Abstract

Carbon dots (CDs), also known as "carbonaceous quantum dots", are zero-dimensional carbon structures with remarkable physicochemical characteristics. Its tuneable optoelectronic properties like fluorescence and electron donating/accepting capabilities along with better aqueous-based solubility/dispersity and cytocompatibilities make them a promising candidate in various biomedical and environmental remediation applications. The selection of precursors and methods has largely impacted the inherent properties of CDs in terms of their applicability in various fields. The use of biomass precursors and bottom-up methods (microwave, hydrothermal, etc.) for the production of CDs represents a sustainable and environmentally friendly approach, aligning with the principle of green chemistry. Doping and surface passivation are techniques that enhance the optoelectronics properties of CDs by either incorporating heteroatoms within the core or attaching functional groups on the surface. The primary goal of this study was to Synthesis and modification of clove bud-derived carbon dots for multifaceted applications ranging from biomedical to water remediation.

The first objective adapted a simple and environmentally friendly hydrothermal method to synthesize clove buds-derived carbon dots (CCDs) at different temperatures between 120-200 °C. The optical characteristics of CCDs made at various temperatures were examined and compared, showing carbonization temperature-dependent influence on the optical properties. Optimized sample with higher fluorescence intensity was further tested for their suitability in the biological environment using cytocompatibility and hemolysis tests. Further CCDs were explored for in vitro cellular imaging showing strong and multicolour emission when excited with different laser sources. Interestingly, CDs are capable of brightening up RNA-rich nucleoli. Testing using ribonuclease digestion validates the localization of the CCDs in the nucleolus. Further, intracellular stability and good counterstaining compatibility feature them as a promising fluorescence probe for nucleolus imaging.

The second objective includes the utilization of in situ passivation and doping strategy to explore the multifaceted potential of clove bud-derived CDs. In the experiment, polyvinylpyrrolidone K-30 (PVP) as a passivating agent and iodine precursor (aqueous KI and resublimed I_2 solution) as dopant were used with clove buds for the synthesis of PPCCDs and I-CCDs samples that were explored for numerous interdisciplinary applications. Physicochemical characterizations of both CDs revealed their formations and the presence of passivating/doping agents in samples. The study further demonstrates their suitability in biological environments as an outcome of cytocompatibility results. PPCCDs have shown cellular imaging capabilities, significant antioxidant activity against DPPH (EC_{50}: 57 μg/mL), suppression of superoxide anion radical (EC_{50}: 53 μg/mL), and an efficient catalytic activity towards degradation of Rhodamine-B (Rh-B) dye demonstrating their versatility. I-CCDs represent a reduction in bacterial cell viability of 99.98% and 99.999% antibacterial activity for gram-positive and gram-negative strains along with efficient catalytic potential for cationic dye degradation (MB, Rh-B) at their highest studied concentrations. This indicates in situ passivation and doping of clove buds derived CDs have efficient potential to tune their applicability in various fields.

Eugenol, the major phytochemical of clove at higher doses acts as, a prooxidant causing local irritation, organ damage, and allergic reactions. The presence of clove powder in hydrothermal vessel during carbonization at higher temperatures might result in an increase of phenolic components in produced CDs. Through a facile, low-cost, and environmentally friendly method of synthesizing CDs, utilizing an aqueous extract of clove buds facilitated a significant reduction in toxicity associated with eugenol. The effect of CECDs concentrations on cell toxicity, hemocompatibility, and ex-vivo CAM assay was performed to recognize its usefulness in a biological environment. The bactericidal activity of CECDs also represents its effectiveness toward both gram-positive (*Staphylococcus. aureus*) and gram-negative (*Escherichia. coli*) strains. The antibacterial study reveals a log kill value of 3.5 and 4.2 for *E. coli* and *S. aureus* bacterial strains at 1mg/mL concentration, respectively. While dye degradation study reveals a 99.98 % reduction of selective methylene blue in 12 min at the same concentration. The obtained CECDs have shown a better potential to serve as antibacterial agents for disinfectant formulation and nanocatalysts and can be integrated into the current wastewater treatment and purification systems utilizing continuous flow-based novel bioreactor.

Keywords: Carbon dots, Clove buds, Surface passivation, Nucleolus imaging, ROS Scavenging, Antibacterial, Water remediation.