Electronic Supplementary Information

Facile synthesis of biomass waste-derived fluorescent N, S, P co-doped carbon dots for detection of Fe$^{3+}$ ions in solutions and living cells

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**Materials and Apparatus**

Fresh green peppers were obtained from a local market and were washed thoroughly before use. Solutions of Na\(^{+}\), K\(^{+}\), Ca\(^{2+}\), Mg\(^{2+}\), Zn\(^{2+}\), Ni\(^{2+}\), Co\(^{2+}\), Mn\(^{2+}\), Al\(^{3+}\), Ag\(^{+}\), Cu\(^{2+}\) and Fe\(^{3+}\) ions were prepared from NaCl, KCl, CaCl\(_2\), MgCl\(_2\)·6H\(_2\)O, Zn(NO\(_3\))\(_2\)·6H\(_2\)O, NiSO\(_4\), CoCl\(_2\)·6H\(_2\)O, MnCl\(_2\)·4H\(_2\)O, AlCl\(_3\), AgNO\(_3\), CuSO\(_4\)·5H\(_2\)O and FeCl\(_3\)·6H\(_2\)O, respectively. Amino acid was purchased from Sigma Aldrich Trading Co. LTD. The water sample used was taken from Mei Lake of Zhengzhou University. The reagents used in the experiment were of analytical grade. All solutions were prepared using ultrapure water, which was obtained through a Millipore Milli-Q water purification system (Billerica, MA, USA) and had an electric resistance >18.2 M\(\Omega\).

Ultraviolet-visible (UV-vis) absorption spectra were measured with a TU-1810 ultraviolet and visible spectrophotometer. The infrared spectra were recorded on a NEXUS–470 Fourier transform infrared (FT-IR) spectrophotometer. Transmission electron microscopy images (TEM) were captured by a FEI Tecnai G2 instrument. XPS experiments were carried on an ESCALAB 250Xi instrument. The fluorescence measurements were carried out on a FL–7100 spectrophotometer.

**Quantum yield measurement**

The QY was measured according to the method previously reported by comparing the as-prepared NSP-CDs with the reference quinine sulfate of their absorbency values and integrated photoluminescence intensities. The quinine sulfate
(QY=0.54) was dissolved in 0.1M H$_2$SO$_4$ solution and the CDs was dissolved in distilled water.

$$\varphi = \varphi_c \times \frac{I}{I_s} \times \frac{A_s}{A} \times \frac{\eta^2}{\eta_R^2}$$

Where $\varphi$ is the quantum yield, I is the measured integrated emission intensity, $\eta$ is the refractive index, and A is the optical density.

**Cytotoxicity assay**

MTT assay was employed to explore its cytotoxicity and bio-compatibility nature. Here Hela cells were taken as a model for cell imaging. The Hela cell was implanted in 96 well culture plates for 24 h, at DMEM medium supplemented with 10% heat-inactivated FBS and 1% antibiotic-antimycotic solution, in a CO$_2$ incubator at 37 °C with 5% CO$_2$. After removing the cultural medium, progressively 0–200 μg mL$^{-1}$ concentration NSP-CDs were added to each well and remained for 24 h (37 °C, 5% CO$_2$). Then add MTT solution to the cell microenvironment and incubate for 4 hours, discard the supernatant, add DMSO one by one, and then read the absorbance value at 570 nm on the multifunctional microplate reader.

**Cell imaging**

To culture human epithelial carcinoma (HeLa) cells, DMEM with 10% fetal bovine serum and 1% penicillin streptomycin with 5% CO$_2$ were used as media and the cell culture was carried out at 37 °C. Before cell imaging, the cells were pre-cultured with the above media (1 mL), mixed with 50 μL of NSP-CDs (1 mg mL$^{-1}$) and incubated for 4 h. Then the cells were washed thoroughly three times with PBS (1mL each time) and kept in PBS for the fluorescence imaging. Thereafter, 100 μM
and 200 μM Fe$^{3+}$ was added and incubated for 30 minutes. Cells were imaged by Leica TCS SP8 X (confocal laser scanning microscope, CLMS) with a 63× oil immersion lens.
**Fig. S1.** The EDS spectrum analysis of the NSP-CDs.
**Fig. S2.** Fluorescence intensity of the NSP-CDs containing various concentrations of NaCl.
**Fig. S3.** Fluorescence intensity of the NSP-CDs at different pH values.
**Fig. S4.** Fluorescence intensity variation of the NSP-CDs as a function of time under 330 nm light illumination.
**Fig. S5.** Fluorescence intensity under different incubation time after the addition of Fe\textsuperscript{3+} ions.
Fig. S6. Fluorescence decay curve of the NSP-CDs in the absence (black line) and presence (red line) of Fe$^{3+}$ ions.
Fig. S7. FT-IR analysis of NSP-CDs before (red line) and after (black line) the addition of Fe$^{3+}$ ions.
Fig. S8. Zeta-potential analysis of NSP-CDs before (black line) and after (red line) the addition of Fe$^{3+}$ ions.
Fig. S9. Viability of HeLa cells in the presence of different concentrations of NSP-CDs.
Table S1. Comparison on analytical performance of this work with previous studies for the detection of Fe$^{3+}$.

<table>
<thead>
<tr>
<th>Sensing system</th>
<th>Test method</th>
<th>Linear range (μM)</th>
<th>LOD (μM)</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td>N-doped carbon dots</td>
<td>Fluorescence</td>
<td>1–250</td>
<td>0.52</td>
<td>1</td>
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<tr>
<td>N/S-doped carbon dots</td>
<td>Fluorescence</td>
<td>25–500</td>
<td>4</td>
<td>2</td>
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<tr>
<td>N-doped carbon dots</td>
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<td>3</td>
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<tr>
<td>N/P-doped carbon dots</td>
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<td>1–150</td>
<td>0.33</td>
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<tr>
<td>Polydopamine nanoparticles</td>
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<td>0.15</td>
<td>5</td>
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<td>Gold nanoclusters</td>
<td>Fluorescence</td>
<td>2–100</td>
<td>1.4</td>
<td>6</td>
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<tr>
<td>Dual-emission carbon dots</td>
<td>Fluorescence</td>
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<td>0.8</td>
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<tr>
<td>MoS$_2$ quantum dots</td>
<td>Fluorescence</td>
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<td>1</td>
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<tr>
<td>NSP-CDs</td>
<td>Fluorescence</td>
<td>1-500</td>
<td>0.1</td>
<td>Our work</td>
</tr>
</tbody>
</table>
References


