Abstract

Microalgae have emerged as a sustainable biomass feedstock to address the contemporary challenges of healthcare, energy and environment through the production of high-value bioactive carotenoids, poly-unsaturated fatty acids and low-value biofuels with concomitant CO_2 mitigation in a biorefinery model. However, there has been a question mark on the viability and sustainability of microalgal biorefinery, mainly for low biomass and product yields and discrete downstream processing steps. In this context, the present thesis endeavours to optimize and integrate the bioprocess for improved production of biomass, lutein and lipid with CO_2 mitigation using the microalga *Chlorella minutissima*, and develop integrated downstream processing for concurrent recovery of lutein and biodiesel. Firstly, a suitable production medium was formulated through screening and optimization of essential nutrients by adopting Plackett–Burman design followed by artificial neural network–particle swarm optimization (ANN–PSO) technique. On optimization of critical medium components including nitrate, phosphate, manganese and copper, the productivities (mg L^{-1} d^{-1}) of biomass, lutein and lipid were found to be 570 ± 11, 3.45 ± 0.07 and 95.2 ± 3.3, respectively. Upon optimizing the influential process parameters like light intensity, CO_2 and aeration rate in a 2–L airlift photobioreactor by ANN–PSO technique, the productivities (mg L^{-1} d^{-1}) of biomass, lutein and lipid were enhanced to 672 ± 18, 4.32 ± 0.011 and 142.2 ± 5.6, respectively with CO_2 captured at a rate of 1.2 ± 0.03 g L^{-1} d^{-1}. The production of microalgal lutein and lipid was not significantly affected when flue gas was used as an alternative carbon source, suggesting possible utilization of flue gas through biological sequestration. As light influences lutein synthesis critically, light-feeding strategies were optimized followed by semi-continuous operation for facilitating higher rate of lutein synthesis. On integrating the optimized light-feeding strategy with semi-continuous mode, the productivities (mg L^{-1} d^{-1}) of biomass, lutein and lipid could be further improved to 870 ± 21, 6.34 ± 0.12 and 134.6 ± 5.2, respectively with photosynthetic efficiency of 11.7 ± 0.2% and CO_2 fixation rate of 1.59 ± 0.04 g $L^{-1}d^{-1}$. The performance of *C. minutissima* for co-production of lutein and lipid stands out to be efficient, as compared with most of the studies reported in literature. An integrated downstream process was subsequently designed to achieve simultaneous biomass harvesting and disruption using reusable magnetic nanocomposites (MNCs) namely, chitosan coated core-shell structures of Fe_3O_4–TiO_2. The harvesting efficiency of >98% was obtained at 0.07 g MNCs per g biomass. The harvested wet-biomass was then photocatalytically disrupted using visible light for 3 h. The cationic, photocatalytic and magnetic properties of MNCs were not significantly affected upon recycling it for five consecutive batches. Finally, lutein and lipid products were concomitantly separated through binary solvent systems followed by parallel saponification and transesterification to recover 94.3 ± 2.1% of lutein and 92.4 ± 1.8% of biodiesel. The recovered lutein product showed significant antioxidant activity by efficiently scavenging the free radicals induced by DPPH. The fuel properties of microalgal biodiesel complied with the international ASTM D6751 and EN 14214 standards. Thus, the thesis showcases the development of a green microalgal refinery model for integrated bioprocessing of algal biomass towards strategic enhancement of lutein and lipid production with CO_2 capture for healthcare, energy and environment applications.

Keywords: Microalgal biorefinery; Process optimization & integration; Photobioreactor; Light feeding strategy; Semi-continuous reactor operation; Downstream processing; Reusable biopolymer nanocomposites; Lutein; Lipid; Biodiesel; Flue gas CO_2 capture