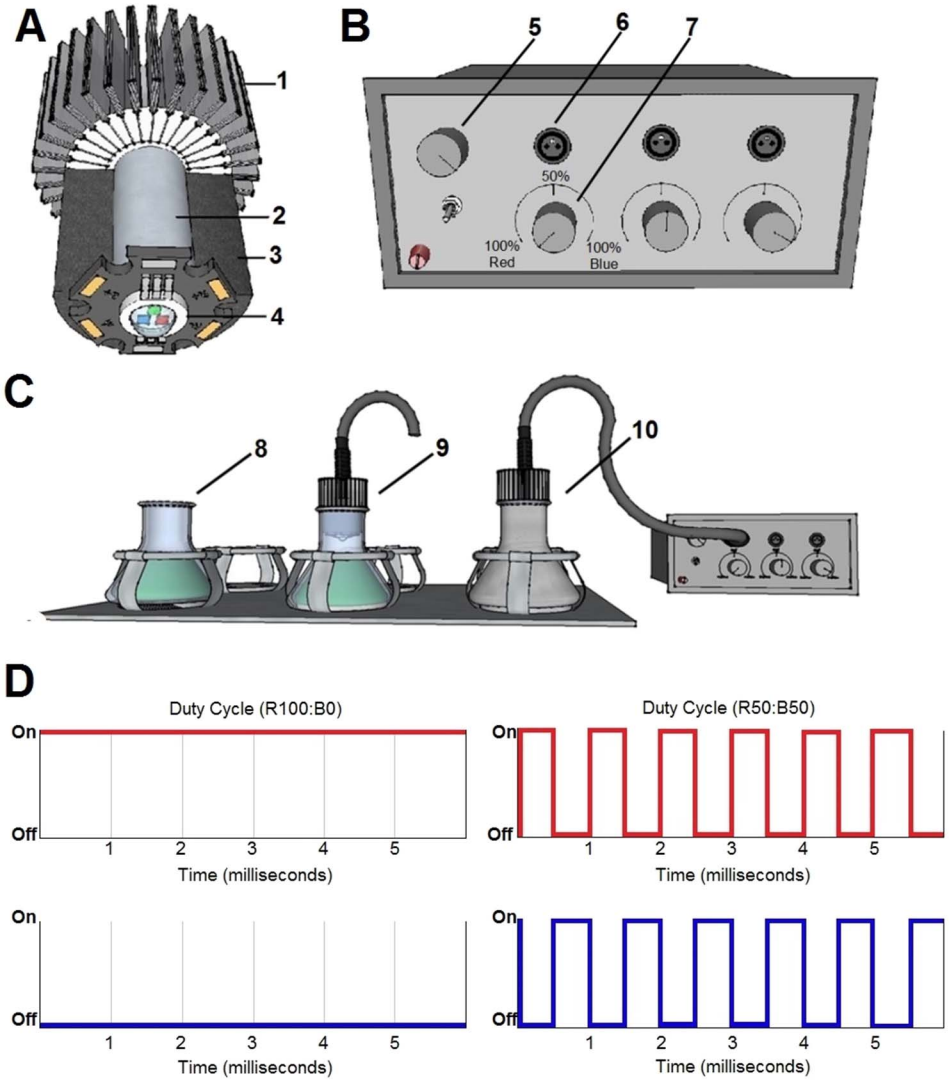

Fig. 1. (A) LED device in detail (A-1: heat sink; A-2: aluminum bar; A-3: foam for adjustment to the Erlenmeyer flask mouth; A-4: light emitting diode); (B) Power supply and spectral quality adjustment (B-5: potentiometer for general power adjustment; B-6: power output to LED device; B-7: potentiometer for spectral quality adjustment); (C) Experimental setup scheme (C-8: Erlenmeyer flask with cell suspension; C-9: Erlenmeyer flask with cell suspension equipped with an LED device; C-10: Erlenmeyer flask with cell suspension, equipped with LED device, wrapped by a protective cover and connected to the power supply and spectral quality adjustment); (D): Duty cycle graph of LEDs emitting 100% red and 50% red and 50% blue (Red line: operating cycle of red diode on or off with 1.0 and 0.5 duty cycle; Blue line: operating cycle of blue diode on or off with 1.0 and 0.5 duty cycle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

by the nutraceutical industry [5,6].

In addition to phycocyanin, the species within the genus *Arthrospira* also have other commercially important pigments [7,8], such as chlorophyll *a* (0.5% to 1% of the dry mass, on average) and carotenoids (0.1% to 0.2% of the dry mass, on average), which can be sold for very high prices in the market, ranging from US$ 3.00–US$ 25.00 per milligram for the raw pigment up to US$ 1500.00 per milligram for the purified pigment [9].

Several studies have been performed with the purpose of increasing the biotechnological knowledge and productive potential of *Arthrospira platensis* and of other microalgae, and most of them have focused on the following culture parameters: the light intensity [10–13], light sources and light regime (photoperiod) [13–16], temperature [17–20], pH [21–24], nutrient composition [25–27] and the type of culture system used to grow these organisms [28,29]. However, few of the studies published to date have focused on the spectral quality of light as an important parameter that influences the growth of the cultures and the biosynthesis dynamics of several biomolecules. Examples include studies by Abiusi et al. [30], Lee et al. [31], Schulze et al. [32], Schulze et al. [33], and Yeh et al. [34]. Among these authors, only Lee et al. [31] and Schulze et al. [33] studied the combination of different colors (red and blue); however, they only used continuous blue and red light illuminating the same culture in different proportions by managing the photon flux density of LEDs emitting light at different wavelengths. In addition, only Lee et al. [31] used *Arthrospira platensis*, and they did not investigate the production of carotenoids, which are pigments that have great commercial importance. This study presents a new approach to evaluating the influence of light on the production of microalgal biomass and compounds of interest given that LEDs are indeed optimal to study the effects of alternating flashing light in order to use different proportions of lights with different wavelengths by manipulating the relative duration of the light flash of each type of LED. Analyses were performed to study the influence of the spectral quality of light produced by light-emitting diodes (LEDs) on *A. platensis* cultures grown under controlled conditions, including the temperature, light intensity and pH, on the biomass productivity and commercial pigment content (total carotenoids, chlorophyll *a* and phycocyanin). LEDs were used as light sources because of their ideal optoelectronic characteristics (emissions within specific spectral bands and ability to work over a wide range of light pulse frequencies) and because they are a highly promising light source for use in commercial-scale cultures [32,34].

2. Materials and methods

2.1. Production of A. platensis inoculum

The species *A. platensis* from the Elizabeth Aidar Microalgae Collection that was provided by Professor Sergio Lourenço (Fluminense