Abstract

Dwindling fossil fuel reserves, increasing population, market volatility, and ecological repercussions have driven the need to develop alternative energy sources and efficient wastewater treatment systems. Photosynthetic Microbial Fuel Cells (PMFCs) emerge as a multifaceted solution, combining wastewater treatment, power generation, and valuable microalgae biomass recovery for potential biofuel applications within a single framework. Researchers have enhanced PMFC performance by refining electrodes, cathode catalysts, reactor design, and optimizing anodic bacteria to facilitate efficient electron transfer. However, widespread industrial adoption of PMFCs still needs to be improved.

To amplify the potential of PMFC-based microalgae biorefineries, selecting a cathodic strain that bolsters power output and yields high-value products (like carotenoids) is pivotal. In this context, our initial study identified a suitable microalgae strain, *Chlamydomonas reinhardtii*, boosting power generation efficiency (15.31 W/m^3) in PMFC when operated at 100 ml working volume in a fed-batch mode. Moreover, this strain yielded high-value microalgae biomass enriched with pigments, antioxidants, and antibacterial properties against known pathogens.

Subsequently, the *C. reinhardtii* strain was Genetically Modified (GM) to enhance carotenoid biosynthesis by exogenous expression of two critical genes, β-carotene ketolase and β-carotene hydroxylase from *Hematococcus pluvialis*, through nuclear transformation. The resultant GM algal lines exhibited a remarkable 5.39-fold increase in β-carotene production and showed astaxanthin production. Further, this Wild Type (WT) and GM C. *reinhardtii* were tested for MFC application at lab-scale reactor of 100 ml working volume in a fed-batch mode. GM microalgae didn't compromise MFC performance, while β-carotene production escalated 2.49 times compared to the WT microalgae. Collectively, this strategy overcomes significant challenges by generating alternative energy sources and producing high-value carotenoids, presenting an economically viable biorefinery approach.

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