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Selective Fluorescence Sensing of Methylene Blue Dye Using Yeast-Based Carbon Dots: Experimental and Computational Study

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Synthetic dyes released from textile and related industries are a major source of aquatic pollution and can pose risks to ecosystem and human health. Methylene blue (MB), a widely used cationic thiazine dye in industrial dyeing and pharmaceutical applications, is of particular concern because it can persist in water and affect photosynthetic activity, aquatic biodiversity, and water quality. However, monitoring dye contamination often relies on laboratory-based analytical techniques that are costly and time-consuming, limiting rapid assessment in field conditions.

In this study, yeast powder (a low-cost and renewable bio-precursor) was converted into fluorescent carbon dots (C-dots) using a simple one-pot hydrothermal synthesis route. The as-prepared C-dots showed excitation-dependent fluorescence emission with a clear red shift from 360 to 460 nm. Structural and chemical characterisation using UV–Vis, TEM, XPS, XRD, FTIR and Raman spectroscopy confirmed quasi-spherical particles with an average size of 3–8 nm and an amorphous carbon structure enriched with oxygen-containing functional groups. The C-dots exhibited high stability across a wide range of pH and salinity (NaCl), under prolonged UV exposure and during storage.

The C-dots were then applied as a fluorescence-based sensor for rapid and selective detection of methylene blue in water. A strong decrease in fluorescence intensity was observed upon addition of MB, with a linear response in the range of 1 ppb to 1 ppm. The sensor achieved a limit of detection (LOD) of 73.9 ppb and a limit of quantification (LOQ) of 246.4 ppb, demonstrating high sensitivity. The sensing mechanism was attributed to fluorescence quenching dominated by FRET, supported by experimental spectroscopy and computational investigations. Theoretical analysis further indicated that π–π stacking and hydrogen bonding interactions between MB molecules and the C-dot surface contribute to strong binding and enhanced selectivity.

Finally, the developed sensor was successfully applied to real water samples, showing satisfactory recoveries between 96% and 116%. Overall, this work demonstrates a green, cost-effective and highly sensitive fluorescent nanosensor for MB monitoring, offering strong potential for real-time

water quality assessment and pollution control in freshwater and wastewater systems.