A facile synthesis of CDs from quinoa for nanosensors and bio-imaging

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Abstract
Carbon dots (CDs) with strong fluorescence were synthesized by a facile and green hydrothermal method using biomass quinoa as the carbon source. The as-prepared carbon dots (CDs) aqueous solution shows bright blue photoluminescence under the irradiation of UV lamp with a quantum yield of 14% and considerable luminescence stability and excellent strong photobleaching resistance. The as-prepared CDs was nontoxic for in vitro and in vivo applications. In addition, not only the as-prepared CDs were used for HeLa cells imaging, but also detect Fe3+ ions in cells, and the ideal imaging pictures were obtained under excitation of 405 nm. The as-prepared carbon dots possessed excellent responsive properties towards Fe3+. The quenching phenomenon can be used to detect the Fe3+ ions within a linear range of 0–300 μmol l−1 with a limit of detection of 50 nmol l−1.

1. Introduction
Carbon nanomaterials (including carbon nanotube, fullerenes and graphene) have been made significant progress in nanotechnology, biological sensing and drug transport areas [1–3]. In particular, the carbon dots, as a new star of carbon nanomaterials have attracted great attention owing to their low cytotoxicity, good biocompatibility and chemical reactivity, as well as their potential applications in optical, ion sensing, electrical, catalytic and bio-based fields [4, 5].

Nowadays, a variety of strategies have been exploited to synthesize carbon dots (laser ablation, arc discharge, thermal and chemical oxidation, electrochemical etching, etc.) [6]. For example, Qiao developed a direct chemical oxidation route to prepare multicolour photoluminescent carbon dots [7]. Soeren described the fabrication of graphene QDs by the AFM etching technique [8]. Even though these methods have advantages in the synthesis process, they usually refer to expensive carbon sources and complex synthesis and post-processing steps. Thus, in order to overcome these flaws, it is meaningful to find green, economical carbon sources and simple, effective routes to synthesize carbon dots with excellent water solubility, good PL performance, low toxicity, superior resistance to photobleaching. Based on this view, biomass, such as sugar, starch, and wood that supply amounts of C, H and O elements, can be chosen for the fabrication of carbon dots [9]. In addition, the biomass may contain certain content of trace elements like N, S, P and so on, which can improve the optical properties of the carbon dots. According to the reports, Muruganandam synthesized carbon dots by using carrot as carbon source, which can be used in optical imaging and nanocatalyst [10]. Ma presented an ultrasonic method for synthesis of blue emission N doped CDs using glucose and aqueous ammonia as precursors [11]. Gong used ATP as carbon, nitrogen, phosphorus source simultaneously to prepare blue light carbon dots by hydrothermal treatment [12]. Ye developed a facile one-pot synthesis of N and S co-doped fluorescent carbon...
The quinoa was purchased from Three Rivers Fertile Soil Co., Ltd. Cu2.1. Chemical and material

Hg2 dots from pigeon feathers, egg and manure via the pyrolysis carbonization method, which can be applied in application in the field of biological imaging and ion sensors. Moreover, Fe3 organic dyes hemoglobin, and a cofactor in enzyme-base reactions [14, 15]. In recent years, a lot of chemosensors based on organic frameworks [19] are used as the ions sensors due to their admirable selectivity. However, the expensive source materials, complex synthesis equipment and the precision technology are required in the process of ions sensing mentioned above. In addition, most of the chemosensors are poisonous, poor biologically compatible, and even water-insoluble, which are greatly limited their application in Fe3+ detection. Thus, it is urgent to develop a new probe possessing the good photostability, low toxicity, excellent water-soluble, high sensitivity fluorescent to detect Fe3+ ions [20–22].

Herein, we reported a blue-emission carbon dots with fluorescent quantum yield of 14% by one-step hydrothermal method using quinoa as carbon and nitrogen source simultaneously. The United Nations food and agriculture organization (FAO) believes that the quinoa is a monomer plant that can meet the basic demand of human body, officially recommended quinoa is the most suitable ‘whole foods’ for human, which is listed as one of the global top 10 healthy nutrition food [23]. Quinoa is rich in C, H, O, N elements (protein 27%, carbohydrate 22%, energy 19%, dietary fiber 18%, vitamin 17%, fat 11%, sodium 1%) [24], and really economical and available. To our best knowledge, there is no report on the use of quinoa as carbon source to prepare carbon dots. The one step hydrothermal method is simple, without any use of additional chemical reagents such as strong acids, surface passivators and complex post-processing. What’s more, the as-prepared carbon dots can serve as sensitive fluorescent probe to detect Fe3+ in aqueous solution with a limit of detection (LOD) as low as 50 nmol l−1. The as-prepared carbon dots are also employed to cell imaging and cell culture. The results indicate the CDs can be clearly imaged in cytoplasm and are non-toxic to cells, so they have potential application in the field of biological imaging and ion sensors.

2. Experimental

2.1. Chemical and material

The quinoa was purchased from Three Rivers Fertile Soil Co., Ltd. Cu(NO3)2, MnCl2·4H2O, CaCl2, ZnCl2, FeSO4·7H2O, Fe(NO3)3·9H2O, NaCl, MgCl2, Ni(NO3)2·6H2O, AgNO3, Pb(NO3)2, KNO3, Co(NO3)2·6H2O, Cd(NO3)2·4H2O were all purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China). Quinine sulphate were purchased from Aladdin Chemistry Co., Ltd Cell Counting Kit-8 (CCK-8) and Bovine serum albumin (BSA) were purchased from Aladdin Chemistry Co. Ltd The GIBCO Life Technologies supplied Dulbecco’s modified Eagle’s medium (DMEM) and fetal bovine serum (FBS). Phosphate buffered saline (PBS) were obtained from HyClone. Human cervical carcinoma (HeLa cells) was purchased from Shanghai Institute of Cell Biology. All the chemicals were of analytical grade and used as received without any further purification. High-purity deionized water with the resistivity of greater than 18 MΩ·cm−1 obtained from the Millipore system was used throughout the experiments.

2.2. Preparation of carbon dots (CDs)

The simple one-step hydrothermal method was used to synthesize the carbon dots using quinoa as the only carbon source. In a typical synthesis, 1.5 g quinoa were soaked in deionized water for 30 min, and mixed with 15 ml deionized water. Then the mixture was added into a Teflon-lined autoclave (20 ml) and heated at 220 °C for 6 h. The autoclave was naturally cooled down to room temperature, the obtained reaction was centrifuged twice at 11000 rpm for 10 min, the light-yellow supernatant was collected after removing the precipitation. Afterwards, the supernatant was filtered with a microporous membrane (0.22 μm), and then subjected to dialysis through a dialysis membrane in ultrapure water, which MWCO is 500. Finally, the dialysate was freeze-dried into carbon dots powder in the freeze drier. The 0.3 mg mol l−1 carbon dots aqueous solution was prepared for following tests.

2.3. Measurements

D/ MAX2500+/PC X-Ray Powder Diffraction (XRD) spectrometer (Shimadzu, Japan) was performed to obtain XRD pattern. The fluorescence spectra (PL) were measured through RF-5301PC fluorescence spectrophotometer (Shimadzu, Japan). The morphology of the as-prepared carbon dots was recorded on transmission electron microscopy (TEM) (Hitachi-7650 transmission electron microscope, Japan) at 200 kV. Raman spectra were recorded using INVIA Microscopic Confocal Raman Spectrometer (Renishaw PLC,
England) under He-Ne laser with an excitation wavelength of 632.8 nm. X-ray photoelectron spectroscopy (XPS) analyses were performed on Wscalab X-ray photoelectron spectrometer (ThermoFisher, UK). Fourier transform infrared spectra (FTIR) were evaluated on Nicolet iS10 FTIR spectrometer (Thermo Scientific, USA). Ultraviolet-visible (UV–vis) absorption spectra were monitored on UV-3600 UV–vis spectrophotometer (Shimadzu, Japan).

2.4. Quantum yield (QY) measurement
The photoluminescence quantum yield (QY) of the as-prepared carbon dots in aqueous solution was calculated by slope method as previous research [5]. The solution of quinine sulphate in 0.1 mol l⁻¹ H₂SO₄ (QY of 54%, \( \eta = 1.33 \)) was set as the reference. The value of the QY was calculated according to the following equation:

\[
Q_k = \frac{Q_a}{K_a \left( \frac{n_s}{n_a} \right)^2}
\]

Where Q is QY, K is slope, \( \eta \) is the refractive index with 1.33 as the default for both quinine sulphate and carbon dots. The footnote ‘st’ refer to quinine sulphate, ‘x’ refers to the as-prepared carbon dots.

2.5. Metal ion detection
The aqueous solution of as-prepared carbon dots was employed in the metal ions detection. 3.5 ml of CDs solution (0.3 mg ml⁻¹) was put in the cuvette as reference, and the other 3.5 ml of CDs solution were added into salt solution (0.5 ml, 200 \( \mu \)mol l⁻¹) in the presence of representative metal ions of Cu²⁺, Mn²⁺, Ca²⁺, Zn²⁺, Fe³⁺, Fe²⁺, Na⁺, Mg²⁺, Ni²⁺, Ag⁺, Pb²⁺, K⁺, Co²⁺, Cd²⁺. The fluorescence intensity (PL) was recorded at an excitation wavelength of 360 nm. The slits of excitation and emission were 1.5 nm. The pH of metal solution we used is around 7. All the experimental processes were carried out under the same condition. In addition, different concentrations of Fe³⁺ were added into the aqueous solutions of carbon dots to explore the effect of concentration of Fe³⁺ on it’s detection.

2.6. Cell experiments

(1) Cell culture and cytotoxicity assessment
A human cervical carcinoma cells (HeLa cells) were used in this study. The cells were grown in Dulbecco’s Modified Eagle’s Medium (DMEM) containing 10% (vol⁻¹) fetal bovine serum (FBS), penicillin (100 μg ml⁻¹) and streptomycin (100 μg ml⁻¹) at 37 °C with 5% CO₂. To investigate in vitro cytotoxicity of the as-prepared CDs, Cell Counting Kit-8 (CCK-8) assays were examined. Briefly, cells were seeded onto a 96-well plate at a density of 8 \( \times \) 10³ per well cultured overnight (37 °C, 5% CO₂). Then, the culture medium was replaced by fresh culture medium containing nanomaterials at different concentrations (0, 150, 200, 250, 300, 350 μg ml⁻¹) for 24 h and 48 h. After being rinsed with PBS twice, each group was added into 100 μl fresh DMEM containing 10 μl of CCK-8. After incubating for an additional 2 h, the absorbance at 450 nm was measured using a microplate reader (SPARK, TECAN). The cell viability (%) was calculated from following equation:

\[
\left( \frac{OD_{sample} - OD_{blank}}{OD_{control} - OD_{blank}} \right) \times 100\%
\]

(2) In Vitro Cellular Image

Typically, HeLa cells were put into well, incubated at 37 °C with 5% CO₂. After 12 h incubation, 2 ml sample (200 μg ml⁻¹) was added to well and incubated for 2 h. After the cells were washed with PBS four times, the cells were observed by a confocal laser microscope (Olympus FV 3000, Japan).

For metal ions detection in cells, 5 ml of CDs solution containing Fe³⁺ (4 mmol l⁻¹) were prepared. HeLa cells were put into well, incubated at 37 °C with 5% CO₂. After 12 h incubation, 2 ml sample (200 μg ml⁻¹) was added to well and incubated for 2 h. After the cells were washed with PBS four times, the cells were imaged by a confocal laser microscope (Olympus FV 3000, Japan).

3. Results and discussion

3.1. Composition and structure of CDs
Quinoa is difficult to dissolve in water at room temperature, but under high temperature and high pressure in the autoclave, as a carbon source, the structure of quinoa is destroyed, which dissolves in the hydrothermal medium-water, and then carbonizes. When the solute concentration is higher than the supersaturation required
for the nucleation of graphitized carbon core of carbon quantum dots, the nucleation and growth of graphitized grains of carbon dots begin. With the crystallization process, the concentration of quinoa used for crystallization in water becomes lower than the solubility of quinoa, which makes the dissolution of precursors continue. Repeatedly, under 220 °C, 6h, the water solution of quinoa can be transformed into carbon dots. Meanwhile, as illustrated in Scheme 1, quinoa, as carbon source and a nitrogen source, forms surface functional groups around the sp2 core while carbonizing, such as –COOH, –NH₂. These surface groups provide surface defects that introduce new defect energy levels, thus giving the CDs new fluorescence properties.

The TEM images (figures 1(a) and (b)) show the morphology of the carbon dots fabricated by the hydrothermal method. It can be seen from the TEM images that the as-prepared carbon dots particles present a spherical structure and evenly distributed with the diameter of about 2.1 nm as shown in the size distribution histograms. The particles are not agglomerated with each other. The inset in figure 1(b) shows the high-resolution TEM (HRTEM) image of the carbon dots, the lattice fringe distance at around 0.3 nm agrees well with the d spacings of the graphite (002) planes. Figure 1(c) shows the XRD pattern of the carbon dots, in which a broad and low-intensity diffraction peak mainly centred at 2θ = ~ 23°. The interlayer spacing (d) corresponding to the XRD is 0.39 nm, which is larger than that of the graphite (d = 0.34 nm) [25]. The increase

![Scheme 1. Illustration of formation of CDs from hydrothermal treatment of quinoa.](image)

![Figure 1. (a) TEM images of the CDs. (b) size distribution histogram. (c) XRD pattern of the CDs. (d) and Raman spectrum of the CDs.](image)
of the interlayer spacing is contributed to enlarged interlayer distance, resulting from steric hindrance of functional surface groups on the graphite edge or the plane distortion from sp³ C in the graphite plane [26]. The Raman spectrum of the carbon dots is shown in figure 1(d), which has two mainly broad peaks at around 1356 cm⁻¹ (D-band) and 1589 cm⁻¹ (G-band), respectively. The D band represents the lattice defect of the carbon atom and the disordered graphite structure. The G band is inherent to natural graphite [4]. The result is consistent with what we have discussed above. As it is known, the ratio of ID/IG is characteristic of the degree of graphite and the ratio of sp³/sp² carbon. The ratio of ID/IG is 1.15, which is higher than the original graphite film (1.05), indicating that highly conjugate sp² carbon domain takes dominant place in the core part of carbon dots. The result is consistent with what we have discussed above in TEM analysis. All these analyses can confirm that the as-prepared carbon dots have core–shell structure.

X-ray photoelectron spectroscopy (XPS) spectra were used to analyse the surface elemental composition of CDs. As shown in figure 2(a), the three peaks of 285, 532 and 400 eV corresponding to C 1s, O 1s and N 1s [27, 28], respectively, which indicates that the prepared carbon dots are composed of a large amount of C and O element, as well as a small amount of N element, and the content ratios are 59.04%, 23.52% and 17.44%, respectively. Among them, the appearance of the N 1s peak indicates that the successful doping of the N element enters the C skeleton. In the C 1s high-resolution XPS spectrum as shown in figure 2(b), four peaks at 286.1, 287.8, 288.5 and 289.4 eV can be observed, corresponding to C–N (286.1), C–O (287.8), C=O (288.3) and COOH (289.4) groups [29, 30]. Figure 2(c) is a high-resolution XPS spectrum of O 1s, which contains characteristic peaks at 531 and 532 eV, corresponding to C=O and C–O, respectively [31]. In figure 2(d), the high-resolution XPS spectrum of N 1s mainly contains two characteristic peaks at 399.5 and 400.5 eV, which attribute to pyridinic N of –N= and pyrrolic N of –NH–, respectively [32, 33].

Figure 3 shows a more detailed analysis of the functional groups on the surface of the carbon dots using the FTIR spectrometer. The wide absorption band at 3398 cm⁻¹ is derived from the vibration of O–H and N–H groups [34]. The absorption peak at 2946 cm⁻¹ is corresponded to the symmetry and antisymmetric vibration of C–H [35]. The peak at 1298 cm⁻¹ is due to stretching vibration of C–N. The characteristic peak at 1629 and 1396 cm⁻¹ originate from the vibration of COO⁻, and the peak at 1091 cm⁻¹ is generated from the C–OH group [36, 37]. The characteristic peaks at 954 and 709 cm⁻¹ are assigned to the oxygen groups C–O at the surface of CDs [38], which allows the carbon dots to have excellent hydrophilic properties without further subsequent treatment.
3.2. Optical properties of CDs

Figure 4(a) shows the photoluminescence (PL), photoluminescence excitation (PLE) and UV–vis absorption spectra of the CDs aqueous dispersion; the maximum emission at a wavelength of 437 nm (red line) with an excitation wavelength of 354 nm (blue line) is observed. The insets in figure 4(a) how the optical images of the CDs aqueous dispersion under visible/UV light, and a blue emission color under UV light (365 nm) irradiation can be clearly observed, revealing that CDs show strongly blue luminescence in aqueous solution. There are three absorption peaks in the ultraviolet visible light absorption spectrum, one of them is a distinct absorption peak around 244 nm, which is the typical absorption peak of carbon core caused by the $\pi-\pi^*$ transition of the aromatic sp$^2$ orbital. The other one peak is around 320 nm, which is generally considered to be the absorption peak due to the chemical state and molecular state of the CDs surface, and may be the n-$\pi^*$ transition of $-\text{NH}_2$.

The third peak at 363 nm can be ascribed to n-$\pi^*$ transition of C=O. This confirm that the carbon dots have a large stokes shift, that is, the fluorescence spectrum of the carbon dots has a larger red shift compared with the corresponding absorption spectrum. Figure 4(b) shows a typical excitation-dependent property of CDs materials, which means the fluorescence emission wavelength of CDs solution varies with the excitation wavelength. The phenomenon is mainly due to the fact that different energy levels form different surface states through different functional groups, and which have different effects on the band gap of CDs. At the excitation wavelength of 354 nm, the CDs have the strongest PL intensity, which located at 437 nm, emitting blue light. After calculation, the fluorescence quantum yield is 14%, which is higher than the quantum yields of CDs prepared by eggs (QY = 5.9%) and grapefruit peel (QY = 6.9%) reported before [32, 39]. The main reasons are as follows: (1) Quinoa has a unique chemical structure and composition, and introduces new surface groups on
the surface of the CDs to provide more light-emitting sites; (2) The rich protein in Quinoa makes the prepared CDs rich in a large amount of N elements, and N is doped into CDs as a heteroatom, which enhances the surface activity of CDs and thus increases the fluorescence quantum yield as well as the chemical activity. However, compared with the CDs prepared from orange juice by hydrothermal method [3], QY of quinoa CDs is relatively low, which is mainly because the photoluminescence of CDs originates from surface emissive traps, while as a solid carbon source in water, the degree of carbonization is lower than that of liquid carbon source, resulting in the lower ratio of the number of trap sites-to-the number of photo excitable electrons and hence QY of CDs is lower. In addition, quinoa, as a carbon source, mainly contains C, N, O. Compared to other elements doped carbon dots from hydrothermal method, such as N, P doped CDs, N, B doped CDs, it lacks different kinds of surface states corresponding to a relatively wide distribution of different energy levels introduced by additional elements, resulting in the lower QY [40, 41].

To further analyse the fluorescence stability of CDs under different conditions, the CDs aqueous solution was continuously irradiated under ultraviolet light, and the fluorescence intensity was recorded as shown in figure 5(a). The fluorescence intensity of CDs is not significantly attenuated during the irradiation time increased from 0–60 min. In addition, different concentrations of NaCl solution were added into the aqueous solution of CDs. As shown in figure 5(b), the fluorescence intensity remained relatively stable as the salt ion concentration increased, confirming that the fluorescence intensity of CDs was not affected by the ultraviolet irradiation time and the NaCl concentration, in other words, the CDs had extremely strong photobleaching resistance. Figure 5(c) shows the change of fluorescence with the change of the temperature of the CDs solution, as the temperature increases, the fluorescence intensity decreases slightly, which may be caused by the synergistic action of a large number of oxygen-containing groups and hydrogen bonds on the surface of the CDs. What’s more, in order to investigate the effect of pH on the PL intensity of CDs, we characterized the PL intensity of CDs aqueous solution with the pH value of 1, 2, 3, 4, 5, 7, 9, 11 and 12, respectively. As shown in figure 5(d), it is found that the fluorescence intensity fluctuates with the change of pH value, and has the typical pH-dependent characteristics. When the CDs are dispersed under acidic conditions (pH is around 5), the fluorescence intensity is higher, which is consistent with the fact that the pH of CDs is generally acidic [42]. Its pH-dependent properties are consistent with previous studies, which are mainly related to the protonation and deprotonation of functional groups such as –NH₂, –COOH, –C=O– on the surface of the CDs.
3.3. Applications of CDs in ions detection

As illustrated in figure 6(a), except for Fe\(^{3+}\), no obvious change of the fluorescent quenching values (F/F\(_0\)) of CDs was observed upon adding different metal ions including Cu\(^{2+}\), Mn\(^{2+}\), Ca\(^{2+}\), Zn\(^{2+}\), Fe\(^{2+}\), Fe\(^{3+}\), Na\(^{+}\), Mg\(^{2+}\), Ni\(^{2+}\), Ag\(^{+}\), Pb\(^{2+}\), K\(^{+}\), Co\(^{2+}\) and Cd\(^{2+}\). This result indicated the CDs have strong concentration sensitivity to Fe\(^{3+}\). The strong quenching effect of Fe\(^{3+}\) on the CDs is due to the strong complexation reaction between the Fe\(^{3+}\) ions and the oxygen-containing functional groups on the surface of CDs, resulting in charge transfer, which causes the fluorescence quenching [43, 44].

Ion detection not only requires the matrix material to have high selectivity and specificity for metal ions, but also requires high sensitivity of the fluorescent probe. Since the as-prepared CDs have relatively high detection sensitivity for Fe\(^{3+}\), different concentrations of Fe\(^{3+}\) are added to the CDs solution, and fluorescence intensity is tested after thorough mixing.

The detection results of Fe\(^{3+}\) are shown in figure 6(b), the fluorescence intensity of the aqueous solution of CDs showed a gradual weakening trend with the increase of Fe\(^{3+}\) concentration at 0–300 \(\mu\)mol l\(^{-1}\), showing relatively high detection sensitivity. Figure 6(c) shows the fitted line with the Fe\(^{3+}\) concentration as the abscissa and F/F\(_0\) (F\(_0\) and F are the fluorescence intensity of CDs with no adding and adding Fe\(^{3+}\), respectively) as the ordinate, there is a good linear relationship in the Fe\(^{3+}\) concentration within 300 \(\mu\)mol l\(^{-1}\), the linear correlation regression coefficient is \(R^2 = 0.98657\), and the Fe\(^{3+}\) quenching effect accord with the Stern-Volmer equation:

\[
\frac{F_0}{F} - 1 = K_{sv} \cdot C
\]

where \(K_{sv}\) are the Stern-Volmer quenching constant and the bimolecular quenching constant. C is the concentration of Fe\(^{3+}\), and the limit of detection (LOD) for Fe\(^{3+}\) is 50 nmol l\(^{-1}\) based on \(3s/k\) (s represents the standard deviation for the corrected blank signals with 10 parallel measurements, and k is the slope of the calibration curve), which is better than the sulfur-doped CDs by Xu (0.1 \(\mu\)mol l\(^{-1}\)) [45] or the CDs made from rose-heart radish (0.13 \(\mu\)mol l\(^{-1}\)) [46], but bot the best compared the red fluorescent carbon dots reported by Tan (1.9 nmol l\(^{-1}\)) [47].
3.4. Cytotoxicity assay and fluorescence imaging of Hela cells in vitro

The cytotoxicity of as-prepared CDs on HeLa cells was evaluated by a CCK-8 assay, as shown in figure 7. It can be seen that the as-prepared CDs cause a less than 5% reduction in cell viability at a concentration of 350 μg mL⁻¹ after exposing for 24 h. What’s more, the viability still remains at more than 95% after 48 h of exposure time, which indicate the as-prepared CDs was safe for in vitro and in vivo applications.

Further application of CDs was demonstrated in fluorescence imaging of Hela cells. The experiments were carried out by using a confocal laser scanning microscope (CLSM) and results are shown in figure 8. HeLa cells were incubated with CDs for 2 h was observed under bright field and 405 nm excitation. As shown in figure 8(a), the images of HeLa cells show strong blue fluorescence in the intracellular region of Hela cells, which indicates that the CDs permeate inside the cells by a possible endocytosis mechanism. And no morphological damage to the HeLa cells appears after being incubated with CDs, which suggests that the as-

![Figure 7. Cell toxicity of CDs on HeLa cells viability.](image)

![Figure 8. Images of HeLa cells incubated with CDs. (a: without Fe³⁺ ions; b: with Fe³⁺ ions, Scale bar = 20 μm).](image)
prepared CDs almost have no effect on cell viability [31]. After a long period of UV irradiation, the PL intensity of the fluorescent signal was not significantly attenuated. The experimental results demonstrate that the as-prepared CDs synthesized by quinoa have excellent biocompatibility and can be used as fluorescent probes, which may replace traditional organic dyes and semiconductor quantum dots as a new bioimaging probe materials in the future.

Encouraged by strong fluorescence emission of CDs from cells, To achieve detection of intracellular Fe$^{3+}$, HeLa cells were incubated with fresh medium containing 200 $\mu$g ml$^{-1}$ CDs and 4 mM Fe(NO$_3$)$_3$ for 2 h. As shown in figure 8(b), under 405 nm excitation, the intensity of fluorescence was decreased dramatically, a quite weak fluorescence emission could be detected. The result shows that strong quenching effect of Fe$^{3+}$ on the CDs happened even if in cells and thus the as-prepared CDs can be used for sensitive detection of Fe$^{3+}$ ions.

4. Conclusions

In conclusion, quinoa was selected as carbon source, and a facile and economical hydrothermal method was used to synthesize the blue-emission CDs, which have excellent water solubility and fluorescence stability. The synthesized CDs were tested for PL spectrum at an excitation wavelength of 354 nm, emitting blue fluorescence with the emission wavelength of 438 nm, the fluorescence quantum yield is 14%. There is no need to add any surface passivating agent and additives. The as-prepared CDs was found that has a very sensitive fluorescence quenching effect on Fe$^{3+}$ ions, and the CDs were used as fluorescence probe within a linear range of 0–300 $\mu$mol l$^{-1}$, with a detection limit of 50 nmol l$^{-1}$. In addition, not only the as-prepared CDs were used for HeLa cells imaging, but could detect Fe$^{3+}$ ions in cells as well, and the ideal imaging pictures were obtained under excitation of 405 nm.

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Conflicts of interest

There are no conflicts to declare.

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