Smartphone-Assisted Bicolorimetric and Fluorometric Dual-Mode Detection of Hydrogen Peroxide and Glucose Using Biomass-Derived Carbon Dots

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Abstract

This study used waste straw as a precursor to prepare dual-functional carbon dots (CDs) with blue fluorescence and peroxidase-like activity through a hydrothermal method.In the presence of H2O2, the CDs catalytically oxidized colorless 3,3′,5,5′-tetramethylbenzidine (TMB) into blue oxTMB, and simultaneously quenched the fluorescence of the CDs.Based on this phenomenon, a dual-mode detection technique using biomass-derived CDs was developed, achieving colorimetric and fluorometric synergistic detection of H2O2 and glucose.The detection limits for H2O2 were 86.2 nM and 42.1 nM, and those for glucose were 2.8 μM and 2.4 μM.This work provides a new approach for the high-value conversion and reuse of biomass resources, and opens a new pathway for developing low-cost, high-performance dual-mode sensing platforms.

Full Text

Preamble

Smartphone-Assisted Bicolorimetric and Fluorometric Dual-Mode Detection of Hydrogen Peroxide and Glucose Using Biomass-Derived Carbon Xinai CHEN1, Jiayi YAN1& Xia HONG1* School of Physics, Northeast Normal University, Changchun 130024, China Xia Hong: Propose the research approach and design the research plan;

Xinai Chen: Responsible for conducting experiments and analysing data; Jiayi Yan: Responsible for testing; Xinai Chen: Responsible for drafting the paper; Xia Hong: Responsible for final version revisions.

Abstract

This study used waste straw as a precursor to prepare dual-functional carbon dots (CDs) with blue fluorescence and peroxidase-like activity through a hydrothermal method.

In the presence of H2O2, the CDs catalytically oxidized colorless 3,3′,5,5′-tetramethylbenzidine (TMB) into blue oxTMB, and simultaneously quenched the fluorescence of the CDs.

Based on this phenomenon, a dual-mode detection technique using biomass-derived CDs was developed, achieving colorimetric and fluorometric synergistic detection of H2O2 and glucose.

The detection limits for H2O2 were 86.2 nM and 42.1 nM, and those for glucose were 2.8 μM and 2.4 μM.

This work provides a new approach for the high-value conversion and reuse of biomass resources, and opens a new pathway for developing low-cost, high-performance dual-mode sensing platforms.

Keywords

Biomass; Carbon dots; Colorimetry; Fluorometry; Glucose detection

Introduction

Glucose, as the core energy substance of organisms, plays a critical role in clinical diagnosis,

food processing, environmental monitoring, and biotechnology. Meanwhile, hydrogen peroxide, a key product of glucose oxidative metabolism, also acts as an important reactive oxygen species signaling molecule, and its concentration correlates closely with various pathological processes.

Therefore, highly sensitive detection of these two analytes is indispensable. In recent years, great efforts have been made to accurately determine glucose and H2O2 concentrations, leading to the development of surface-enhanced Raman scattering[1], high-performance liquid chromatography[2],

electrochemical analysis[3], colorimetry[4], and fluorometry[5]. Among these methods, colorimetry and fluorometry have attracted much attention due to their simplicity, low cost, high sensitivity, and visualization. However, many studies rely on single-signal measurement (colorimetric or fluorometric), which is susceptible to environmental interference. Thus, a dual-signal detection method capable of mutual validation for H2O2 and glucose is urgently needed.

During glucose oxidation, glucose oxidase (GOx) catalyzes the oxidation of glucose to gluconic acid and H2O2. Colorimetric and fluorometric methods utilize peroxidase to decompose the generated H2O2, causing chromogenic substrate

coloration and system fluorescence quenching, thereby indirectly determining glucose concentration[6]. Natural peroxidases are greatly affected by environmental factors such as temperature and pH[7], have relatively high costs, and themselves lack fluorescence. Therefore, developing a cost-effective, stable, and dual-signal-validated nanozyme to replace natural enzymes for simple and effective detection of H2O2 and glucose is of particular importance[8].

In this work, biomass waste served as a carbon source for preparing dual-functional CDs with both blue fluorescence and peroxidase-like activity via a hydrothermal method. This material not only achieves high-value utilization of waste resources with advantages of low cost, non-toxicity, and environmental friendliness, but also simultaneously acts as a fluorescent probe and a catalytic nanozyme[9]. Based on this, a colorimetric-fluorometric dual-mode detection system was constructed. This study systematically investigated the detection limits, detection ranges, selectivity, and specificity of the biomass-derived CDs for H2O2 and glucose, opening a green, low-carbon, and sustainable pathway for their detection.

Experimental Section

2.1 Preparation of Carbon Dots

The straw was first washed, dried, crushed, and sieved. Then 0.3 g of straw powder was added to 30 mL of deionized water, and the mixture was transferred into a 40 mL Teflon-lined autoclave and heated at 200°C for 12 hours. After cooling to room temperature, the resulting brown solution was centrifuged to remove large particles and then dialyzed with a 1000 Da dialysis bag for 24 hours.

2.2 Colorimetric and Fluorometric Dual-Mode Detection of H2O2

100 μL of CDs solution (0.2 mg mL-1), 50 μL of TMB (10 mM), and various concentrations of H2O2 were added to an acetate buffer solution and reacted at 37°C. The absorbance at 652 nm and the fluorescence intensity at 420 nm under 365 nm excitation were recorded.

2.3 Colorimetric and Fluorometric Dual-Mode Detection of Glucose 50 μL of different concentrations of glucose and 50 μL of glucose oxidase (2 mg mL-1) were incubated at 37°C to generate H2O2. Subsequently, the above solution was mixed with 100 μL of CDs (0.2 mg mL-1) and 50 μL of TMB solution (10 mM), and incubated at 37°C. The absorbance at 652 nm and the fluorescence intensity at 524 nm under 460 nm excitation were recorded.

2.4 Selectivity and Specificity Analysis

Selectivity analysis was performed by replacing glucose with potential interferents, including common ions (Na+, Cl-, Mg2+, CO$*{3}*2−, *SO*{4}$2-), amino

acids (alanine, lysine), and saccharides (maltose, lactose, fructose). The interferent concentration was ten times that of glucose.

Specificity analysis was conducted by mixing the above interferents with glucose under identical experimental conditions. The experimental procedure and detection method were the same as those used for glucose detection.

2.5 Real Sample Detection

Serum sample analysis was performed using a standard addition method, with glucose spiked at concentrations of 100 μM, 300 μM, 500 μM, 700 μM and 900 μM. The remaining experiments followed the procedures described in Section 2.4 to detect glucose in serum.

2.6 Smartphone-Assisted Detection

After the reaction, the solution was photographed under sunlight and 365 nm UV light using

a smartphone. The built-in color recognition application extracted the red (R), green (G), and blue (B) values. Quantitative analysis was then performed based on the correlation between RGB parameters and glucose concentration.

Results and Discussion

3.1 Characterization of Carbon Dots

Biomass waste straw served as a precursor for synthesizing CDs via a hydrothermal method.

The transmission electron microscopy (TEM) image (Fig. 1a [Figure 1: see original paper]) showed that the CDs were spherical, well-dispersed in aqueous solution, and had a narrow size distribution with an average diameter of

3.5 ± 1.1 nm. High-resolution TEM (HRTEM) revealed lattice fringes (Fig. 1b) with a spacing of 0.22 nm, corresponding to the (100) plane of graphite[10].

pattern of CDs; (d) FTIR spectrum of CDs. The X-ray diffraction (XRD) pattern (Fig. 1c) showed a broad diffraction peak near 26°, corresponding to the (002) plane of graphite, and a shoulder peak at 42° assigned to the (100) plane of carbon dots[26].Fourier transform infrared (FTIR) spectroscopy identified functional groups (Fig. 1d). Absorption peaks at 1608 cm^{-1}, 1513 cm^{-1}, 1457 cm^{-1}, and 1409 cm^{-1} were attributed to the characteristic vibrations of the C=C aromatic ring skeleton. Peaks at 808 cm^{-1}

and 879 cm^{-1} corresponded to C–H vibrations, indicating the aromatic ring structure of the CDs.

The peak at 3286 cm^{-1} arose from -OH stretching. Peaks at 2969 cm^{-1} and 2931 cm^{-1} were assigned to asymmetric stretching of CH_3 and CH_2, respectively. A

strong absorption peak at 1703 cm^{-1} indicated C=O stretching vibration. Peaks at 1267 cm^{-1} and 1211 cm^{-1} were attributed to C-

N stretching vibration, and peaks at 1088 cm^{-1} and 1049 cm^{-1} arose from C-OH stretching.

2 Raman spectrum of carbon dots. The Raman spectrum (Fig. 2 [Figure 2: see original paper]) showed D and G bands at 1330 cm-1 and 1580 cm-1, corresponding to sp3 defect carbon and the sp^2 carbon network, respectively[11]. The intensity ratio ID/IG = 0.64 indicated a relatively high degree of graphitization.

3 XPS survey spectrum of carbon dots (a), and high-resolution XPS spectra of C, N, and O (b-d).

X-ray photoelectron spectroscopy (XPS) (Fig. 3 [Figure 3: see original paper]) further analyzed the chemical composition of the CDs. The XPS survey spectrum showed that the CDs mainly consisted of C, O, and trace N

elements (Fig. 3a). High-resolution XPS spectra provided detailed information. The C 1s spectrum (Fig. 3b) revealed four peaks at 284.8 eV, 285.7 eV, 286.4 eV, and 288.4 eV, corresponding to C=C/C-C, C-N, C-O, and C=O[13]. The high-resolution N 1s spectrum (Fig. 3c) showed two peaks: pyrrolic N at 399.7 eV and C-N at 401.5 eV. The high-resolution O 1s spectrum (Fig. 3d) exhibited C-O (531.8 eV) and C=O (533.4 eV) peaks. These results collectively confirmed the successful preparation of biomass-derived carbon dots.

3.2 Optical Properties of Carbon Dots

UV-Vis absorption and photoluminescence (PL) spectroscopy characterized the optical

properties of the straw-derived CDs. The absorption spectrum (Fig. 4a [Figure 4: see original paper]) showed two broad absorption bands at 266 nm and 341 nm, corresponding to the $\pi \rightarrow \pi^*$ electronic transition of the aromatic C=C sp^2 structure and the $n \rightarrow \pi^*$ transition of surface C=O bonds[14].

The PL spectrum (Fig. 4a) showed an emission peak at 434 nm under 365 nm excitation. The aqueous CDs solution emitted blue fluorescence under 365 nm light (inset of Fig. 4a).

Furthermore, the straw-derived CDs exhibited typical excitation-dependent behavior[15]. As the excitation wavelength increased, the emission peak gradually red-shifted, and the fluorescence intensity first increased and then decreased, reaching a maximum at 360 nm excitation (Fig. 4b).

This phenomenon arises from different emission centers within the CDs, each with distinct energy levels. Under different excitation conditions, different centers dominate, leading to excitationdependent behavior[16]. This excellent fluorescence performance lays a foundation for the CDs in fluorescence sensing.

solution under sunlight and 365 nm UV light); (b) Fluorescence spectra of CDs recorded at excitation wavelengths from 310 nm to 475 nm.

3.3 Catalytic Properties of Carbon Dots

The CDs decompose H_2O_2 to generate hydroxyl radicals ($\cdot$OH) and water. The generated $\cdot$OH then oxidizes TMB, producing a colorimetric reaction (Fig. 5a [Figure 5: see original paper]). Based on this mechanism, the peroxidase-like activity of the straw-derived CDs was evaluated using TMB as a chromogenic substrate. As shown in Fig. 5a, in the presence of H_2O_2, the CDs catalyzed the oxidation of colorless TMB to blue oxTMB, and a distinct characteristic absorption peak appeared at 652 nm. In contrast, control experiments containing only TMB or TMB with H_2O_2 showed no such absorption peak. These results confirm that the prepared CDs possess peroxidase-like activity.

Based on the above catalytic colorimetric results, the reaction likely follows a $\cdot$OH radical

pathway typical of peroxidase mimics. Electron paramagnetic resonance (EPR) experiments further validated the generation of $\cdot$OH radicals. DMPO served as a radical trap to capture possible $\cdot$OH radicals, thereby revealing the catalytic mechanism of H_2O_2 decomposition. As shown in Fig. 5b, the EPR spectrum of the system containing CDs, H_2O_2, and DMPO displayed a characteristic four-peak signal with an intensity ratio of 1:2:2:1 (blue line), indicating the presence of $\cdot$OH radicals. In contrast, the control group without CDs (containing only H_2O_2 and DMPO) showed no such characteristic signal (gray line). Thus, the CDs effectively activate H_2O_2 to generate $\cdot$OH, which subsequently oxidizes TMB to oxTMB, causing the colorimetric reaction.

5 Peroxidase-like activity of CDs. (a) Schematic diagram of the catalytic mechanism; (b) UVVis absorption spectra of different reaction systems: blue line (CDs+TMB+H_2O_2), red line (TMB+H_2O_2), purple line (TMB only) (inset: photographs of reaction solutions, left to right:

CDs+TMB+H_2O_2, TMB+H_2O_2, TMB); (c) EPR spectra of CDs (blue line: CDs + H_2O_2 + trap; gray line: H_2O_2 + trap).

3.4 Optimization of TMB Oxidation Reaction Conditions To achieve optimal catalytic colorimetric efficiency, key factors affecting the peroxidase-like activity of the CDs were optimized, including CDs concentration, TMB concentration, pH, and reaction time (Fig. 6 [Figure 6: see original paper]). As shown in Fig. 6(a), the absorbance at 652 nm first increased and then decreased when the CDs concentration increased from 0.01 mg mL^{-1} to 0.05 mg mL^{-1}, reaching a maximum at 0.02 mg mL^{-1}. Fig. 6(b) shows that the absorbance gradually increased as the TMB concentration increased from 10 μM to 500 μM. When the TMB concentration exceeded 500 μM, the absorbance increase became negligible, suggesting that the reaction reached substrate

saturation. When the pH of the reaction system was adjusted from 2 to 7, the

absorbance first increased and then decreased, peaking at pH 4 (Fig. 6c). When the reaction time was extended, the absorbance gradually increased and reached a maximum at 10 min, after which no significant change occurred, indicating that the oxidation reaction reached equilibrium within 10 min (Fig. 6d). Based on these results, the optimal reaction conditions were determined as follows: CDs concentration of 0.02 mg mL^{-1}, TMB concentration of 500 μM, pH 4, and reaction time of 10 min.

6 Effects of carbon dot concentration, substrate concentration, reaction pH, and reaction time on peroxidase-like activity.

3.5 Steady-State Kinetic Analysis of Carbon Dots The Michaelis-Menten equation was used to investigate the affinity of the CDs toward TMB and H2O2. The Michaelis-Menten constant (Km) and maximum reaction velocity (Vmax) were obtained from Lineweaver-Burk double reciprocal plots (Fig. 7 [Figure 7: see original paper]). With the H_2O_2 concentration

fixed and varying TMB concentrations, the double reciprocal plot (Fig. 7a) yielded Km = 0.67 mM and Vmax = 0.52×10^{-8} M s^{-1} for TMB. With the TMB concentration fixed and varying H2O2 concentrations, the double reciprocal plot (Fig. 7b) yielded Km = 0.04 mM and Vmax = 0.28×10^{-8} M s^{-1} for H2O2. A higher Vmax indicates a higher initial reaction rate, while a lower Km reflects stronger affinity between the enzyme and substrate. Compared with various nanozymes reported in the literature (Table 1), the straw-derived CDs in this study showed significant advantages in peroxidase-like activity. The Vmax of the CDs fell within the range of reported peroxidase mimics, indicating a good foundation for catalytic reaction kinetics. More importantly, the Km values for

both H2O2 and TMB were significantly lower than those of most reported materials, demonstrating stronger affinity between the CDs and the substrates. This combination of high catalytic rate and excellent affinity gives the straw-derived CDs broad application prospects. and H2O2 with those reported in the literature.

Materials

Method

Km (mM)

Vmax(10-8 M s-1)

H2 O2

H2 O2

H2 O2

H2 O2

H2 O2

NGQDs

This work

Under different temperatures, the maximum reaction rates varied. Based on the Arrhenius equation Vmax=Ae−RT/Ea, the activation energies (Ea) of the CDs for TMB and H_2O_2 were calculated to be 33.42 kJ mol^{-1} and 13.72 kJ mol^{-1}, respectively. These values indicate that the biomass-derived CDs require low energy barriers for catalysis and possess excellent catalytic reaction kinetics.

The catalytic constant (Kcat) reflects enzyme activity, and the catalytic efficiency constant (Kcat/Km) reflects substrate catalytic efficiency. According to the formula Kcat = Vmax/[E], the Kcat

and Kcat/Km for TMB were 5.28 × 10^{-4} s^{-1} and 0.792 M^{-1} s^{-1}, respectively. For H2O2, the Kcat and Kcat/Km were 2.86 × 10^{-4} s^{-1} and 6.605 M^{-1} s^{-1}, respectively. Therefore, this biomass-derived

CDs possesses good peroxidase-like activity and can serve as a peroxidase mimic.

7 Steady-state kinetic analysis of CDs. (a) Lineweaver-Burk double reciprocal plot with fixed H2O2 concentration (0.1 mM) and varying TMB concentrations; (b) Lineweaver-Burk double reciprocal plot with fixed TMB concentration (0.5 mM) and varying H2O2 concentrations.

3.6 Determination of H2O2 Using the Dual-Mode CDs Detection Platform Based on the peroxidase-like activity and photoluminescence of the straw-derived CDs, both colorimetric and fluorometric methods were employed for H2O2 detection. A microplate reader measured the absorbance at 652 nm, which reflected the H2O2 concentration. As oxTMB formation increased, the fluorescence of the CDs gradually decreased, establishing a relationship between fluorescence intensity and H2O2 concentration. As shown in Fig. 8 [Figure 8: see original paper], two linear relationships (100 nM–10 μM and 10 μM–100 μM) existed between absorbance and H2O2 concentration. The colorimetric detection limit (LOD) was 86.2 nM. Similarly, two linear relationships (100 nM–10 μM and 10 μM–100 μM) existed between fluorescence intensity and H2O2 concentration, and the fluorometric LOD was 42.1 nM.

Linear relationship between absorbance and H2O2 concentration; (c) Calibration curve of ΔF versus H2O2 concentration under optimal conditions; (d) Linear relationship between ΔF and H2O2 concentration.

3.7 Determination of Glucose Using the Dual-Mode CDs Detection Platform Glucose reacts with oxygen under the catalysis of glucose oxidase (GOx) to generate gluconic acid and H2O2. The CDs then catalyze the reaction between the generated H2O2 and TMB, producing oxTMB and causing changes in absorbance and fluorescence intensity. Therefore, the dual-mode detection of glucose can be achieved using the catalytic activity and photoluminescence of the CDs. As shown in Fig. 9 [Figure 9: see original paper], the absorbance increased with increasing glucose concentration and showed a linear relationship in the range of

50 μM to 1 mM, with an LOD of 2.8 μM. The fluorescence intensity decreased with increasing glucose concentration, and the change in intensity also showed a linear relationship in the range of 50 μM to 1 mM, with an LOD of 2.4 μM. Compared with various previously reported glucose detection methods (Table 2), the dual-mode sensing platform in this study exhibited clear advantages in detection limit and linear range. Its detection limits were lower than those of most reported single-mode sensors, and the dual-signal output mode not only mutually validates the results, improving reliability, but also offers flexible choices for different application scenarios.

(b) Linear relationship between absorbance and glucose concentration; (c) Calibration curve of ΔF versus glucose concentration under optimal conditions; (d) Linear relationship between ΔF and glucose concentration.

Materials

Method

Linear range (μM)

LOD (μM)

Colorimetric

200-600 μM

Fluorometric

Colorimetric

Fluorometric

165-8000 μM

Colorimetric

50-1000 μM

This work

Fluorometric

50-1000 μM

3.8 Selectivity and Specificity Evaluation Colorimetric and fluorometric tests evaluated the selectivity and specificity of the detection platform toward glucose (Fig. 10 [Figure 10: see original paper]). When all interferents coexisted with glucose in the test solution, both the measured absorbance and fluorescence intensity were close to those obtained with glucose alone, indicating excellent selectivity of the dual-mode detection platform. In the presence

of glucose only, the absorbance significantly increased compared with the blank control, while the photoluminescence signal significantly decreased. When only

interferents were present, both absorbance and photoluminescence intensity remained essentially the same as those of the blank control, indicating that these interferents did not react with the CDs and demonstrating the good specificity of the constructed dual-mode detection platform. Based on these results, the dual-mode detection method exhibits excellent specificity and selectivity for glucose, giving it great potential

for application in biological or real samples.

3.9 Glucose Detection in Real Samples

To evaluate the application potential of the biomass-derived CDs dual-mode detection technique in real samples, glucose in serum samples was measured. The glucose content in the serum sample, determined by the hexokinase method, was 5302 μM. After 100-fold dilution, standard glucose was added to achieve total glucose concentrations of 100 μM, 300 μM, 500 μM, 700 μM, and 900 μM. Dual-mode detection was then performed, and the results are shown in ranging from 1.27% to 4.36% and recoveries ranging from 96.01% to 104.24%. These results demonstrate that the biomass-derived CDs are suitable for detecting glucose in human serum samples and have broad application potential in clinical diagnosis and health monitoring.

Added concentration

Detected

RSD (%)

Recovery (%)

Detection method

(μM)

concentration 101.3$±$2.52

Colorimetric

101.9$±$2.03

Fluorometric

291.4$±$1.87

Colorimetric

289.1$±$2.81

Fluorometric

521.3$±$1.62

Colorimetric

531.3$±$0.73

Fluorometric

699.3$±$0.89

Colorimetric

706.4$±$1.51

Fluorometric

892.9$±$1.78

Colorimetric

907.6$±$0.84

Fluorometric

(μM)

3.10 Smartphone-Assisted Imaging

To extend the dual-mode detection technique to broader application scenarios and achieve simpler, more portable detection, a field-ready glucose detection method was designed. This method uses a smartphone to digitally capture and analyze the color of the reaction solution, allowing faster and more convenient glucose concentration determination. After the reaction, the solution was photographed under sunlight and 365 nm UV light using a smartphone. The built-in color recognition application extracted the R, G, and B values. Quantitative analysis was then performed based on the correlation between RGB parameters and glucose concentration.

Photographs of solutions with different glucose concentrations under 365 nm UV light; (c) Smartphone screenshots for analyzing different glucose concentrations.

As shown in Fig. 11 [Figure 11: see original paper], photographs of solutions containing different glucose concentrations (100, 200, 300, 400, 500, 600, 700, 800, and 900 μM) were taken under sunlight (Fig. 11a) and 365 nm UV light (Fig. 11b). Under sunlight, the blue color gradually deepened as the glucose concentration increased. Under UV light, the fluorescence gradually weakened as the glucose concentration increased. After selecting the analysis region, the built-in color recognition application extracted the corresponding RGB values. To ensure method accuracy, the relationship between glucose concentration and the B/G ratio was established (Fig. 12 [Figure 12: see original paper]). Fig. 12a shows the relationship between the color information analyzed by the smartphone and the glucose

concentration in colorimetric mode, and Fig. 12b shows this relationship in fluorometric mode.

Based on these linear relationships, the glucose concentration can be determined using only the smartphone without any specialized instruments.

12 Relationship between the color information (B/G) analyzed by the smartphone and glucose concentration: (a) Colorimetric mode; (b) Fluorometric mode.

This method effectively overcomes the limitations of traditional detection instruments, such as complex operation procedures and bulky equipment, enabling field testing without specialized instruments. At the same time, by converting color information into objective digital signals, this method significantly reduces the subjective errors inherent in visual interpretation and improves the accuracy and repeatability of detection results, thus offering the possibility of developing lowcost, portable point-of-care testing.

4. Conclusion Biomass waste served as a raw material for preparing carbon dots with both green, non-toxic catalytic performance and photoluminescence. A colorimetric-fluorometric dual-mode sensing platform was constructed for H2O2 and glucose detection, achieving sensitive detection of both

analytes. The colorimetric LOD for H2O2 was 86.2 nM, and the fluorometric LOD was 42.1 nM.

The colorimetric LOD for glucose was 2.8 μM, and the fluorometric LOD was 2.4 μM. The detection ranges of the two methods were consistent, and the platform exhibited good specificity, selectivity, and serum sample detection capability. Furthermore, digital acquisition and analysis of the reaction solution color enabled faster and more convenient determination of glucose concentration. This work provides a new approach for developing highly sensitive and accurate

H2O2 and glucose detection technologies.

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Fig. Legends pattern of CDs; (d) FTIR spectrum of CDs. 2 Raman spectrum of carbon dots. 3 XPS survey spectrum of carbon dots (a), and high-resolution XPS spectra of C, N, and O (b-d). solution under sunlight and 365 nm UV light); (b) Fluorescence spectra of CDs recorded at excitation wavelengths from 310 nm to 475 nm. 5 Peroxidase-like activity of CDs. (a) Schematic diagram of the catalytic mechanism; (b) UVVis absorption spectra of different reaction systems: blue line (CDs+TMB+H_2O_2), red line (TMB+H_2O_2), purple line (TMB only) (inset: photographs of reaction solutions, left to right:

CDs+TMB+H_2O_2, TMB+H_2O_2, TMB); (c) EPR spectra of CDs (blue line: CDs + H_2O_2 + trap; gray line: H_2O_2 + trap). 6 Effects of carbon dot concen-

tration, substrate concentration, reaction pH, and reaction time on peroxidase-like activity. 7 Steady-state kinetic analysis of CDs. (a) Lineweaver-Burk double reciprocal plot with fixed H2O2 concentration (0.1 mM) and varying TMB concentrations; (b) Lineweaver-Burk double reciprocal plot with fixed TMB concentration (0.5 mM) and varying H2O2 concentrations.

Linear relationship between absorbance and H2O2 concentration; (c) Calibration curve of ΔF versus H2O2 concentration under optimal conditions; (d) Linear relationship between ΔF and H2O2 concentration. (b) Linear relationship between absorbance and glucose concentration; (c) Calibration curve of ΔF versus glucose concentration under optimal conditions; (d) Linear relationship between ΔF and glucose concentration.

Photographs of solutions with different glucose concentrations under 365 nm UV light; (c) Smartphone screenshots for analyzing different glucose concentrations. 12 Relationship between the color information (B/G) analyzed by the smartphone and glucose concentration: (a) Colorimetric mode; (b) Fluorometric mode.

Figures

Tables the literature. Materials

Method

Km (mM)

NGQDs

Vmax(10-8 M s-1)

This work

Materials

Method

Linear range (μM)

LOD (μM)

Colorimetric

200-600 μM

Fluorometric

Colorimetric

Fluorometric

165-8000 μM

Colorimetric

50-1000 μM

This work

Fluorometric

50-1000 μM

Added concentration (μM)

Detected concentration

RSD (%)

Recovery (%)

Detection method

101.3$±$2.52

Colorimetric

101.9$±$2.03

Fluorometric

291.4$±$1.87

Colorimetric

289.1$±$2.81

Fluorometric

521.3$±$1.62

Colorimetric

531.3$±$0.73

Fluorometric

699.3$±$0.89

Colorimetric

706.4$±$1.51

Fluorometric

892.9$±$1.78

Colorimetric

907.6$±$0.84

Fluorometric

(μM)

Note: Figure translations are in progress. See original paper for figures.