

ABSTRACT

This study investigates the performance enhancement of microbial fuel cell (MFC) anodes through gold nanoparticle (AuNP) decoration on carbon nanotubes (CNTs), using lime juice as a green bioreductor. The objectives were to characterize the structure of CNT, CNT modified with polyethyleneimine (CNT/PEI), and CNT/PEI decorated with AuNPs synthesized at 5, 30, and 60 minutes; to analyze their electrochemical properties; and to evaluate their performance in *Saccharomyces cerevisiae*-based MFCs under semi-anaerobic conditions. Initial characterization included phytochemical screening and HPLC analysis, confirming the presence of reducing agents such as ascorbic acid, flavonoids, terpenoids, and alkaloids in lime juice. UV–Vis spectroscopy validated AuNP formation. Structural analysis was conducted using FTIR (functional group identification), XRD (crystallinity and grain size), FE-SEM with EDX–mapping (surface morphology and elemental distribution), and TEM–EELS (nucleation, dispersion, and clustering of AuNPs). Electrochemical behavior was examined using cyclic voltammetry and rate-determining step (RDS) analysis to determine the electron transfer rate constant (k_s). MFC performance was tested through voltage output, power density, and biofilm accumulation. Results revealed diffusion-controlled electron transfer through cytochrome *c*, as shown by the nonlinear RDS curves. The electron transfer rate constant (k_s) increases with longer AuNP synthesis duration, from $1.5328 \pm 0.0213 \text{ s}^{-1}$ (CNT) to $2.7161 \pm 0.0397 \text{ s}^{-1}$ (CNT/PEI/AuNPs 60 min). The best-performing anode (CNT/PEI/AuNPs 60 min) produced an average voltage of 50.39mV and a maximum power density of 40mW/m², outperforming CNT (24.18mV and 15mW/m²). Biofilm analysis showed CNT/PEI/AuNPs supported higher microbial growth (0.4096g) than CNT (0.1419g). Decorating CNTs utilizing lime juice as a bioreductor to form AuNPs significantly improves anode conductivity, biofilm formation, and electrochemical activity, leading to enhanced MFC performance under semi-anaerobic conditions.

Keywords: Microbial fuel cell-anode (MFC), gold nanoparticle (AuNP), carbon nanotube (CNT), polyethyleneimine (PEI), lime juice