A Review on Carbon Dots: Synthesis, Characterization and Its Application in Optical Sensor for Environmental Monitoring

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Abstract: The development of carbon dots (CDs), either using green or chemical precursors, has inevitably led to their wide range application, from bioimaging to optoelectronic devices. The reported precursors and properties of these CDs have opened new opportunities for the future development of high-quality CDs and applications. Green precursors were classified into fruits, vegetables, flowers, leaves, seeds, stem, crop residues, fungi/bacteria species, and waste products, while the chemical precursors were classified into acid reagents and non-acid reagents. This paper quickly reviews ten years of the synthesis of CDs using green and chemical precursors. The application of CDs as sensing materials in optical sensor techniques for environmental monitoring, including the detection of heavy metal ions, phenol, pesticides, and nitroaromatic explosives, was also discussed in this review. This profound review will offer knowledge for the upcoming community of researchers interested in synthesizing high-quality CDs for various applications.

Keywords: carbon dots; green synthesis; chemical synthesis; optical sensor; environmental pollution

1. Introduction

Fluorescent carbon dots (CDs), also known as carbon quantum dots (CQDs) or carbon nanodots (CNs), have drawn a great deal of attention in recent years, owing to their high photostability, excellent water solubility, tuneable fluorescence and optical properties, low toxicity, good biocompatibility, and environmental friendliness [1]. To date, a variety of precursors have been utilized to prepare CDs through “bottom-up” or “top-down” approaches [2]. Among these approaches, hydrothermal/carbonization treatment is frequently applied for the preparation CDs because of the outstanding advantages, such as high yield, simple manipulation, easy control, uniform products, lower air pollution, low energy consumption and so on [3]. Despite these advantages, CDs cannot be produced without the presence of starting materials, also known as precursors. In this regard, the development of green and chemical synthesis methods for producing high fluorescent CDs has gathered the focus of researchers. The green synthesis methods by means of green precursors of synthesis involves the usage of inexpensive or recycled materials, while the chemical synthesis methods involve toxic chemical reagents or organic solvents as precursors. CDs synthesized using these methods usually contain a certain amount of oxygen, hydrogen, and nitrogen. With all these options to prepare CDs under certain experimental conditions, it is no surprise that differential fluorescence properties of CDs were easily acquired. In addition, surface passivation (generally involves functional groups such as amine groups and hydroxyl groups) and the heteroatom doping (n-type doping: nitrogen, phosphorus, sulfur, and chlorine or p-type doping: boron) approach is another factor that paves the way to efficiently improve the fluorescent properties, quantum yield,
and other physicochemical properties of CDs [4]. Such intriguing properties have triggered new capabilities in the field of sensing and bioimaging.

To date, many review articles on the preparation of CDs, heteroatom doped CDs, and their applications have been published [5–8]. However, there is no comprehensive review exploring various green and chemical precursors as the carbon source in CDs and their application in environmental monitoring. The purpose of this review is, therefore, to update and organize the green and chemical precursors used in CD preparation. The final section will give a concise overview of their application in the optical sensing of heavy metal ions, phenol, pesticides, and nitroaromatic explosives.

2. CDs Synthesized from Green Precursors

Carbon dots (CDs) can be synthesized using two precursors, either from green or chemical sources. As of now, researchers focus more on simple, low-cost, and greenway synthesis for the large-scale production of high-quality CDs. Numerous green sources, such as fruits, vegetables, flowers, leaves, seeds, stems, crop residues, fungi/bacteria species and waste products, have been used as a carbon source for the preparation of CDs. In this section, all green sources used for the synthesis of CDs are briefly arranged and compared.

2.1. Fruits

Orange juice and watermelon peels were among the very first precursors used as a carbon source to synthesize CDs. The studies reveal the as-prepared CDs have different fluorescence properties, due to the presence of different chemical groups in the raw materials and synthesis method. The synthesized CDs from orange juice showed the quantum yield of 26% at an emission of 441 nm, whereas a 7.1% quantum yield was demonstrated by watermelon peel-derived CDs at an emission of 490–580 nm [9,10]. In 2014, Du et al. reported renewable wastes of sugar cane bagasse as a new precursor for fluorescent CDs [11]. It, thus, demonstrated that such bagasse-derived CDs could function as highly effective fluorescent sensing probes for labeling and imaging in biomedical applications.

Lemon peels, prunus avium extract, cornstalk, corn bract, dried lemon peels, pulp-free lemon juice, citrus lemon peels, citrus sinensis peels, etc. are another precursor that have been used in the development of CDs, as shown in Table 1 [12–41]. Among these precursors, acidic fruits, such as lemon peels, lemon juice, and citrus sinensis, were frequently chosen. This is because the juice extract is rich in sucrose, glucose, fructose, citric acid, and ascorbic acid, while the peels are mainly composed of proteins, fibers, and less of oils and antioxidants. Consequently, CDs from juice extract exhibit higher fluorescence properties than peels, due to the high acid and sugar contents that provide a considerable amount of carbon and hydrogen elements. A comparison study of the different precursors used in hydrothermal synthesis was then carried out to understand the role of citric acid [30]. It was found that lemon juice has higher photoluminescence (PL) emission than ripe lemon juice and orange juice. This result is because lemon juices have higher concentrations of citric acid than orange juices. Moreover, the decrease in PL emission of ripe lemon juice was due to a significant decrease in the grade of constituents and destroyed their surface structure.

Instead of just relying on carbon sources to produce high quantum yields of CDs, it has been found that by passivating CDs with amine-containing molecules, such as ethylenediamine, one can increase the quantum yield and selectively sensing analytes. Figure 1 shows the hydrothermal reaction of CDs from citrus lemon juice in the presence of ethylenediamine to produce nitrogen-doped CDs. The results showed that the prepared nitrogen-doped CDs had the quantum yield of 31% under bright blue emission [28]. However, there are limits to these blue emissive CDs, especially in the field of bioimaging because of strong tissue autofluorescence at low wavelength emissions. Herein, Ding et al. (2017) have heated an ethanol solution of pulp-free lemon juice to produce very high red-luminescent CDs, which hold the promise for in vitro and in vivo bio-imaging [17].
### Table 1. Summary of the synthesis CDs from fruits.

| Carbon Source          | Precursor                | Technique         | Particle Size | Properties | Quantum Yield | Year | Reference |
|------------------------|--------------------------|-------------------|---------------|------------|---------------|------|-----------|
| Orange juice           | -                        | Hydrothermal      | TEM-2.5 nm    | $\lambda_{em}$: 411 nm $\lambda_{ex}$: 360 nm | 26%            | 2012 | [9]       |
| Watermelon peels       | -                        | Carbonization     | TEM-2.0 nm    | $\lambda_{em}$: 490–580 nm | 7.1%           | 2012 | [10]      |
| Sugar cane bagasse     | Sodium hydroxide solution| Hydrothermal      | HRTEM-1.8 nm  | $\lambda_{em}$: 475 nm $\lambda_{ex}$: 370 nm | 12.3%          | 2014 | [11]      |
| Lemon peels            | Sulfuric acid            | Hydrothermal      | TEM-1 to 3 nm | $\lambda_{em}$: 441 nm $\lambda_{ex}$: 360 nm | 14%            | 2016 | [12]      |
| Prunus avium extract   | Ammonia                  | Hydrothermal      | HRTEM-7 nm    | $\lambda_{em}$: 411 nm $\lambda_{ex}$: 310 nm | 13%            | 2016 | [13]      |
| Cornstalk              | Distilled water          | Hydrothermal      | TEM-5.2 nm    | $\lambda_{em}$: 500 nm $\lambda_{ex}$: 420 nm | 7.6%           | 2017 | [14]      |
| Corn bract             | Anhydrous ethanol        | Solvothermal      | TEM-1.8–3.4 nm| $\lambda_{em}$: 470 nm $\lambda_{ex}$: 406 nm | 6.9%           | 2017 | [15]      |
| Dried lemon peel       | Deionized water          | Hydrothermal      | TEM-9.5 nm    | $\lambda_{em}$: 505 nm $\lambda_{ex}$: 425 nm | 11%            | 2017 | [16]      |
| Pulp-free lemon juice  | Ethanol                  | Solvothermal      | AFM-1.5 nm    | $\lambda_{em}$: 631 nm $\lambda_{ex}$: 540 nm | 28%            | 2017 | [17]      |
| Citrus lemon peels     | -                        | Carbonization     | TEM-4.5 nm    | $\lambda_{em}$: 435 nm $\lambda_{ex}$: 330 nm | 16.8%          | 2017 | [18]      |
| Citrus sinensis peels  | -                        | Carbonization     | TEM-6.5 nm    | $\lambda_{em}$: 455 nm $\lambda_{ex}$: 365 nm | 15.5%          | 2017 | [18]      |
| Lemon juice            | -                        | Thermal decomposition | -      | $\lambda_{em}$: 400 nm $\lambda_{ex}$: 320 nm | 7%             | 2018 | [19]      |
| Lemon juice            | Poly(ethyleneimine)      | Carbonization     | TEM-5.7 nm    | $\lambda_{em}$: 540 nm $\lambda_{ex}$: 420 nm | -              | 2018 | [20]      |
| Citrus lemon juice     | -                        | Hydrothermal      | TEM-5.8 nm    | $\lambda_{em}$: 450 nm $\lambda_{ex}$: 360 nm | 10.20%         | 2018 | [21]      |
| Watermelon juice       | Ethanol                  | Hydrothermal      | TEM-3–7 nm    | $\lambda_{em}$: 439 nm $\lambda_{ex}$: 355 nm | 10.6%          | 2018 | [22]      |
| Jackfruit juice        | Ethanol and distilled water| Hydrothermal     | HRTEM-<2.5 nm | $\lambda_{em}$: 485 nm $\lambda_{ex}$: 395 nm | 14.6%          | 2018 | [23]      |
| Lemon                  | Ethylenediamine          | Hydrothermal      | TEM-20 nm     | -                 | 20%            | 2018 | [24]      |
| Durian juice           | Water and ethanol        | Carbonization     | -              | -                 | -              | 2018 | [25]      |
| Acerola fruit          | Water                    | Hydrothermal      | -              | $\lambda_{em}$: 504 nm $\lambda_{ex}$: 360 nm | -              | 2019 | [26]      |
| Bitter orange juice    | -                        | Hydrothermal      | AFM-2–4 nm    | $\lambda_{em}$: 390 nm $\lambda_{ex}$: 325 nm | 19.9%          | 2019 | [27]      |
| Citrus lemon juice     | Ethylenediamine          | Hydrothermal      | HRTEM-3 nm    | $\lambda_{em}$: 452 nm $\lambda_{ex}$: 360 nm | 31%            | 2019 | [28]      |
| Lemon and onion juices | Ammonium hydroxide solution| Microwave assisted carbonization | TEM-6.15 nm | $\lambda_{em}$: 425 nm $\lambda_{ex}$: 340 nm | 23.6%          | 2019 | [29]      |
| Lemon juice            | -                        | Hydrothermal      | HRTEM-3–15 nm | $\lambda_{em}$: 524 nm $\lambda_{ex}$: 420 nm | 21.37%         | 2019 | [30]      |
| Durian shell           | Tris base and deionized water| Hydrothermal    | TEM-6.5 nm    | $\lambda_{em}$: 414 nm $\lambda_{ex}$: 340 nm | 12.93%         | 2019 | [31]      |
| Lemon                  | Hydroxylamine            | Hydrothermal      | HRTEM-2 nm    | $\lambda_{em}$: 430–470 nm $\lambda_{ex}$: 360 nm | 5%             | 2020 | [32]      |
| Pomegranate            | Sodium hydroxide and polyethylene glycol| Microwave | HRTEM-1 to 5 nm | $\lambda_{em}$: 532 nm $\lambda_{ex}$: 515 nm | -              | 2020 | [33]      |
| Watermelon peels       | Water                    | Hydrothermal      | TEM-2.5 nm    | $\lambda_{em}$: 450 nm $\lambda_{ex}$: 360 nm | 24.8%          | 2020 | [34]      |
| Citrus fruit peels     | Deionized water          | Sand bath         | TEM-4.6 nm    | $\lambda_{em}$: 510 nm $\lambda_{ex}$: 420 nm | -              | 2021 | [35]      |
| Banana peel            | Deionized water          | Hydrothermal      | TEM-5 nm      | $\lambda_{em}$: 355 nm $\lambda_{ex}$: 355 nm | 20%            | 2021 | [36]      |
| Elaeagnus angustifolia | Ultrapure water          | Hydrothermal      | TEM-<10 nm    | $\lambda_{em}$: 410 nm $\lambda_{ex}$: 330 nm | 16.8%          | 2021 | [37]      |
At present, Bael patra fruit-derived CDs turned out to be an excellent carbon source without the need of chemical additives [39]. Typically, three different components of Bael patra fruit, i.e., hard shell, edible pulp, and a mixture of pulp and gum were reported for the successful synthesis of emissive CDs, and it was found that CDs derived from the hard shell had the highest quantum yield of 59.39%. This is because the synthesized CDs via the carbonization approach resulted in more production of carbon content and micropores over its surface. These micropores can provide a higher ratio of surface-active sites for the adsorption of toxins from wastewater samples, thus significantly improving the sensing performance.

2.2. Vegetables

The exploration of new carbon sources that possess abundant reserve, green, simple and high quality CDs has drawn tremendous attention in the area of kitchen waste, such as vegetables. Various green and non-green vegetables, such as celery leaves, sweet pepper, lemon grass, tomato, carrot, rose-heart radish, turmeric, cinnamon, red chili, black pepper, hongcaitai, cauliflower, kelp, tomato, crown daisy leaves, cabbage, cherry tomatoes, scallion leaves, and red beet, have been reported, as shown in Table 2 [42–58]. Both green and non-green vegetables have many properties and their own advantages. For instance, the family of green vegetables, such as celery leaves, lemon grass, hongcaitai, kelp, cabbage, crown daisy leaf, and scallion, often contain many organic compounds, such as organic acids, amides, amino acids, proteins, saccharides, carbohydrates, chlorophyll, etc., which can bring good physical and chemical properties to CDs. Meanwhile, non-green vegetables, such as tomato, red chili, turmeric, black pepper, cinnamon, and red beet, are plants rich in various bioactive compounds of lycopene, capsaicin, curcumin, piperine,
and cinnamaldehyde, respectively, which enable their application in the biomedical field. It was reported that bioactive compounds will partially remain inside or at the surface of the CDs after the hydrothermal process, leading to different photoluminescent and biomedical properties. Vasimalai et al. (2018) have demonstrated the uses of cinnamon, red chili, turmeric, and black pepper as CD precursors for biomedical applications [48]. They found that black pepper CDs have the highest quantum yield of 43.6% due to the various functional groups present in the sample, namely O–H, C–H, C–O–N, C=O, C–O, and C–N vibrational stretching peaks. All in all, the CDs prepared using celery leaves have contributed to the highest quantum yield of 53%. It was discovered that celery leaves contain abundant folic acid with affluent -COOH and the addition of L-glutathione as N, S-dopant has enriched their surface groups, which are beneficial for improving the quantum yield of CDs [42].

2.3. Flowers

Flowers such as Selenicereus grandifloras, water hyacinth, Osmanthus fragrans, rose flowers, and Tagetes erecta have also shown promise as carbon precursors, which were subsequently used to bind pesticides and metal ions. From Table 3, we can observe that there is an increase in quantum yield from 3.8% in 2019 to 63.7% in 2021. This significant improvement was attained by the presence of surface-active organic groups of C–N, –NH, and –OH, as shown in the FTIR analyses [59–63].

| Precursor | Technique | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|-----------|-----------|--------------|--------------|---------------|------|-----------|
| Celery leaves | Glutathione and double distilled water | Hydrothermal | TEM-2.08 nm | $\lambda_{em}$ 415 nm, $\lambda_{ex}$ 340 nm | 53% | 2013 [42] |
| Sweet pepper | Water | Carbonization | TEM- 4.6 nm | $\lambda_{em}$ 450 nm, $\lambda_{ex}$ 360 nm | 19.3% | 2013 [43] |
| Lemon grass | Water | Hydrothermal | - | $\lambda_{em}$ 440 nm, $\lambda_{ex}$ 320 nm | 23.3% | 2016 [44] |
| Tomato juice | - | Hydrothermal | HRTEM- 3 nm DLS- 3 nm | $\lambda_{em}$ 440 nm, $\lambda_{ex}$ 367 nm | 13.9% | 2016 [45] |
| Carrot juice | - | Hydrothermal | TEM- 5.5 nm | $\lambda_{em}$ 442–565 nm, $\lambda_{ex}$ 520–560 nm | 5.16% | 2017 [46] |
| Rose-heart radish | Ultrapure water | Hydrothermal | TEM- 3.6 nm | $\lambda_{em}$ 420 nm, $\lambda_{ex}$ 330 nm | 13.6% | 2017 [47] |
| Turmeric | Ethylenediamine | Hydrothermal | TEM- 20 nm | - | 20% | 2018 [24] |
| Cinnamon | Ultrapure water | Hydrothermal | TEM- 3.4 nm | $\lambda_{em}$ 465 nm, $\lambda_{ex}$ 370 nm | 35.7% | |
| Red chili | Ultrapure water | Hydrothermal | TEM- 3.1 nm | $\lambda_{em}$ 477 nm, $\lambda_{ex}$ 380 nm | 26.8% | 2018 [48] |
| Turmeric | - | Hydrothermal | TEM- 4.3 nm | $\lambda_{em}$ 460 nm, $\lambda_{ex}$ 370 nm | 38.3% | |
| Black pepper | Ultrapure water | Hydrothermal | TEM- 3.5 nm | $\lambda_{em}$ 489 nm, $\lambda_{ex}$ 390 nm | 43.6% | |
| Hongcaitai | Ultrapure water | Hydrothermal | TEM- 1.9 nm | $\lambda_{em}$ 410 nm, $\lambda_{ex}$ 330 nm | 21.0% | 2018 [49] |
| Cauliflower | - | Hydrothermal | AFM- 4 nm DLS- 154 nm | $\lambda_{em}$ 380 nm, $\lambda_{ex}$ 325 nm | 43% | 2019 [50] |
| Kelp | Ethylenediamine | Microwave irradiation | TEM- 3.7 nm | $\lambda_{em}$ 450 nm, $\lambda_{ex}$ 370 nm | 23.5% | 2019 [51] |
| Tomato | Sulphuric acid | Chemical oxidation | HRTEM- 5–10 nm | $\lambda_{em}$ 450 nm, $\lambda_{ex}$ 360 nm | 12.70% | |
| | Phosphoric acid | Chemical oxidation | - | $\lambda_{em}$ 520 nm, $\lambda_{ex}$ 420 nm | 4.21% | 2019 [52] |
| | - | Chemical oxidation | - | $\lambda_{em}$ 560 nm, $\lambda_{ex}$ 460 nm | 2.76% | |
| Crown daisy leaf waste | Ultrapure water and urea | Hydrothermal | TEM- 5–10 nm | $\lambda_{em}$ 380 nm, $\lambda_{ex}$ 330 nm | - | 2019 [53] |
Table 2. Cont.

| Precursor         | Passivation/Solvent | Technique   | Properties | Year | Reference |
|-------------------|---------------------|-------------|------------|------|-----------|
| Cabbage           | Anhydrous ethanol   | Solvothermal| TEM-3.4 nm |      |           |
| Cherry tomatoes   | -                   | Hydrothermal| TEM-7 nm   |      |           |
| Tomato            | Hydroxylamine       | Hydrothermal| HRTEM-3 nm |      |           |
| Scallion leaves   | Water               | Hydrothermal| TEM-3.5 nm |      |           |
| Tomato            | -                   | Hydrothermal| HRTEM-9 nm |      |           |
| Red beet          | Water               | Hydrothermal| TEM-4.66 nm|      |           |

Table 3. Summary of the synthesis of CDs from flowers.

| Precursor                      | Carbon Source | Passivation/Solvent | Technique   | Properties | Year | Reference |
|--------------------------------|---------------|---------------------|-------------|------------|------|-----------|
| Selemicereus grandiflorus      | -             | Boiling             | HRTEM-2.5 nm| λem - 440 and 365 nm | 2019 | [59]      |
| Water hyacinth                 | Phosphoric acid| Carbonization       | SEM - ≤10 nm| λem - 370 nm | 2019 | [60]      |
| Osmanthus fragrans             | Ultrapure water| Hydrothermal       | TEM-2.23 nm | λem - 410 nm | 2019 | [61]      |
| Rose flowers: Yellow           | Water         | Hydrothermal        | TEM-37 nm   | λem - 335 nm | 2020 | [62]      |
|                                | Ethanol       | Hydrothermal        | TEM-30 nm   | λem - 420 nm |      |           |
| Tagetes erecta                 | Deionized water| Solvothermal carbonization| FESEM-3.41 nm| λem - 495 nm | 2021 | [63]      |

In another study, Shekarbeygi et al. (2020) evaluated the effect of rose pigments (blue, red, and yellow) and the effect of their extraction methods (aqueous and alcohol) on optical properties of the synthesized CDs [62]. The results indicated that the quantum yields obtained for all the CDs were not affected by the rose pigments and extraction methods, as the yields were almost the same. However, such rose pigments and extraction methods affected the CDs’ thermal stability and emission wavelengths. In the case of thermal stability, the fluorescence intensities were reduced in both aqueous and alcoholic CDs, with an increase in temperature ranging from 17 to 57 °C, yet aqueous CDs showed a higher decreasing rate than alcoholic CDs. As for the emission wavelengths, the alcohol extract had a larger wavelength than the aqueous extract, which may be due to the change in dielectric constant of solvent and the presence of more phenolic groups in the alcoholic extract. Thus, this work showed that CDs prepared with alcoholic extract with yellow petals has higher stability and a longer emission wavelength with better quantum yield than the others.

2.4. Leaves, Seeds, and Stems

In this section, we focused on the parts of plant-derived CDs, namely leaves (such as Ocimum sanctum leaves, bamboo leaves, gingko leaves, Gynostemma leaves, betel leaves, Calotropis procera leaves, Elettaria cardamomum leaves, Cornus walteri leaves, tea leaves, Kentucky bluegrass), seeds (such as Acacia concinna seeds, fennel seeds, Pearl millet seeds), and stem (lotus root), as presented in Table 4 [64–78]. Most of them have excellent healing properties, such as anti-inflammatory, antioxidant, antimicrobial, and antitoxin properties.
Due to those health benefits, the synthesized CDs could serve simultaneously in the fluorescent sensing of metal ions and as contrast agents for live cells [64–66]. Nonetheless, more efforts are still needed to explore the effect of reaction temperature, time, and pH, despite the remarkable use of carbon precursors. The work of Dager et al. (2019) witnessed complete carbonization of fennel seeds (hydrocarbon converted to the graphitic structure) when the reaction temperature increased to the highest temperature at 500 °C for 3 h [70]. It was also found that by heating the sample longer (for 5 h) did not result in any significant change in either PL or crystallinity. Furthermore, when the synthesized CDs were dispersed in water at different pHs ranging from 3 to 13, the emission intensity gradually increased from acidic to basic media and eventually decreased when the reaction pH was higher than 9.

**Table 4.** Summary of the synthesis of CDs from leaves, seeds, and stems.

| Carbon Source | Passivation/Solvent | Technique | Particle Size | Fluorescence (λ<sub>ex</sub> - λ<sub>em</sub>) | Quantum Yield | Year | Reference |
|---------------|----------------------|-----------|---------------|-----------------------------------|--------------|------|-----------|
| Lotus root    | -                    | Microwave | TEM- 9.41 nm  | λ<sub>em</sub> - 435 nm; λ<sub>ex</sub> - 360 nm | 19.0%        | 2016 | [64]     |
| Ocimum sanctum leaves | Distilled water | Hydrothermal | TEM- 2.23 nm | λ<sub>em</sub> - 410 nm; λ<sub>ex</sub> - 340 nm | 9.3%         | 2017 | [65]     |
| Acacia concina seeds | Methanol | Microwave treatment | HRTEM- 2.5 nm | λ<sub>em</sub> - 468 nm; λ<sub>ex</sub> - 390 nm | 10.20%       | 2018 | [66]     |
| Bamboo leaves | Sodium hydrosolate and sodium hypochlorite | Pyrolysis | AFM- 2 nm | λ<sub>em</sub> - 425–475 nm | -            | 2018 | [67]     |
| Gynostemma     | -                    | Pyrolysis | TEM- 4.11 nm  | λ<sub>em</sub> - 427 nm; λ<sub>ex</sub> - 360 nm | 21.7%        | 2018 | [68]     |
| Fennel seeds  | -                    | Calcination | TEM- 2.5 nm | λ<sub>em</sub> - 400 nm; λ<sub>ex</sub> - 320 nm | 5.7%         | 2019 | [69]     |
| Bamboo leaves | -                    | Calcination | TEM- 11 nm | λ<sub>em</sub> - 419 nm; λ<sub>ex</sub> - 313 nm | 5.18%        | 2020 | [71]     |
| Betel leaves  | Ammonia              | Hydrothermal | HRTEM- less 10 nm PSA- 3.7 nm | λ<sub>em</sub> - 402 nm; λ<sub>ex</sub> - 320 nm | 4.21%        | 2021 | [72]     |
| Calotropis procera leaves | Deionized water | Hydrothermal carbonization | FETEM- 4.3 nm | λ<sub>em</sub> - 416 nm; λ<sub>ex</sub> - 340 nm | 71.95%       | 2021 | [73]     |
| Elettaria cardamomum leaves | Distilled water | Ultrasonication | - | λ<sub>em</sub> - 520 and 850 nm; λ<sub>ex</sub> - 514 nm | -            | 2021 | [74]     |
| Pearl millet seeds | Double distilled water | Thermal treatment | HRTEM- 4-5 nm | λ<sub>em</sub> - 415 nm; λ<sub>ex</sub> - 250 nm | 52%          | 2021 | [75]     |
| Cornus Walteri leaves | Maleic anhydride, hydrogen peroxide and water | Hydrothermal | TEM- 3.53 nm | λ<sub>em</sub> - 550 nm; λ<sub>ex</sub> - 420 nm | 18.34%       | 2022 | [76]     |
| Tea leaves    | Urea and ultrapure water | Hydrothermal | TEM- 2.32 nm | λ<sub>em</sub> - 455 nm; λ<sub>ex</sub> - 360 nm | -            | 2022 | [77]     |
| Kentucky bluegrass | Ethylenediamine | Hydrothermal | TEM- 9 nm | λ<sub>em</sub> - 370–470 nm; λ<sub>ex</sub> - 280–400 nm | 7%           | 2022 | [78]     |

Leaves are recognized as the most excellent carbon precursors by reason of exhibiting higher quantum yields than seeds and stem. Most interestingly, the *Calotropis procera* leaf-derived CDs provided an excellent quantum yield (71.95%) without any toxic agents or surface passivation chemicals [73]. It is noteworthy that an excellent quantum yield resulted from the functional groups (OH, N–H, C=O, and C=N bond) derived from the carbon precursors itself. Furthermore, the synthesized CDs have a strong peak around 320 nm in the UV–Vis spectra of CDs (Figure 2), implying that it was spawned by the n → π* transition of C=O bonds over the surface of CDs.
2.5. Crop Residues

Crop residues, such as sago waste, palm kernel shell, and wheat straw, are another potential carbon source used in the green preparation of CDs (Table 5). In the year of 2014, Tan et al. successfully demonstrated the conversion of sago waste into fluorescent CDs via thermal pyrolysis without any surface passivation [79]. The heating temperature of pyrolysis was found to alter the degree of carbonization of bulk sago waste into carbonaceous residues. It was observed that heating treatments of lower than 400 °C can lead to incomplete carbonization, while higher temperatures can cause severe decomposition of the organic structures in sago waste into ashes, which leads to the loss of the fluorescing property. The optimum temperature of carbonization was found to be 400 °C. However, the synthesized CDs may suffer from low quantum yields due to the absence of solvent.

Table 5. Summary of the synthesis of CDs from crop residues.

| Precursor                  | Technique                  | Properties                              | Year | Reference |
|----------------------------|----------------------------|-----------------------------------------|------|-----------|
| Sago waste                 | Thermal pyrolysis          | SEM-6–17 nm; λem: 390 nm, λex: 315 nm  | 2014 | [79]      |
| Palm kernel shell          | Microwave irradiation      | TEM-6.6 to 7 nm; λem: 438–459 nm, λex: 370 nm | 2020 | [80]      |
| Palm kernel shell          | Hydrothermal               | TEM-2 nm; λem: 430–450 nm, λex: 350–400 nm | 2021 | [81]      |
| Wheat straw                | Hydrothermal               | TEM: 2.1 nm; DLS: 5.7 nm; λem: 470 nm, λex: 380 nm | 2021 | [82]      |

Solvents, especially solvents with high boiling points, play an important role in providing better carbonization rates for the formation of CDs. Of these, controlling the reaction conditions by adding solvent is of particular importance. Thus, to date, diethylene glycol [80], ultrapure water and ethanol [81], and deionized water [82] have been used as solvents to improve carbonization efficiency. The results showed that the reaction of diethylene glycol (DEG) on palm kernel shell-derived CDs had the highest quantum yield of 44%. This advancement is due to the higher boiling point of DEG than the others, thus allowing a more complete reaction for the formation of CDs at higher temperatures.
2.6. Fungi/Bacteria Species

The conversion of fungi/bacteria species into a value-added product such as carbonaceous nanomaterials has contributed to the green and sustainable improvement. Algal blooms [83], yogurt [84], enokitake mushroom [85], microalgae biochar [86], mushroom [87], agarose waste [88], and *Shewanella oneidensis* [89] have been previously chosen as a carbon resource (Table 6). A study conducted by Pacquiao et al. (2018) demonstrated the increment of quantum yield of 11% to 39% upon passivation with tetraethylenepentamine in the presence of 5% v/v sulfuric acid [85]. The XPS spectrum revealed the presence of small signals of nitrogen and sulfur at 399 eV (N 1s) and 168 eV (S 2p), respectively, thus confirming the successful heteroatoms doping on CDs and sulfuric acid as a reagent. Furthermore, the effect of temperatures (180, 200, and 250 °C) and reaction times (4, 6, and 8 h) on the quantum yield was evaluated, yielding the optimum temperature and reaction time at 250 °C for 4 h. The research, thus, concluded that higher temperatures and shorter reaction times can produce higher quantum yields. Even so, CDs prepared from agarose waste-derived CDs without using other passivation chemicals exhibited the highest quantum yield of 62% [88]. This quantum efficiency can be attributed to the presence of different functional groups (–C=O, –OH, and N–H) on the surface of CDs, in addition to being related to the surface defects and the particle size of CDs.

| Precursor               | Technique          | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|------------------------|--------------------|---------------|--------------|---------------|------|-----------|
| Algal blooms           | Microwave          | TEM- 8.5 nm   | λ<sub>ex</sub>: 438 nm, λ<sub>em</sub>: 360 nm | 13%            | 2016 | [83]      |
| Yogurt                 | Pyrolysis          | TEM- 3.5 nm   | λ<sub>ex</sub>: 420 nm, λ<sub>em</sub>: 320 nm | 2.4%           | 2018 | [84]      |
| Enokitake mushroom     | Hydrothermal       | TEM- 4 nm     | λ<sub>ex</sub>: 470 nm, λ<sub>em</sub>: 360 nm | 11%            | 2018 | [85]      |
| Microalgae biochar     | Oxydizing agent and autoclave | AFM- 68 nm | λ<sub>ex</sub>: 398 nm, λ<sub>em</sub>: 280 nm | -              | 2019 | [86]      |
| Mushroom               | Hydrothermal       | TEM- 5.8 nm   | λ<sub>ex</sub>: 440 nm, λ<sub>em</sub>: 360 nm | 11.5%          | 2020 | [87]      |
| Agarose waste          | Thermal treatment  | HRTEM- 2-10 nm| λ<sub>ex</sub>: 420 nm, λ<sub>em</sub>: 300 nm | 62%            | 2021 | [88]      |
| *Shewanella oneidensis*| Luria-Bertani      | -             | λ<sub>ex</sub>: 410 nm, λ<sub>em</sub>: 320 nm | 7%             | 2022 | [89]      |

2.7. Waste Products

There are ongoing efforts to improve the photoluminescent properties while reducing the production cost and protecting the environment. Of the different plant and fungi sources, the reuse of waste (Table 7), such as frying oil [90], biocrude oil [91], polystyrene [92], tea powders [93], expired milk [94], coal powder [95], papers [96], polyolefin [97], polypropylene plastic waste [98], bike soot [99], etc. [100–111], has become one of the hottest scientific research topics nowadays for the development of CDs. Among these materials, plastic waste and heavy oil products offer a promising precursor, as they have produced high quantum yields of more than 60%. In the case of plastic waste, cup-derived CDs have displayed the highest quantum yield value of 65% at 310 nm compared to bottles (64%) and polybags (62%) [108]. The high quantum yield of CDs is highly dependent on the carbonyl groups in CDs, revealing the presence of NH<sub>2</sub>. Furthermore, all the three prepared CDs displayed a slight red shift in the emission peak, with respect to the excitation wavelength. These behavioral variations were mainly due to the presence of epoxy and hydroxyl functional groups in the CDs prepared from the plastic waste, which resulted in creating new energy levels between n–π* gaps. Due to this reason, the energy gaps of the CDs between the lowest unoccupied molecular orbital (LUMO) and the highest occupied
molecular orbital (HOMO) became reduced with the increasing degree of surface oxidation, thereby contributing to the enhanced fluorescence property (Figure 3).

Figure 3. Scheme illustration of tunable PL of CDs with different degrees of oxidation.

Recently, the precursors with higher molecular weight, higher heteroatoms and higher aromatic structures were shown to be more conducive to the production of CDs. Ma et al. (2021) observed that CDs synthesized with asphalt as the precursor have the highest fluorescence quantum yield compared to heavy oil, light deasphalted oil (LDAO), and heavy deasphalted oil (HDAO) [110]. The reason is that the CDs from asphalt had the highest aromatic carbon ratio and the lowest naphthenic carbon ratio and alkyl carbon ratio. In addition, the asphalt had higher molecular weight, more oxygen, nitrogen and sulfur contents, and higher carbon/hydrogen atomic ratio than the other precursors. This result was further confirmed by the presence of the doublet γ peak and (002) peak in the X-ray diffraction pattern of asphalt, which indicated that the asphalt had a great quantity of graphite-like ordered structures.

Table 7. Summary of the synthesis of CDs from waste products.

| Carbon Source                        | Technique                           | Particle Size | Properties                         | Quantum Yield | Year  | Reference |
|--------------------------------------|-------------------------------------|--------------|------------------------------------|---------------|-------|-----------|
| Waste frying oil                    | Sulfuric acid                        | Carbonization| TEM- 2.6 nm                         |               |       |           |
| Nanochloropsis biocrude oil         | Sulfuric acid                        | Hydrothermal | TEM- 4 nm                          | λem - 378 nm  | 3.66% | 2014 [90]|
| Polystyrene                          | Ethylenediamine                      | Solvothermal | TEM- 4 nm                          | λem - 456 nm  | 13.71%| 2017 [91]|
| Assam CTC tea                       | Acetic acid                          | Carbonization| TEM- <10 nm                        | λem - 380–500 nm | -     | 2017 [92]|
| Expired milk                         | Water                                | Subcritical water| TEM- <5 nm                         | λem - 440 nm  | 6.64% | 2018 [94]|
| Long flame coal powder               | Deionized water                      | Ozone oxidation| DLS- 4.2 nm                        | λem - 530 nm  | 8.4% | 2018 [95]|
| Paper waste                          | Sodium hydroxide and distilled water | Hydrothermal | TEM- 2–4 nm                        | λem - 420 nm  | 20%  | 2018 [96]|
| Waste polyolefin                     | Sulfuric acid and nitric acid        | Ultrasound-assisted chemical oxidation| TEM- 2.5 nm           | λem - 540 nm  | 4.84% | 2018 [97]|
| Polypropylene plastic waste          | Ethanol                              | Heating process| TEM- <20 nm                        | λem - 410–465 nm | -     | 2018 [98]|
| Bike soot                            | Deionized water                      | Hydrothermal | TEM- 4.2 nm                        | λem - 396 nm  | -5.63%| 2018 [99]|
|                                      | Nitric acid                          |              | TEM- 5.6 nm                        | λem - 560 nm  | 3.25% | 2018 [99]|
|                                      | Phosphoric acid                      |              | TEM- 4.2 nm                        | λem - 460 nm  | 2.76% | 2018 [99]|

The gaps of the CDs between the lowest unoccupied molecular orbital (LUMO) and the highest occupied molecular orbital (HOMO) became reduced with the increasing degree of surface oxidation, thereby contributing to the enhanced fluorescence property (Figure 3).

Table 7. Summary of the synthesis of CDs from waste products.
Table 7. Cont.

| Carbon Source       | Passivation/Solvent | Technique                             | Particle Size | Properties          | Quantum Yield | Year | Reference |
|---------------------|---------------------|---------------------------------------|---------------|----------------------|---------------|------|-----------|
| Coke powder         | Hydrogen peroxide   | Chemical oxidation                    | TEM- 6.5 nm   | \(\lambda_{em} \approx 410 \text{ nm}\) \(\lambda_{ex} \approx 330 \text{ nm}\) | 9.2%          | 2019 | [100]    |
| Waste plastic bottles | Hydrogen peroxide | Air oxidation and hydrothermal      | TEM- 3–10 nm  | \(\lambda_{em} \approx 434 \text{ nm}\) \(\lambda_{ex} \approx 340 \text{ nm}\) | 5.2%          | 2019 | [101]    |
| Waste tea powder    | Nitric acid         | Chemical oxidation                    | TEM- 3.2 nm   | \(\lambda_{em} \approx 430 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) | 2.47%         | 2019 | [102]    |
| Waste tea powder    | -                   | Carbonization                         | TEM- 5 nm     | \(\lambda_{em} \approx 415 \text{ nm}\) \(\lambda_{ex} \approx 315 \text{ nm}\) | 4.76%         | 2019 | [103]    |
| Waste green tea powder | Deionized water and manganese chloride | Hydrothermal                        | TEM- 5 nm     | \(\lambda_{em} \approx 410-440 \text{ nm}\) \(\lambda_{ex} \approx 360 \text{ nm}\) | 12%           | 2019 | [104]    |
| Tieguanin Tea leaves | Acetic acid         | Hydrothermal                          | TEM- 7–9 nm   | \(\lambda_{em} \approx \text{blue}\) \(\lambda_{ex} \approx 325 \text{ nm}\) | -             | 2019 | [105]    |
| Peanut shell        | Nitric acid         | Oxidative acid treatment              | HRTEM- 5 nm   | \(\lambda_{em} \approx 510 \text{ nm}\) \(\lambda_{ex} \approx 360-365 \text{ nm}\) | ~3%           | 2019 | [106]    |
| Paper waste         | Deionized water     | Hydrothermal                          | TEM- 2.6 nm   | \(\lambda_{em} \approx \text{blue}\) \(\lambda_{ex} \approx 360 \text{ nm}\) | 12%           | 2019 | [107]    |
|                     | Ethanol             | /solvothermal                         | TEM- 4.0 nm   | \(\lambda_{em} \approx 435 \text{ nm (cyan)}\) \(\lambda_{ex} \approx 360 \text{ nm}\) | 27%           | 2020 | [107]    |
|                     | 2-propanol          |                                        | TEM- 4.4 nm   | \(\lambda_{em} \approx 435 \text{ nm (cyan)}\) \(\lambda_{ex} \approx 360 \text{ nm}\) | 10%           |       |          |
| Polybags            | -                   | Hydrothermal carbonization            | HRTEM- 5–10 nm| \(\lambda_{em} \approx 420-425 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) | 62%           | 2021 | [108]    |
| Cups                | -                   |                                        | Haw shows     | \(\lambda_{em} \approx 420-425 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) | 65%           | 2021 | [108]    |
| Bottles             | -                   |                                        |               | \(\lambda_{em} \approx 420-425 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) | 64%           |       |          |
| Polymeric waste     | 4,7,10-trioxa-1,13-tridecanediamine | Hydrothermal                          | TEM- 3 nm     | \(\lambda_{em} \approx 400 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) \(\lambda_{ex} \approx 365 \text{ nm}\) | -             | 2021 | [109]    |
| Heavy oil           | -                   |                                        |               | \(\lambda_{em} \approx 400 \text{ nm}\) \(\lambda_{ex} \approx 310 \text{ nm}\) \(\lambda_{ex} \approx 365 \text{ nm}\) | -             |       |          |
| Light deasphalted oil (LDAO) | - | -                                      |               | \(\lambda_{em} \approx 610 \text{ nm}\) \(\lambda_{ex} \approx 475 \text{ nm}\) | 11.5%          | 2021 | [110]    |
| Heavy deasphalted oil (HDAO) | - | -                                      |               | \(\lambda_{em} \approx 560 \text{ nm}\) \(\lambda_{ex} \approx 420 \text{ nm}\) | 17.7%         |       |          |
| Asphalt             | -                   |                                        | TEM- 1.21 nm  | \(\lambda_{em} \approx 510 \text{ nm}\) \(\lambda_{ex} \approx 410 \text{ nm}\) | 28.3%         |       |          |
| Waste tobacco leaves | Ethylenediamine and ultrapure water | Hydrothermal                       | TEM- 6.30 nm  | \(\lambda_{em} \approx 430 \text{ nm}\) \(\lambda_{ex} \approx 360 \text{ nm}\) | 13.7%         | 2021 | [111]    |

3. CDs Synthesized from Chemical Precursors

Although many natural precursors have been used in the preparation of low-cost CDs, chemical precursors are still being explored to this day to produce high quantum yields of CDs. This section reviews two types of reaction chemical precursors used in CD preparation, namely acid and non-acid reagents, which were briefly summarized in Tables 8 and 9.

3.1. Acid Reagents

Since 2012, carbon sources based on acid reagents, such as citric acid, phosphoric acid, acetic acid, folic acid, ascorbic acid, sodium citrate, ascorbic acid, glutamic acid, malonic
acid, maleic anhydride, boric acid, pyrogallic acid, phthalic acid, 3-aminobenzeneboronic acid, succinic acid, p-aminosalicylic acid, diethylenetriamine-pentacetate acid, maleic anhydride, DL-thioctic acid, sulfamic acid, tartaric acid, 2-aminoterephthalic acid, trans-aconitic acid, dehydroabietic acid, dithiosalicylic acid, etc., have been intensively employed in the production of CDs [112–197].

Dong et al. (2013) first compared the fluorescence properties of the following three types of CDs: (i) O-CDs synthesized from citric acid only, (ii) N-CDs synthesized from citric acid and glycine, and (iii) N,S-CDs synthesized from citric acid and L-cysteine [113]. It was observed that the doping of nitrogen into O-CDs can introduce a new kind of surface state (labelled as the N-state). Electrons trapped by the new formed surface states are able to facilitate a high yield of radiative recombination. Although the quantum yield of N-CDs was found to be higher than that of O-CDs, the fluorescence spectra were still broad and excitation-dependent. In such cases, the introduction of sulfur atoms into CDs could lead to more significant enhancement, offering higher yields and excitation-independent emission. The introduced sulfur atoms seem to be able to eliminate the O-states and enhance the N-state, meaning that the original surface states are almost neglected in the N,S-CDs. However, when the authors tuned the ratio of L-cysteine into citric acid, from 1 g:2 g into 0.125 g:2 g, the quantum yield of N,S-CDs decreased from 73% to 37% and the emission wavelength was dependent on excitation and yielded a red-shift from 415 to 540 nm under the excitation wavelength of 375 to 480 nm. Interestingly, when the excitation wavelength was set lower than 375 nm, the emission wavelength was excitation independent. Although the aforementioned CDs were highly enhanced by nitrogen and sulfur co-doping, the chemistry involved therein is extremely challenging due to the involvement of oxygen, let alone the interference from defects. Therefore, until single nitrogen doping-sources, such as urea, ethylenediamine, PEG diamine, melamine, etc., have been widely reported, as shown in Table 8.

On the other hand, citric acid as the carbon source was commonly used in the chemical synthesis of CDs. Citric acid has considerable advantages over other acid reagents, such as being relatively cheap, more sour, less harmful to the environment, and readily available in large commercial quantities. Consequently, two highest fluorescence quantum yields were attributed to the reflux reaction of citric acid and diethylenetriamine [133] and hydrothermal reaction of citric acid and ethylenediamine [176] at 82.40% and 85.69%, respectively. As expected, ethylenediamine as N-doping agents plays a major role in improving the fluorescence properties in CDs. By way of example, Wang et al. (2015) have reported the influence of three different polyethylenic amine molecules, i.e., ethylenediamine (EDA), diethylenetriamine (DETA), and tetraethylenepentamine (TEPA) with a combination of citric acid on photoluminescence performance [129]. The results showed that the CDs-EDA has the highest PL quantum yield at 69.3%, followed by CDs-DETA (68%) and CDs-TEPA (33.4%). The results imply that the increasing presence of cyclic imines (C=N) with the enhancement of conjugated π-domains in CDs imparts superior PL efficiency.

There is another study that reported the fabrication of CDs from different nitrogen sources, such as ethylenediamine (e), hexamethylenetetramine (h), and triethanolamine (t) [130]. From the X-ray photoelectron spectroscopy analyses, the ratios of carbon to nitrogen in these CDs were determined, namely, 83:17 for e-CDs, 86.14 for h-CDs, and 96:4 for t-CDs. Because of the high nitrogen content in e-CDs, the quantum yield was found to be highest at 53%. The amount of nitrogen can be typically correlated with a high photoluminescence quantum yield and confirms similar features in the absorption spectra (a shoulder at 234 nm and a broad peak at 340 nm) between e-CDs and pure citrazinic acid, the basic unit from the presumed class of fluorophores. However, at wavelengths longer than 400 nm, pure citrazinic acid has no absorption characteristic, unlike e, h and t-CDs, as shown in Figure 4a. The presence of broad absorption in this energy is commonly assigned to surface states related to the functional surface groups in CDs, which form low-energy sub-band gaps within the n−π∗ band gap.
which can effectively improve the optical and chemical properties while urea acts as nitrogen-doping precursors, which both are responsible for the increase in quantum yield. The reaction mechanism was proposed to include the formation of -COOH, -NH, and -SH functional groups of amino acids via condensation polymerization and then the esterification of citric acid with amino acids, followed by dehydration to generate N and/or S-doped CDs under microwave exposure. The research concluded that only cysteine-CDs were found to possess the highest quantum yield of 89.5% upon the N and S atoms containing CDs.

The highest quantum yield of 93% was achieved when sodium citrate dihydrate and urea were used as precursors [179]. Sodium citrate dihydrate plays an important role as a self-assembly trigger for a carbon-based structure, due to the intermolecular H-bonding, while urea acts as nitrogen-doping precursors, which both are responsible for the increase in quantum yield. In another study, instead of using common synthesis methods such as oxidation, combustion, and hydrothermal, Ji et al. (2021) established another method, which is simpler and timesaving. Briefly, 0.34 g of L-cysteine, 0.15 g of urea, and 8.5 g of diphosphorus pentoxide were mixed, followed by the addition of 6 mL of water with a rapid stirring process [193]. These CDs were then embedded in in polyvinyl alcohol.
(PVA) gel substrate to form a smooth and high fluorescent CD/PVA film for further use in hexavalent chromium detection.

Table 8. Summary of the synthesis of CDs from acid reagents.

| Precursor | Passivation/Solvent | Technique | Particle Size | Properties | Year | Reference |
|-----------|---------------------|-----------|---------------|------------|------|-----------|
| Carbon Source | | | | | | |
| Citric acid | Terbium (III) nitrate pentahydrate | Carbonization | TEM- 3 nm | λ_{em} - 450 nm λ_{ex} - 320 nm | 2012 | [112] |
| Citric acid | L-cysteine | Hydrothermal treatment | HRTEM- 7 nm | λ_{em} - 415 nm λ_{ex} - 345 nm | 2013 | [113] |
| Citric acid | Glycine | - | - | λ_{em} - 415 nm λ_{ex} - 345 nm | 2013 | [114] |
| Citric acid | Urea | Microwave | TEM-4 to 6 nm | λ_{em} - 460 nm λ_{ex} - 360 nm | 2013 | [115] |
| Ethylene glycol bis-(2-aminomethyl ether)- N,N,N',N'-tetraacetic acid | - | Hydrothermal | TEM- 5 nm | λ_{em} - 425 nm λ_{ex} - 310 nm | 2014 | [116] |
| Citric acid | PEG-diamine | Solid-phase | TEM- 1.7 nm | λ_{em} - 435 nm λ_{ex} - 360 nm | 2014 | [117] |
| Citric acid | Poly(ethyleneimine) | Pyrolysis | HRTEM- 3.5-4.5 nm | - | 2014 | [118] |
| Folic acid | Ethylene glycol and nanopure water | Hydrothermal | TEM- 4.5 nm | λ_{em} - 470 nm λ_{ex} - 395 nm | 2015 | [119] |
| Poly(ethylene glycol) and ascorbic acid | Distilled water | Microwave | TEM- 2.3 nm | λ_{em} - 450 nm λ_{ex} - 373 nm | 2015 | [120] |
| Citric acid | Ethylenediamine | Microwave-assisted pyrolysis | TEM- 3 nm | λ_{em} - 455 nm λ_{ex} - 280 nm | 2015 | [121] |
| Citric acid | L-Tyrosine methyl ester hydrochloride | Hydrothermal | TEM- 3.7 nm | λ_{em} - 433 nm λ_{ex} - 348 nm | 2015 | [122] |
| Citric acid | Ethylenediamine and double distilled water | Hydrothermal | - | - | 2015 | [123] |
| Citric acid | 1-Aminopropyl-3-methy-imidazolium bromide | Pyrolysis | HRTEM- 0.6-1.6 nm | λ_{em} - 440 nm λ_{ex} - 380 nm | 2015 | [124] |
| Glacial acetic acid | N-Acetyl-L-cysteine, diplosphorous pentoxide and distilled deionized water | Simple mixing | TEM- 2.51-3.44 nm | λ_{em} - 480 nm λ_{ex} - 300 nm | 2015 | [125] |
| Citric acid | L-cysteine, urea and ultrapure water | Microwave | TEM- 1.1 nm | λ_{em} - 450 nm λ_{ex} - 355 nm | 2015 | [126] |
| Citric acid | Dithiooxamide and distilled water | Microwave-assisted hydrothermal | STEM- 2 nm | λ_{em} - 448 nm λ_{ex} - 360 nm | 2015 | [127] |
| Citric acid monohydrate | Ammonia and double distilled water | Hydrothermal | TEM- 3.7 nm | λ_{em} - 442 nm λ_{ex} - 350 nm | 2015 | [128] |
| Sodium citrate | Urea and ultrapure water | Electrochemical carbonization | TEM- 2.4 nm | λ_{em} - 433 nm λ_{ex} - 351 nm | 2015 | [129] |
| Citric acid anhydrous | Ethylenediamine | Condensation carbonization | TEM- 3.9 nm | λ_{em} - 445 nm λ_{ex} - 365 nm | 2015 | [130] |
| Citric acid anhydrous | Diethylenetriamine | Condensation carbonization | TEM- 3.7 nm | λ_{em} - 445 nm λ_{ex} - 365 nm | 2015 | [131] |
| Citric acid anhydrous | Tetraethylenepentamine | Condensation carbonization | TEM- 4.1 nm | λ_{em} - 445 nm λ_{ex} - 365 nm | 2015 | [132] |
| Citric acid anhydrous | Ethylenediamine and deionized water | Hydrothermal | - | λ_{em} - 440 nm λ_{ex} - 320 nm | 2016 | [133] |
| Citric acid anhydrous | Hexamethylenetetramine and deionized water | Hydrothermal | - | λ_{em} - 420 nm λ_{ex} - 320 nm | 2016 | [134] |
| Citric acid anhydrous | Triethanol-amine and deionized water | Hydrothermal | - | λ_{em} - 420 nm λ_{ex} - 320 nm | 2016 | [135] |
| Carbon Source                  | Precursor                        | Technique               | Particle Size       | Fluorescence | Quantum Yield | Year | Reference |
|--------------------------------|----------------------------------|-------------------------|---------------------|--------------|--------------|------|-----------|
| Citric acid                    | Ethylenediamine and deionized water | Hydrothermal            | TEM-5 to 7 nm       | $\lambda_{\text{ex}}$ 433 nm $\lambda_{\text{em}}$ 365 nm | -  | 2016 | [131]    |
| Citric acid                    | Branched polyethylenimine        | Condensation            | DLS-1.9 nm          | $\lambda_{\text{ex}}$ 450 nm $\lambda_{\text{em}}$ 350 nm | -  | 2016 | [132]    |
| Citric acid                    | Diethylenetriamine               | Reflux treatment        | TEM-5-7 nm          | -            | 82.40%       | 2016 | [133]    |
| Ascorbic acid and valine       | Ethanol and distilled water      | Hydrothermal            | TEM-4 nm            | $\lambda_{\text{ex}}$ 430 nm $\lambda_{\text{em}}$ 352 nm | 4.8%| 2016 | [134]    |
| L-glutamic acid                | Silica gel powders and water     | Microwave               | TEM-1.64 nm         | $\lambda_{\text{ex}}$ 450 nm $\lambda_{\text{em}}$ 370 nm | 41.2%| 2016 | [135]    |
| Malonic acid                   | Urea and ultrapure water         | Hydrothermal            | TEM-2.5 nm          | $\lambda_{\text{ex}}$ 397 nm $\lambda_{\text{em}}$ 320 nm | 12.6%| 2017 | [136]    |
| Succrose and phosphoric acid   | Sodium hydroxide                 | Carbonization           | SEM-10 nm           | $\lambda_{\text{ex}}$ 524 nm $\lambda_{\text{em}}$ 423 nm | -  | 2017 | [137]    |
| Citric acid                    | Sodium phosphate                 | Solid-phase             | TEM-1.7 nm          | $\lambda_{\text{ex}}$ 435 nm $\lambda_{\text{em}}$ 360 nm | -  | 2017 | [138]    |
| Citric acid                    | Ethylenediamine and ultrapure water | Hydrothermal           | TEM-<10 nm          | $\lambda_{\text{ex}}$ 431 nm $\lambda_{\text{em}}$ 337 nm | 32.25%| 2017 | [139]    |
| Citric acid monohydrate        | Thiourea                         | Microwave solid-phase pyrolysis | TEM-2 nm         | $\lambda_{\text{ex}}$ 436 nm $\lambda_{\text{em}}$ 356 nm | 23.6%| 2017 | [140]    |
| Citric acid                    | Silk                             | Hydrothermal            | TEM-5.6 nm          | $\lambda_{\text{ex}}$ 425 nm $\lambda_{\text{em}}$ 360 nm | 61.1%| 2017 | [141]    |
| Citric acid                    | Melamine                         | Hydrothermal            | TEM-1.8 nm          | $\lambda_{\text{ex}}$ 422 nm $\lambda_{\text{em}}$ 320 nm | 8.11%| 2017 | [142]    |
| Citric acid                    | Tartaric acid, ethanediamine and oleic acid | Solvothermal          | TEM-2.66 nm         | $\lambda_{\text{ex}}$ 460 nm $\lambda_{\text{em}}$ 360 nm | 42.2%| 2017 | [143]    |
| Citric acid and urea           | Water                            | Solvothermal            | TEM-1.7 nm          | $\lambda_{\text{ex}}$ 448-638 nm $\lambda_{\text{em}}$ 375 nm | -  | 2017 | [144]    |
| Maleic anhydride and tetraethylenepentamine | Sulfuric acid and deionized water | Pyrolysis               | TEM-20 nm           | $\lambda_{\text{ex}}$ 450 nm $\lambda_{\text{em}}$ 360 nm | 21%| 2017 | [145]    |
| D-(+) -maltose monohydrate, boric acid and thiocarbamide | -                               | Hydrothermal            | TEM-2.0 nm          | $\lambda_{\text{ex}}$ 415 nm $\lambda_{\text{em}}$ 326 nm | 8.9%| 2017 | [146]    |
| Pyrogallic acid                | N-N-dimethylformamide            | Solvothermal            | TEM-11.9 nm         | $\lambda_{\text{ex}}$ 520 nm $\lambda_{\text{em}}$ 360-450 nm | 16.8%| 2018 | [147]    |
| L-histidine and citric acid    | Ethylene glycol                  | Polyol microwave        | TEM-19 nm           | $\lambda_{\text{ex}}$ 430-511 nm $\lambda_{\text{em}}$ 350 nm | -  | 2018 | [148]    |
| Phthalic acid and triethylenediamine hexahydrate | Deionized water                 | Microwave               | TEM-2-6 nm          | $\lambda_{\text{ex}}$ 520-542 nm $\lambda_{\text{em}}$ 360-440 nm | 16.1%| 2018 | [149]    |
| Citric acid                    | Urea                             | Solvothermal            | TEM-1.87 nm         | $\lambda_{\text{ex}}$ 590 nm $\lambda_{\text{em}}$ 540 nm | 43%| 2018 | [150]    |
| Citric acid                    | Lysine and ultrapure water       | Hydrothermal            | TEM-10 nm           | -            | -            | 2018 | [151]    |
| Citric acid monohydrate        | -                                | Thermal treatment       | TEM-3.5 nm          | $\lambda_{\text{ex}}$ 450 nm $\lambda_{\text{em}}$ 360 nm | 3.54%| 2018 | [152]    |
| Citric acid                    | Ammonium thiocyanate and deionized water | Microwave-assisted HRTEM-30 nm | TEM-1.87 nm         | $\lambda_{\text{ex}}$ 490 nm $\lambda_{\text{em}}$ 410 nm | -  | 2018 | [153]    |
| Folic acid and p-phenylenediamine | Sodium hydroxide                | Hydrothermal            | TEM-2 nm            | $\lambda_{\text{ex}}$ 505 nm $\lambda_{\text{em}}$ 420 nm | 8.4%| 2018 | [154]    |
| 3-Aminobenzeneboronic acid     | Deionized water                  | Hydrothermal            | TEM-3 nm            | $\lambda_{\text{ex}}$ 504 nm $\lambda_{\text{em}}$ 400 nm | -  | 2018 | [155]    |
| Succinic acid                  | Deionized water and glycerol     | Hydrothermal            | TEM-2.3 nm          | $\lambda_{\text{ex}}$ 410 nm $\lambda_{\text{em}}$ 280 nm | 11%| 2018 | [156]    |
| Precursor                        | Carbon Source                        | Technique                          | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|--------------------------------|--------------------------------------|-------------------------------------|---------------|--------------|---------------|------|-----------|
| Phosphoric acid                | Ethylenediamine                      | Simple heating                      | TEM- 3.2 nm   | $\lambda_{em}$ - 430 nm $\lambda_{ex}$ - 340 nm | 5.17% | 2018 [157]|
|                                |                                      | Simple heating (180 °C, 2 h)       |               |              |               |      |           |
| Phosphoric acid and ethanolamine| Water                                | Microwave irradiation               | TEM- 3.4 nm   | $\lambda_{em}$ - 417 nm $\lambda_{ex}$ - 340 nm | 20.52%| 2018 [158]|
| P-aminosalicylic acid          | Ethylene glycol dimethacrylate and double distilled water | Hydrothermal | TEM- 3 nm | $\lambda_{em}$ - 520 nm $\lambda_{ex}$ - 390 nm | 27.2% | 2018 [159]|
| Sodium citrate                 | Urea and dimethylformamide           | Solvothermal                        | TEM- 3.52 nm  | $\lambda_{em}$ - 446 nm $\lambda_{ex}$ - 370 nm | 67%  | 2018 [160]|
| Citric acid monohydrate        | 3-(Aminopropyl)triethoxysilane (APTES) | Thermal decomposition               | TEM- 5–15 nm  | $\lambda_{em}$ - 416 and 480 nm | -    | 2019 [161]|
| Citric acid                    |                                     | Hydrothermal                        |               |              |               |      |           |
|                                | Citric acid                          | Glycine and deionized water         |               |              |               |      |           |
|                                |                                      | Hydrothermal                        |               |              |               |      |           |
| Citric acid and urea           | N,N-dimethylformamide                | Hydrothermal                        | TEM- 3.7 nm   | $\lambda_{em}$ - 630 nm $\lambda_{ex}$ - 550 nm | -    | 2019 [163]|
|                                | N,N-dimethylformamide, NaOH and HCl | Solvothermal                        | TEM- 2.1 nm   |              |              |      |           |
| Procain hydrochloride and citric acid | Double distilled water and ethylenediamine | Hydrothermal | TEM- 3.3 nm | $\lambda_{em}$ - 440 nm $\lambda_{ex}$ - 360 nm | 47.1%| 2019 [164]|
| Anhydrous citric acid          | N-(β-aminoethyl)-γ-(aminopropylmethylidimethoxysilane) | Hydrothermal | TEM- 2.22 nm | $\lambda_{em}$ - 460 nm $\lambda_{ex}$ - 370 nm | 51.8%| 2019 [165]|
| Sodium citrate and aminopyrazine| Thiourea and deionized water         | Microwave-assisted pyrolysis        | TEM- 3.3 nm   |              |              |      |           |
| Citric acid                    |                                      | Ultrapure water                     | Hydrothermal  | $\lambda_{em}$ - 389 nm $\lambda_{ex}$ - 310 nm | 11.8%| 2019 [167]|
|                                | Deionized water and arginine         | Microwave                           | TEM- 11 ± 4 nm | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 430 nm | 3.9 ± 0.4%|      |           |
|                                | Deionized water and lysine           | Microwave                           | TEM- 17 ± 2 nm | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 430 nm | 4.2 ± 1.9%| 2019 [168]|
|                                | Deionized water and histidine        | Microwave                           | TEM- 6 ± 5 nm  | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 433 nm | 2.8 ± 0.2%|      |           |
|                                | Deionized water and cysteine         | Microwave                           | TEM- 10 ± 7 nm | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 420 nm | 89.5 ± 2.3%|      |           |
|                                | Deionized water and methionine       | Microwave                           | TEM- 9 ± 5 nm  | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 407 nm | 2.5 ± 0.6%|      |           |
| Citric acid and phenylalanine  | Ultrapure water                      | Hydrothermal                        | TEM- 2–3 nm   |              |              |      |           |
|                                |                                      | Hydrothermal                        | TEM- 4–6 nm   |              |              |      |           |
| Polyacrylamide and citric acid | Ultrapure water                      | Hydrothermal                        | TEM- 4.1 nm   | $\lambda_{em}$ - 330 nm $\lambda_{ex}$ - 310 nm | 12.6%| 2020 [170]|
| Citric acid and urea           |                                      | Infrared carbonization              | TEM- 5–10 nm  | $\lambda_{em}$ - 475 nm $\lambda_{ex}$ - 360 nm | 22.2%| 2020 [171]|
|                                |                                      |                                     | TEM- 2–7 nm   | $\lambda_{em}$ - 394, 440, 523 nm $\lambda_{ex}$ - 350 nm | 23%  | 2020 [172]|
|                                |                                      | Hydrothermal (180 °C, 20 min)       | TEM- 2–7 nm   | $\lambda_{em}$ - 394, 440, 523 nm $\lambda_{ex}$ - 350 nm | 23%  | 2020 [172]|
|                                |                                      | (230 °C, 20 min)                    |               |              |              |      |           |
| Precursor Description | Technique | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|-----------------------|-----------|---------------|--------------|---------------|------|-----------|
| Citric acid | Hydrothermal | TEM-3.7 nm | $\lambda_{em}$ - 425 nm | $\lambda_{ex}$ - 350 nm | 63.7% | 2020 [173] |
| Citric acid monohydrate | Urea | Microwave irradiation | TEM- 6 nm | $\lambda_{em}$ - 536 and 532 nm | $\lambda_{ex}$ - 350 nm | - | 2020 [174] |
| Citric acid | Hydrothermal | TEM-11.9 nm | $\lambda_{em}$ - 413 nm | $\lambda_{ex}$ - 350 nm | 65% | 2020 [175] |
| Citric acid monohydrate | Ethylenediamine | Hydrothermal | TEM-5–10 nm | $\lambda_{em}$ - blue | $\lambda_{ex}$ - 305–395 nm | 85.69% | 2020 [176] |
| Citric acid | Ethylenediamine and ultrapure water | Hydrothermal | TEM- 5 nm | $\lambda_{em}$ - 444 nm | $\lambda_{ex}$ - 360 nm | - | 2020 [177] |
| Ascorbic acid | Urea and deionized water | Microwave | TEM- 2 nm | $\lambda_{em}$ - 415 nm | $\lambda_{ex}$ - 340 nm | 7% | 2020 [178] |
| Sodium citrate dihydrate | Urea and deionized water | Thermal pyrolysis | TEM-2.75 nm | $\lambda_{em}$ - 525 nm | $\lambda_{ex}$ - 400 nm | 93% | 2020 [179] |
| Citric acid and 3-aminobenzeneboronic acid | Dimethylformamide | Hydrothermal | HRTEM- 3.4 nm | - | - | 2020 [180] |
| Maleic anhydride and triethylenetetramine | Ultrapure water | Carbonization | HRTEM- 2.85 nm | - | - | 2020 [181] |
| DL-thioctic acid | Dimethylformamide, trisodium citrate dihydrate, sodium hydroxide, double deionized water | Hydrothermal | HRTEM- 2.52 nm | $\lambda_{em}$ - 438 nm | $\lambda_{ex}$ - 340 nm | - | 2021 [182] |
| Citric acid and sulfanilic acid | Polyethyleneimine | Two-step hydrothermal | TEM- 5.1 nm | $\lambda_{em}$ - 460 nm | $\lambda_{ex}$ - 340 nm | 29.1% | 2021 [183] |
| Tartaric acid | Urea | Solid-phase thermal | TEM-4.13 nm | $\lambda_{em}$ - 537 nm | $\lambda_{ex}$ - 460 nm | 10.5% | 2021 [184] |
| 2-amino-3-phenylpyridine | Orthophosphoric acid | Microwave-assisted pyrolysis | TEM-3–10 nm | $\lambda_{em}$ - 470 nm | $\lambda_{ex}$ - 410 nm | 67% | 2021 [185] |
| Citric acid | Utrapure water and ethylenediamine | Hydrothermal | TEM-3.1 nm | $\lambda_{em}$ - 445 nm | $\lambda_{ex}$ - 356 nm | - | 2021 [186] |
| Citric acid | Ethylenediamine and water | Microwave | TEM-2.3 nm | $\lambda_{em}$ - 450 nm | $\lambda_{ex}$ - 360 nm | - | 2021 [187] |
| Trans-aconitic acid | Diethylenetriamine and distilled water | Hydrothermal | HRTEM-2–8 nm | $\lambda_{em}$ - 435 nm | $\lambda_{ex}$ - 345 nm | 81% | 2021 [188] |
| Dehydroabietic acid | Ethanolamine | Hydrothermal | TEM-3.2 nm | $\lambda_{em}$ - 433 nm | $\lambda_{ex}$ - 365 nm | 10% | 2021 [189] |
| Citric acid | L-glutamine | Hydrothermal | TEM-3.5 nm | $\lambda_{em}$ - 450 nm | $\lambda_{ex}$ - 360 nm | - | 2021 [190] |
| Dithiosalicylic acid | Acetic acid and o-phenylenediamine | Solvothermal | TEM-4.5 nm | $\lambda_{em}$ - 620 nm | $\lambda_{ex}$ - 560 nm | 4.05% | 2021 [191] |
| L-cysteine and urea | Diphosphorus pentoxide and water | One-pot synthesis | TEM-4.5 nm | $\lambda_{em}$ - 445 nm | $\lambda_{ex}$ - 362 nm | 17% | 2021 [192] |
| Methyl cellulose and L-cysteine | Ethylenediamine | Hydrothermal | TEM-19 nm | $\lambda_{em}$ - 370 nm | $\lambda_{ex}$ - 330 nm | 12.3% | 2021 [193] |
| Ce (NO$_3$)$_3$·6H$_2$O and L-histidine | Sodium hydroxide and deionized water | One-pot hydrothermal | SEM-46 nm | - | - | 2021 [194] |
| Polyethyleneimine and citric acid | Hot water | Microwave-assisted pyrolysis | STEM-12 nm | $\lambda_{em}$ - 442 nm | $\lambda_{ex}$ - 354 nm | 54% | 2022 [195] |
| Citric acid and urea | Ultrapure water | Solvothermal | HRTEM-3.18 nm | $\lambda_{em}$ - 470 nm | $\lambda_{ex}$ - 330 nm | 20.1% | 2022 [196] |
| Citric acid and urea | 20 mL dimethylformamide | Solvothermal | HRTEM-3.25 nm | $\lambda_{em}$ - 500 nm | $\lambda_{ex}$ - 330 nm | 22.1% | 2022 [197] |
Table 8. Cont.

| Carbon Source                                         | Passivation/Solvent               | Technique             | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|-------------------------------------------------------|-----------------------------------|-----------------------|---------------|--------------|---------------|------|-----------|
| Citric acid and urea                                   | 10 mL dimethylformamide and ethanol | Solvothermal          | HRTEM-3.68 nm | λ<sub>em</sub>-595 nm | λ<sub>ex</sub>-330 nm | 2022 | [197]     |
|                                                       |                                   |                       | HRTEM-3.47 nm | λ<sub>em</sub>-539 nm | λ<sub>ex</sub>-330 nm | 21.9%|           |

3.2. Non-Acid Reagents

Carbon sources based on non-acid reagents, namely graphite oxide [198], poly(ethylene glycol) [199,200], 3-(3,4-dihydroxyphenyl)-L-alanine [201], ethanolamine [202], polyimide [203], polyethylene glycol bis(3-aminopropyl) [204], ethanol [205], 3-bromophenol [206], azidoimidizole [207], activated carbon [208], glucose [209], N-methylethanolammonium thioglycolate [209], chitosan [210], chlorophyll [211], microcrystalline cellulose [212], o-phenylenediamine [213], carbon paper [214], papain [215], dextrose solution [216], etc. [217–230], have also been reviewed, as shown in Table 9. 3-Bromophenol is the first insecticide adopted to be a potential precursor, thus suggesting that carbon sources are not limited in typical chemical reagents with high purity or low toxicity [206]. In this study, the effect of mixed solvent of ethanol and water ratio (v/v) such as 1:9, 3:7, 5:5, 7:3 and 9:1 and the effect of temperatures such as 150, 160, 170 °C were evaluated. The results indicate that both much thicker organic solvents and much higher carbonized temperatures are in favour of the formation of C-dots featuring monodispersion, high yield, and smaller size. The proposed mechanism behind the fabrication of insecticide-based CDs was verified by the occurrence of aromatic C-Br and Br anion, Csp2 C-C peak and Csp3 C-C peak found on the XPS spectrum. The three possible main classes of the reaction that happened among the 3-bromophenol molecules are given in Figure 5.

![Figure 5. Proposed possible mechanisms for the formation CDs using 3–bromophenol. Reproduced with copyright permission of Elsevier [206].](image)

Efforts to develop and improve the fluorescence of the CDs have been made toward polymer compounds, including synthetic and natural polymers. Thanks to the toxicity of synthetic polymers, natural polymers extracted from plants have been used as a carbon source with the characteristics of being environment-friendly, non-toxic, low price, good biocompatibility, and stable chemical properties. For this reason, Wu et al. (2017) reported microcrystalline cellulose as a carbon precursor to prepare a facile and low-cost one-step hydrothermal treatment of CQDs [212]. The modification of these CQDs with
ethylenediamine not only allowed nitrogen atoms on its surface but also introduced them into the carbon nuclear lattice to obtain better optical properties and higher quantum yield than CQDs. Fortunately, nitrogen doped CQDs (NCQDs) have a fluorescence emission intensity of 7.1 times stronger than the CQDs, and it can be explained by the reduction of epoxy, ether, and carboxyl groups on the surface of NCQDs via nucleophilic reactions with amidogen, thus forming a few non-radiative recombination centers in NCQDs. The amination and/or amidation also create radiative recombination centers, such as amine (–C–N–) and amide groups (R<sub>2</sub>-NCOR), which belong to electron-donating groups. These electron-donating groups and π-electrons that existed in the –C=N group have contributed to the improvement of the fluorescence intensity of a substance. All in all, these NCQDs successfully provided the highest quantum yield of 55%.

The synthesis of CDs using non-acid reagents can be further explored by attempting to use three different aniline compounds, i.e., 1,2,4,5-benzenetetramine tetrahydrochloride, 1,2,4-benzenetetramine dihydrochloride, and o-phenylenediamine, as carbon sources and ethanol as a solvent [217]. In an approach where more amino groups and a high nitrogen content are present in CDs-benzenetetramine tetrahydrochloride, the excitation and emission wavelengths all exhibited a redshift with an increase in the CD particle size. The quantum yield also greatly increased up to 30.2%. Additionally, the fluorescence intensity of the CDs was observed to gradually increase with the increasing amount of raw material from 0.005 g to 0.025 g. It is important to note that the number of amino groups and particle size of CDs have a great influence on the emission wavelength, while the amount of raw material influences the color and intensity of the fluorescence. In another study, the CDs were synthesized using three types of aldehydes, such as glutaraldehyde, nitrobenzaldehyde and benzaldehyde, via the solvothermal method [225]. The resulting CDs were then composited with chitosan, functionalized by a DNA probe and utilized as a detecting platform for rapid detection of microRNA-21. The function of CDs is further classified as a cross-linking agent and fluorescent donor, while chitosan plays an important role in the preparation of three-dimensional hydrogel frames.

Table 9. Summary of the synthesis of CDs from non-acid reagents.

| Precursor | Technique | Particle Size | Fluorescence | Quantum Yield | Year | Reference |
|-----------|-----------|---------------|--------------|---------------|------|-----------|
| Graphite oxide | Nitric acid | Microwave-hydrothermal | TEM- 4 nm | λ<sub>em</sub>: 520 nm λ<sub>ex</sub>: 470 nm | 2.72% | 2011 | [198] |
| Poly(ethylene glycol) | Sodium hydroxide and distilled water | Reflux method | TEM- 5 nm | λ<sub>em</sub>: bright blue λ<sub>ex</sub>: 350 nm λ<sub>em</sub>: cyan λ<sub>ex</sub>: 390 nm λ<sub>em</sub>: yellow λ<sub>ex</sub>: 470 nm λ<sub>em</sub>: red λ<sub>ex</sub>: 540 nm | - | 2013 | [199] |
| Polyethylene glycol 1500 | Serine and glycerin | Microwave pyrolysis | TEM- 5 nm | λ<sub>em</sub>: 500 nm λ<sub>ex</sub>: 400 nm | 6.3% | 2013 | [200] |
| 3-(3,4-dihydroxyphenyl)-L-alanine | - | Carbonization-oxidation | TEM- 3.64 nm | λ<sub>em</sub>: 475 nm λ<sub>ex</sub>: 360 nm | 1% | 2013 | [201] |
| Ethanolamine | Hydrogen peroxide | Pyrolysis | TEM- 2.7 nm TEM- 8.3 nm | λ<sub>em</sub>: 450 nm λ<sub>ex</sub>: 365 nm | 7% | 2014 | [202] |
| Polymide | - | Hydrothermal | TEM- 4 nm | λ<sub>em</sub>: 490 nm λ<sub>ex</sub>: 365 nm | 20.9% | 2015 | [203] |
| Polyethyleneglycol bis(3-aminopropyl) 6-Bromohexylboronic acid | | Thermal carbonization | TEM- 5 nm | λ<sub>em</sub>: 440 nm λ<sub>ex</sub>: 362 nm | 0.3% | 2015 | [204] |
| Ethanol | Hydrogen peroxide and deionized water | Hydrothermal | TEM- 4.8 nm | λ<sub>em</sub>: 456 nm λ<sub>ex</sub>: 400 nm | 3.7% | 2015 | [205] |
| 3-Bromophenol | Ethanol and deionized water | Carbonization | TEM- 5.2 nm | λ<sub>em</sub>: 440 nm λ<sub>ex</sub>: 367 nm | 19.6% | 2016 | [206] |
| Carbon Source | Precursor | Passivation/Solvent | Technique | Particle Size | Properties | Quantum Yield | Year | Reference |
|---------------|-----------|---------------------|-----------|---------------|------------|---------------|------|-----------|
| Azidomimidazole | Ethanol | - | AFM- 5–10 nm | $\lambda_{em}^-$ 515 nm $\lambda_{ex}^-$ 460 nm | - | 2016 | [207] |
| Activated carbon | Potassium permanganate, sulfuric acid, deionized water, hydrogen peroxide | Exhausted oxidation | TEM- 12 nm | $\lambda_{em}^-$ 465 nm $\lambda_{ex}^-$ 350 nm | 3.94% | 2016 | [208] |
| Glucose | Water and sodium hydroxide | Ultrasonic | | | 7% | 2016 | [209] |
| Glucose | Water and sodium hydroxide | Water and hydrogen peroxide | TEM- 1–6 nm | $\lambda_{em}^-$ 426–436 nm $\lambda_{ex}^-$ 360 nm | 55% | 2017 | [212] |
| Carbon paper | Ethylenediamine | Hydrothermal | TEM- 4.8 nm | $\lambda_{em}^-$ 450 nm $\lambda_{ex}^-$ 350 nm | 5.1% | 2018 | [214] |
| Papain and PEG6000 | Ultrapure water | Hydrothermal | TEM- 2–3 nm | $\lambda_{em}^-$ 420 nm $\lambda_{ex}^-$ 320 nm | 9.45% | 2018 | [215] |
| Microcrystalline cellulose | Ethylenediamine | Hydrothermal | TEM- 3–2 nm | $\lambda_{em}^-$ 400–600 nm $\lambda_{ex}^-$ 350–500 nm | 20% | 2018 | [213] |
| Chitosan | Water | - | Carbonization | TEM- 1–2 nm | $\lambda_{em}^-$ 390 nm $\lambda_{ex}^-$ 310 nm | 4.34% | 2016 | [210] |
| Chlorophyll | Water | Hydrothermal | DLS- 18 nm | $\lambda_{em}^-$ 520 nm $\lambda_{ex}^-$ 440 nm | - | 2017 | [211] |
| Microcrystalline cellulose | Ethylenediamine | Hydrothermal | TEM- 3.2 nm | $\lambda_{em}^-$ 426–436 nm $\lambda_{ex}^-$ 360 nm | 55% | 2017 | [212] |
| o-Phenylenediamine | Ethanol | Hydrothermal | TEM- 1–2 nm | $\lambda_{em}^-$ 400–600 nm $\lambda_{ex}^-$ 350–500 nm | 20% | 2018 | [213] |
| Carbon paper | Nitric acid | Hydrothermal | TEM- 4.8 nm | $\lambda_{em}^-$ 450 nm $\lambda_{ex}^-$ 350 nm | 5.1% | 2018 | [214] |
| Glucose and taurine | Distilled water | Hydrothermal | TEM- 3 nm | $\lambda_{em}^-$ 410 nm $\lambda_{ex}^-$ 340 nm | 11% | 2019 | [219] |
| Polyethylene glycol | - | Pyrolysis | DLS- 10 nm | $\lambda_{em}^-$ 380 nm $\lambda_{ex}^-$ 340 nm | 16% | 2020 | [220] |
| m-Phenylenediamine | Deionized water | Hydrothermal | TEM- 5.1 nm | $\lambda_{em}^-$ 420 nm $\lambda_{ex}^-$ 340 nm | 12% | 2020 | [221] |
| Glucosamine | Ethylenediamine and water | Microwave digestion | TEM- 4.45 nm | $\lambda_{em}^-$ 466 nm $\lambda_{ex}^-$ 384 nm | 25.38% | 2020 | [222] |
| Lactose | Hydrochloric acid | Hydrothermal | TEM-7 to 8 nm | - | - | 2021 | [223] |
| Selenourea and o-phenylenediamine | Hydrochloric acid | Hydrothermal | TEM- 3 nm | $\lambda_{em}^-$ 625 nm $\lambda_{ex}^-$ 564 nm | 23.6% | 2021 | [224] |
| Glutaraldehyde | Ethanol | Solvothermal | TEM- 1 nm | $\lambda_{em}^-$ 453 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Nitrobenzaldehyde | Ethanol | Solvothermal | TEM- 5 nm | $\lambda_{em}^-$ 421 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Benzaldehyde | - | - | $\lambda_{em}^-$ 430 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Diphenyl ether | p-Phenylenediamine, dopamine and tris (hydroxymethylaminomethane) | TEM- 2.8 nm | $\lambda_{em}^-$ ultraviolet $\lambda_{ex}^-$ 285 nm | 8% | 2021 | [226] |
| 1,2,4,5-Benzenetetramine tetrahydrochloride | Ethanol | Solvothermal | TEM- 9.39 nm | $\lambda_{em}^-$ 605 nm $\lambda_{ex}^-$ 540 nm | 30.2% | 2019 | [217] |
| 1,2,4-Benzene triamine dihydrochloride | Ethanol | Hydrothermal | TEM- 8.60 nm | $\lambda_{em}^-$ 598 nm $\lambda_{ex}^-$ 510 nm | 13.4% | 2019 | [217] |
| o-Phenylenediamine | Ethanol | Hydrothermal | TEM- 6.50 nm | $\lambda_{em}^-$ 538 nm $\lambda_{ex}^-$ 420 nm | 16.7% | 2019 | [217] |
| Copper (II) chloride dihydrate | Ethylenediamine | Hydrothermal | TEM- 1.8 nm | $\lambda_{em}^-$ 380 nm $\lambda_{ex}^-$ 320 nm | 7.8% | 2019 | [218] |
| Nitrobenzaldehyde | Ethylenediamine | Hydrothermal | TEM- 1.8 nm | $\lambda_{em}^-$ 380 nm $\lambda_{ex}^-$ 320 nm | 7.8% | 2019 | [218] |
| Lactose | Hydrochloric acid | Hydrothermal | TEM- 7 to 8 nm | - | - | 2021 | [223] |
| Selenourea and o-phenylenediamine | Hydrochloric acid | Hydrothermal | TEM- 3 nm | $\lambda_{em}^-$ 625 nm $\lambda_{ex}^-$ 564 nm | 23.6% | 2021 | [224] |
| Glutaraldehyde | Ethanol | Solvothermal | TEM- 1 nm | $\lambda_{em}^-$ 453 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Nitrobenzaldehyde | Ethanol | Solvothermal | TEM- 5 nm | $\lambda_{em}^-$ 421 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Benzaldehyde | - | - | $\lambda_{em}^-$ 430 nm $\lambda_{ex}^-$ 360 nm | - | 2021 | [225] |
| Diphenyl ether | p-Phenylenediamine, dopamine and tris (hydroxymethylaminomethane) | TEM- 2.8 nm | $\lambda_{em}^-$ ultraviolet $\lambda_{ex}^-$ 285 nm | 8% | 2021 | [226] |
| Dextrose solution | Hydrochloric acid | Mechano-chemical | TEM- 10 nm | $\lambda_{em}^-$ 456 nm $\lambda_{ex}^-$ 390 nm | 40% | 2018 | [216] |
Table 9. Cont.

| Precursor | Carbon Source | Passivation/Solvent | Technique | Particle Size | Properties | Quantum Yield | Year | Reference |
|-----------|---------------|---------------------|-----------|---------------|------------|---------------|------|-----------|
| o-Phenylenediamine | Ethanol | Deionized water | Two separate solutions mixed in one-pot hydrothermal | TEM- 5 nm | λ<sub>ex</sub>- ~570 nm λ<sub>em</sub>- 430 nm | - | 2022 | [227] |
| Ammonium sulfate | Glucose | Deionized water | Hydrothermal | TEM- 8.9 nm | λ<sub>ex</sub>- 450 nm λ<sub>em</sub>- 350 nm | - | 2022 | [228] |
| Glucose | Boric acid | Hydrothermal | TEM- 6.2 nm | λ<sub>ex</sub>- 400 nm λ<sub>em</sub>- 320 nm | - | 2022 | [228] |
| Sodium persulfate | Urea | Hydrothermal | TEM- 6.9 nm | λ<sub>ex</sub>- 400 nm λ<sub>em</sub>- 320 nm | - | 2022 | [228] |
| p-Phenylenediamine and thylenediamine | Anhydrous ethanol | Hydrothermal | TEM- 2.76 nm | λ<sub>em</sub>- 450 nm λ<sub>ex</sub>- 390 nm | 11% | 2022 | [229] |
| m-Phenylenediamine | Ethanol | Solvothermal | TEM- 6.9 nm | λ<sub>ex</sub>- 440 nm λ<sub>em</sub>- 380 nm | 11% | 2022 | [230] |
| o-Phenylenediamine | Ethanol | Solvothermal | TEM- 7.8 nm | λ<sub>em</sub>- 550 nm λ<sub>ex</sub>- 380 nm | 17% | 2022 | [230] |

4. Application of CD-Based Optical Sensor for Environmental Monitoring

The incorporation of CDs in optical sensors for environmental monitoring, including the detection of heavy metal ions, phenol, pesticides, and nitroaromatic explosives, are reviewed below (Figure 6). This review aims to survey state-of-the-art CD-based optical sensors with their sensing performance, namely range of detection, limit of detection, and linear correlation coefficient.

4.1. Heavy Metal Ions

Environmental pollutions caused by toxic heavy metal ions (HMI) have resulted in the development of different optical sensors using nanoscale materials [231–237]. Of late, CD-based optical sensors have garnered tremendous research interest, which is summarized chronologically in Table 10. Herein, an optical fibre sensor for Hg<sup>2+</sup> and Cu<sup>2+</sup> detection was developed using CDs functionalized with poly(ethylene glycol) and N-acetyl-l-cysteine [238]. This sensor has quite interesting analytical potential, as it allows for higher linear coefficients when detecting Hg<sup>2+</sup> in aqueous solutions. Furthermore, the concentration range of Hg<sup>2+</sup> was successfully lowered to femtomolar detection using a fluorescent sensor [199]. The outstanding nature of the sensing performance can be probably attributed...
to the Hg$^{2+}$ ions, which have stronger affinity toward carboxylic groups on the surface of CDs and stronger quenching effect on the PL of the prepared CDs.

On the other hand, Co$^{2+}$ and Cu$^{2+}$ ions have been detected using CD-based composites. In the presence of CTAB to PEG-passivated CDs, a long fluorescence lifetime with higher emission efficiency was noticed due to the rapid production of •OH radicals from the Co(II)-H$_2$O$_2$-OH$^-$ system, which is responsible for the highly selective response of the present chemiluminescence system towards Co$^{2+}$ ions [200]. On the other hand, the electrochemiluminescence of the oxidized CDs/K$_2$S$_2$O$_8$ system resulted in higher quenching to 20 nM of Cu$^{2+}$ compared to 1 µM of Pb$^{2+}$, Ni$^{2+}$, Mn$^{2+}$, Fe$^{2+}$, and Co$^{2+}$ [201]. Another HMI of interest is Fe$^{3+}$, which have been detected three times in a row in the year of 2014 using diverse optical sensors [116,117,119]. Among them, the phenolic hydroxyl of N-doped CDs exhibited higher sensitivity toward Fe$^{3+}$ quenching, with the linearity range of 0.01–500 µM and detection limit of 2.5 nM [116]. The reason is that the hydroxyl group has a good binding affinity for Fe$^{3+}$, leading to the splitting of d orbital of Fe$^{3+}$ and consequently causing significant fluorescent quenching. Similarly, nitrogen-doped CQDs were used as an effective fluorescent sensing platform for label-free sensitive detection of Hg$^{2+}$ ions in an ultrapure water solution with a detection limit of 0.23 µM [118]. Due to the excellent sensitivity and selectivity of the Hg$^{2+}$ sensor, this sensor was further applied to the determination of Hg$^{2+}$ in tap water and real lake water samples. The results showed that the PL intensity (excited at 360 nm) decreased gradually with the increasing concentration of Hg$^{2+}$ in both tap water and lake water from 5 to 50 µM.

In other work, the sensing potential of fluorescent CDs synthesized through the pyrolysis method was evaluated for Cu (II), Cr (II), Co (II), Ni (II), Al (III), Ca (II), Pb (II), Zn (II), Sn (II) and Hg (II) ions [79]. Among all the metal ions tested, Cu (II) and Pb (II) have the highest sensitivity, while Zn (II), Hg (II) and Ca (II) have the lowest sensitivity. The reason for this relatively low sensitivity might be due to the diamagnetic properties of Zn (II), Hg (II) and Ca (II) ions, which eliminate the paramagnetic quenching mechanism with the CDs.

With the accelerating demand of mercury in the skin lightening industry, a high number of optical techniques for Hg$^{2+}$ have been reported [15,23,54,65,89,122,124–128,133,142,143,152,153,160,178,207]. Notably, fluorescence techniques are the most employed. Altogether, there are several phenomena about the quenching effect of CDs to Hg$^{2+}$, which are as follows: (i) electron transfer from excited nitrogen and sulfur atoms in CDs to Hg$^{2+}$ (nonradiative recombination); (ii) strong binding between Hg$^{2+}$ and S atoms or carboxylate or hydroxyl groups from CDs; and (iii) Hg$^{2+}$ has a larger ionic radius and polarization; therefore, deformation happened more easily when it interacted with the nitrogen and sulfur atoms. Fortunately, the Hg$^{2+}$ can be detected as low as 2.6 nM using CD-labeled oligodeoxyribonucleotide (ODN) and quenched by graphene oxide [122]. In this study, CD-ODN acted as the energy donor and molecular recognition probe and GO served as the fluorescence resonance energy transfer acceptor.

Due to the concerns about improving and protecting living organisms, more optical detection methods that utilize CDs as a sensing element have been developed to detect Fe$^{2+/3+}$ [13,22,38,40,72,78,87,124,135,142,151,159,166,169,219,226], Cu$^{2+}$ [53,66,97,141,227,239], Pb$^{2+}$ [65,87,181,240], Cr$^{6+/4+}$ [23,85,193,241], and Co$^{2+}$ [51]. For instance, Shamsipur et al. (2018) prepared green-emitting CDs instead of common blue-emitting CDs for selective and sensitive detection of Fe$^{3+}$ [159]. This green CDs approach could detect Fe$^{3+}$ in the range of 0.05–10.0 µM, with a detection limit of 0.0137 µM. The detection limit was found to be significantly lower than the maximum level of Fe$^{3+}$ (0.54 µM) allowed in drinking water by the U.S. Environmental Protection Agency.

Li et al. (2021) invested in interesting research to detect low concentrations of Pb$^{2+}$ ions [181]. An electrochemiluminescence (ECL) aptasensor was prepared by modifying a glassy carbon electrode (GCE)/NCQDs with amino aptamers by NHS/EDC linkage for selective and sensitive detection of Pb$^{2+}$. As shown in Figure 7, the binding of the hairpin aptamer with Pb$^{2+}$ forms the G-quadruplex, and thus exposes the amino group

**References:**

1. Li et al. (2021) investigated in interesting research to detect low concentrations of Pb$^{2+}$ ions [181]. An electrochemiluminescence (ECL) aptasensor was prepared by modifying a glassy carbon electrode (GCE)/NCQDs with amino aptamers by NHS/EDC linkage for selective and sensitive detection of Pb$^{2+}$. As shown in Figure 7, the binding of the hairpin aptamer with Pb$^{2+}$ forms the G-quadruplex, and thus exposes the amino group.
to the NCQDs, causing significant changes in ECL intensity. The results revealed that the GCE/NCQDs/aptamer sensor can detect Pb$^{2+}$ quickly and accurately, providing the lowest detection limit of 18.9 pM. Importantly, the proposed aptasensor did not suffer from interference and it had excellent stability.

![Figure 7. Surface functionalization of (a) GCE/NCQDs, (b) GCE/NCQDs/aptamer, and (c) GCE/NCQDs/aptamer/Pb$^{2+}$.](image-url)

The fabrication of CDs with industrial/agricultural waste has proven to be useful as a detection probe for metal ions. A study conducted by Yan et al. (2020) demonstrated that the synthesized N-CDs from crown daisy leaves had abundant surface functional groups that could selectively and sensitively detect Cu$^{2+}$ at a very low detection limit of 1.0 nM by the fluorescent quenching effect [53]. This result is due to the selective complexation interaction between Cu$^{2+}$ and carboxyl and amino groups of the N-CDs.

On the other hand, improving the detection performance of hexavalent chromium (Cr$^{6+}$) even at the nanomolar level has become an enduring concern of researchers. Rajendran and Rajendiran (2018) reported that the CQDs can be effectively used as fluorescent probes for the detection of Cr$^{6+}$ at the nanomolar level [23]. This research reported strong fluorescence quenching with increasing Cr$^{6+}$ concentration, resulting in an improved detection limit of 10 nm. Nevertheless, the detection limit of Co$^{2+}$ was found to be higher at the micromolar level despite using CD-based optical sensors [51]. The proposed sensor was then applied in the analysis of real river water samples with a recovery value of 95.0–106.8% and a relative standard deviation below 5.3%, indicating that the synthesized CDs had great application prospects in Co$^{2+}$ detection.

### 4.2. Phenols

The existence of different forms of phenolic in petrochemical engineering, printing, food processing, and dyeing has been continuously reported as the most harmful pollutant due to its high toxicity and low biodegradability [242]. Table 11 summarizes the chronological order of the detection of phenolic compounds using optical sensors. Among the reported studies, 2-4-6-trinitrophenol, also called picric acid, is the most common pollutant monitored by means of fluorescent sensor [72,112,114,134,136,150,170,221]. It is well known that 2-4-6-trinitrophenol is a representative electron-deficient nitroaromatic, due to the electron-withdrawing nature of the three nitro groups. From the perspective of the sensor performance, Niu et al. (2013) explored the feasibility of using amine-capped CDs for the detection of 2-4-6-trinitrophenol in aqueous and ethanol solutions [114]. For the detection of 2-4-6-trinitrophenol in ethanol, the amine-capped CDs demonstrated obvious fluorescent quenching and superior sensitivity to 2-4-6-trinitrophenol in aqueous solution. Since water is much more polar than ethanol, the detection is, therefore, driven by an electrostatic interaction between 2-4-6-trinitrophenol and CDs.

Generally, there are three possible mechanisms causing fluorescence quenching between the phenolic compounds and proposed CDs, which are as follows: (i) electron transfer; (ii) fluorescence energy transfer; and (iii) inner filter effect. Amid all the mechanisms, fluorescence energy transfer (FET) is a dominant quenching pathway due to the electron-rich nature of the CDs and the electron-deficient aromatic group of the phenol [115,134,243]. In contrast to FET, the electron transfer process became possible for phenol fluorescence quenching [112,150,204]. Notably, electron transfer in the excited state of CDs can occur...
from the lowest unoccupied molecular orbital (LUMO) to the LUMO of phenols, if possible. In addition, there are certain rules that are required to fulfil FET quenching. The rules are as follows: (i) the absorption spectrum of the quencher (phenols) should overlap with the emission spectrum fluorophore and (ii) there is a change in the fluorescence lifetime of CDs before and after the addition of the quencher. Furthermore, the inner filter effect (IFE) is also considered important and has been applied as a developing novel fluorescent assay in recent studies [34,136,170,218,219,226]. This approach offers more simplicity and expediency because IFE-based sensors use fluorophore and the receptor directly rather than chemically interacting with each other.

In another study, Xue et al. (2018) found that phenol can form hydrogen bonds with the carboxyl group on the surface of the fluorescence CQDs, which will facilitate the fluorescence quenching of the CQDs in the excited state, leading to the high sensitivity and selectivity of CQDs for the detection of phenol [95]. In addition, the fluorescence quenching effect can be explained by either a dynamic or static process. Interestingly, a static quenching effect between N-CDs and tannic acid found in the works of [167] can be proved by several measurements, which are as follows: (i) a decrease in the fluorescence lifetime; (ii) a rate that is constant more than $1.0 \times 10^{10} \text{M}^{-1}\text{s}^{-1}$; and (iii) a blue-shift of the absorption peak of CDs. Wang et al. (2019) compared the selectivity of the CDs@MIP and CDs@MIP to 4-nitrophenol, which resulted in good selectivity of CDs@MIP on 4-nitrophenol, due to the hydrogen bonding interactions, leading to the charge transfer from CDs to 4-nitrophenol [165]. There is still much room for further development of CD-based optical sensors for the detection of phenolic compounds, despite achieving a high quantum yield and good sensing performance. For instance, Saravanan et al. (2020) successfully synthesized N@CDs from m-phenylenediamine as a single source of carbon and nitrogen to detect 2,4,6-trinitrophenol [221]. The fluorescent N@CD probe showed high selectivity toward 2,4,6-trinitrophenol relative to other nitro explosives, such as 4-nitrophenol, 4-amino-3-nitrophenol, 2,5-dinitrophenol, phenol, 2-chlorophenol, 3-nitrophenol, and 4-amino-triphenol.

Table 10. Summary of the developed optical sensors for heavy metal ions detection.

| Heavy Metal Ions | Material | Optical Sensor | Range of Detection | Limit of Detection | Linear Correlation Coefficient | Year | Reference |
|-----------------|----------|----------------|-------------------|-------------------|-------------------------------|------|-----------|
| Hg$^{2+}$       | CDs@PEG and N-acetyl-l-cysteine | Optical fibre | 0–2.69 µM | - | 0.977 | 2010 | [238] |
| Cu$^{2+}$       | CDs | Fluorescent | 0–5 fM | 1 fM | - | 2013 | [199] |
| Co$^{2+}$       | CTAB@CDs | Chemiluminescent | 1.0–1000 nM | 0.67 nM | 0.992 | 2013 | [200] |
| Cu$^{2+}$       | α-CDs/K$_2$S$_2$O$_8$ | Electrochemiluminescent | 0–4 nM | - | - | 2013 | [201] |
| Fe$^{3+}$       | N-CDs | Chemiluminescent | $1.0 \times 10^{-7}$–$1.0 \times 10^{-6}$ M | 66.7 nM | 0.993 | 2014 | [117] |
| Fe$^{3+}$       | N-doped CDs | Fluorescent | 0.01–500 µM | 2.5 nM | - | 2014 | [116] |
| Fe$^{3+}$       | N@MIP CDs | Electrochemiluminescent | 5–80 µM | 700 nM | 0.993 | 2014 | [119] |
| Hg$^{2+}$       | N-CQDs | Fluorescent | 0–25 µM | 0.23 µM | 0.994 | 2014 | [118] |
| Pb$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Cu$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Al$^{3+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Ni$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Cr$^{3+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Sn$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Ca$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Fe$^{3+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Zn$^{2+}$       | CDs | Fluorescent | 0–47.62 µM | - | - | 2014 | [79] |
| Heavy Metal Ions | Material | Optical Sensor | Range of Detection | Limit of Detection | Linear Correlation Coefficient | Year | Reference |
|-----------------|----------|----------------|-------------------|-------------------|-------------------------------|------|----------|
| Fe^{3+}         | CDs      | Fluorescent    | 0.10–10 µM        | 31.5 nM           | 0.9977                        | 2015 | [124]    |
| Hg^{2+}         | CDs      | Fluorescent    | 0.01–2.0 µM       | 15.3 nM           | 0.9977                        | 2015 | [128]    |
| Hg^{2+}         | ODN-CDs  | Fluorescent    | 5–200 nM          | 2.6 nM            | 0.974                         | 2015 | [122]    |
| Hg^{2+}         | N-S-CDs  | Fluorescent    | 0–40 µM           | 2.0 µM            | 0.994                         | 2015 | [125]    |
| Hg^{2+}         | N-CDs    | Fluorescent    | 0–8 µM            | 0.087 µM          | 0.9962                        | 2015 | [127]    |
| Hg^{2+}         | N-rich CDs| Fluorescent   | 0–20 µM           | 0.63 µM           | 0.989                         | 2016 | [207]    |
| Hg^{2+}         | N-doped CDs| Fluorescent | 0–1000 µM         | 100 µM            | -                             | 2016 | [135]    |
| Hg^{2+}         | N,S-co-doped CDs | Fluorescent | 0–20 µM          | 0.18 µM           | 0.9975                        | 2015 | [122]    |
| Hg^{2+}         | N-doped CDs| Fluorescent | 0–1000 µM         | 100 µM            | -                             | 2016 | [135]    |
| Hg^{2+}         | N-rich CDs| Fluorescent   | 0–80 µM           | 0.201 µM          | 0.9982                        | 2016 | [128]    |
| Hg^{2+}         | N-CDs    | Fluorescent    | 0–80 µM           | 0.201 µM          | 0.9982                        | 2016 | [128]    |
| Hg^{2+}         | LR-CDs   | Fluorescent    | 0.1–1.5 µM        | 18.7 nM           | 0.9919                        | 2016 | [64]     |
| Hg^{2+}         | CDs      | Fluorescent    | 0–40 µM           | 9 nM              | 0.9896                        | 2017 | [15]     |
| Pb^{2+}         | CDs      | Fluorescent    | 0–300 µM          | 0.16 µM           | 0.9811                        | 2018 | [22]     |
| Cu^{2+}         | CDs      | Fluorescent    | 0–100 µM          | 0.73 µM           | 0.9903                        | 2018 | [85]     |
| Cu^{2+}         | CQDs     | Fluorescent    | 1–8 µM            | 6.33 nM           | 0.998                         | 2018 | [97]     |
| Cu^{2+}         | CDs      | Fluorescent    | 0.01–500 µM       | 4.3 nM            | 0.9907                        | 2018 | [66]     |
| Cu^{2+}         | CQDs     | Fluorescent    | 0–100 µM          | 31.5 µM           | 0.9897                        | 2018 | [239]    |
| Fe^{3+}         | CdSe@SiO_2-CDs| Fluorescent | 9–120 µM          | 0.26 µM           | 0.995                         | 2018 | [151]    |
| Fe^{3+}         | CDs      | Fluorescent    | 0.05–10.0 µM      | 13.7 nM           | 0.992                         | 2018 | [159]    |
| Hg^{2+}         | N-CDs    | Fluorescent    | 0.001–5 µM        | 0.65 µM           | 0.985                         | 2018 | [160]    |
| Hg^{2+}         | CDs      | Fluorescent    | 0–100 µM          | 2.47 µM           | 0.9892                        | 2018 | [152]    |
| Hg^{2+}         | N-S-CDs  | Fluorescent    | 0.01–50 µM        | 0.008 µM          | 0.9622                        | 2018 | [153]    |
| Hg^{2+}         | CQDs     | Fluorescent    | 5–70 nM           | 8 nM              | 0.9970                        | 2018 | [23]     |
| Cr^{3+}         | CDs      | Fluorescent    | 1–2 µM            | 0.39 µM           | 0.9912                        | 2019 | [51]     |
| Pb^{2+}         | CDs      | Fluorescent    | 1–700 µM          | <1 µM             | 0.993                         | 2019 | [219]    |
| Pb^{2+}         | VV-CDs   | Fluorescent    | 1–100 µM          | 12 nM             | 0.99853                       | 2020 | [87]     |
| Pb^{2+}         | GCE/NCDs/aptamers| Electrochemiluminescence | 50–387.9 nM     | 0.0189 nM         | 0.998                         | 2020 | [181]    |
| As^{3+}         | CDs-MnO_2| Fluorescent    | 0–200 nM          | 16.8 nM           | 0.992                         | 2020 | [177]    |
| Cu^{2+}         | CDs      | Fluorescent    | 0–120 nM          | 1.0 nM            | 0.997                         | 2020 | [53]     |
| Fe^{3+}         | Phe-CDs  | Fluorescent    | 5–500 µM          | 0.720 µM          | 0.9959                        | 2020 | [169]    |
| Hg^{2+}         | N-CDs    | Fluorescent    | 0.15–90 µM        | 0.20 µM           | 0.993                         | 2020 | [178]    |
| Fe^{3+}         | N-CdS    | Fluorescent    | 0.01–5 µM         | 6.25 nM           | 0.991                         | 2020 | [54]     |
| Cr^{3+}         | S,N-CDs  | Fluorescent    | 0.03–50 µM        | 21.14 nM          | 0.966                         | 2021 | [193]    |
| Fe^{3+}         | N-CDs    | Fluorescent    | 0.3–3.3 µM        | 0.135 µM          | 0.9918                        | 2021 | [72]     |
| Fe^{3+}         | CdS@PDA  | Fluorescent    | 2–27 µM           | 3.75 µM           | 5.82 µM                       | 2021 | [226]    |
| Pb^{2+}         | N-CDs/R-CDs@ZIF-8| Fluorescent | 0.05–50 µM      | 4.78 nM           | 0.9952                        | 2021 | [240]    |
| Cr^{3+}         | BNC-CDs  | Fluorescent    | 0–100 µM          | 0.41 µM           | 0.999                         | 2021 | [241]    |
Table 10. Cont.

| Heavy Metal Ions | Material          | Optical Sensor | Range of Detection | Limit of Detection | Linear Correlation Coefficient | Year | Reference |
|------------------|-------------------|----------------|-------------------|-------------------|--------------------------------|------|-----------|
| Fe³⁺             | KBNCDs            | Fluorescent    | 0–25 µM           | 1.2 µM            | 0.997                          | 2022 | [78]      |
| Mn²⁺             |                   |                |                   | 1.4 µM            | 0.998                          |      |           |
| Hg²⁺             | CDs               | Fluorescent    | 0–46 µM           | 2 µM              | 0.997                          | 2022 | [89]      |
| Fe³⁺             | CDs               | Fluorescent    | 20–100 µM         | 0.07 µM           | 0.9977                         | 2022 | [38]      |
| Fe³⁺             | M-CDs             | Fluorescent    | 5–30 µM           | 0.47 µM           | 0.998                          | 2022 | [40]      |
| Cu²⁺             | NS-CDs            | Colorimetric   | 1–100 µM          |                   |                                |      |           |

Where CDs@PEG: carbon dots functionalized poly(ethylene glycol), CTAB: cationic cetyltrimethylammonium bromide, o-CDs/K₂S₂O₈: oxidized carbon dots/potassium persulfate, N-CDs: nitrogen doped carbon dots, N-CQDs: nitrogen doped carbon quantum dots, ODN-CDs: carbon dots-labeled oligodeoxyribonucleotide, N₅-CDs: nitrogen and sulphur co-doped carbon dots, LR: lotus root, CdSe@SiO₂-CDs: silica coated cadmium selenide carbon dots, VV-CDs: Volvariella volvacea-carbon dots, GCE: glassy carbon electrode, MnO₂: manganese dioxide, Phe-CDs: phenylalanine-carbon dots, CDs@PDA: p-phenylenediamine-derived carbon dots, N-CDs/R-CDs@ZIF-8: nitrogen-doped carbon dots/red-carbon dots@zeolite imidazole, BNCDs: boron-nitrogen co-doped carbon dots, KBNCDs: Kentucky bluegrass nitrogen-doped carbon dots, M-CDs: Morus nigra carbon dots, Hg²⁺: mercury ions, Fe³⁺: ferric ions, Pb²⁺: lead ions, Al³⁺: aluminum ions, Ni²⁺: nickel ions, Cr²⁺/³⁺/⁶⁺: chromium ions, Sn²⁺: tin ions, Ca²⁺: calcium ions, Zn²⁺: zinc ions, As³⁺: arsenic ions.

Table 11. Summary of the developed optical sensors for phenol detection.

| Phenolic Compound | Material          | Optical Sensor | Range of Detection | Limit of Detection | Linear Correlation Coefficient | Year | Reference |
|-------------------|-------------------|----------------|-------------------|-------------------|--------------------------------|------|-----------|
| 2,4,6-Trinitrophenol | Amine-capped CDs | Fluorescent    | 0–50 × 10⁻⁵ M     | 0.9996 µM         | -                              | 2013 | [114]     |
| 2,4,6-Trinitrophenol | Tb-CDs           | Fluorescent    | 500 nM–100 µM     | 200 nM            | 0.991                          | 2013 | [112]     |
| 4-Nitrophenol     | CDs               | Fluorescent    | 0.1–50 µM         | 28 nM             | -                              | 2014 | [115]     |
| Tannic acid       | PEGA-CDs         | Fluorescent    | 0.05–0.6 µM       | 0.01 µM           | -                              | 2015 | [204]     |
| 2,4,6-Trinitrophenol | N-CQDs           | Fluorescent    | 0.27–34.1 µM      | 50 nM             | 0.992                          | 2016 | [134]     |
| 2,4,6-Trinitrophenol | CDs              | Fluorescent    | 0.1–26.5 µM       | 51 nM             | 0.995                          | 2017 | [136]     |
| 2,4,6-Trinitrophenol | CDs              | Fluorescent    | -                 | 0.127 µM          | -                              | 2018 | [150]     |
| Phenol            | CDs               | Fluorescent    | 0–50 µM           | 0.076 µM          | 0.998                          | 2018 | [95]      |
| Tannic acid       | N-CDs             | Fluorescent    | 0.4–9.0 µM        | 0.12 µM           | 0.9990                         | 2019 | [167]     |
| 4-Nitrophenol     | CDs@MIPs          | Fluorescent    | 0.0–0.3694 mM     | 35 nM             | -                              | 2019 | [165]     |
| p-Nitrophenol     | Cu-doped carbon dots | Fluorescent    | 0.5–50 µM        | 0.08 µM           | 0.998                          | 2019 | [218]     |
| 2,4,6-Trinitrophenol | CDs              | Fluorescent    | 0–305.54 µM      | 0.023 µM          | -                              | 2020 | [170]     |
| o-Nitrophenol     | CQDs              | Fluorescent    | 0.08–40 µM        | 15.2 nM           | 0.999                          | 2020 | [34]      |
| 4-Nitrophenol     | N,CDs             | Fluorescent    | 0.25–125 µM       | 0.05 µM           | 0.9919                         | 2020 | [222]     |
| 2,4,6-Trinitrophenol | N@CDs            | Fluorescent    | 1–75 µM           | 2.45 µM           | 0.994                          | 2020 | [221]     |
| Trinitrophenol    | wsNP-CDs          | Fluorescent    | 100–300 µM        | 23 µM             | 0.9861                         | 2020 | [243]     |
| Tannic acid       | Nitrogen-doped CDs | Chemiluminescence | 0.2–10 µM   | 39.3 nM           | 0.9971                         | 2020 | [173]     |
| Chlorogenic acid  | N,S-CDs           | Fluorescent    | 0.9314–83.82 µM   | 0.3287 µM         | 0.9970                         | 2021 | [184]     |
| 4-Nitrophenol     | CDs@PDA           | Fluorescent    | 2–34 µM           | 7.29 µM           | 0.992                          | 2021 | [226]     |
| 2,4,6-Trinitrophenol | N-CDs            | Fluorescent    | 0.3–3.3 µM        | 0.11 µM           | 0.9923                         | 2021 | [72]      |
| p-Nitrophenol     | G-CDs             | Fluorescent    | 0–50 µM           | 0.0175 µM         | 0.9951                         | 2022 | [76]      |

Where Tb-CDs: terbium doped carbon dots, PEGA-CDs: polyethyleneglycol bis(3-aminopropyl)-carbon dots, CDs@MIPs: carbon dots fabricated with molecularly imprinted polymers, N₅@CDs: nitrogen doped carbon dots, wsNP-CDs: water soluble nitrogen and phosphorous doped carbon dots, CDs@PDA: polydopamine encapsulated carbon dots, G-CDs: green-emitting carbon dots.

In addition, ultra-weak chemiluminescent (CL) systems have become one of the focuses of the increasing attention on the determination of tannic acid [173]. Interestingly,
tannic acid could dramatically suppress the CL intensity of the FNCDs-H$_2$O$_2$-K$_3$Fe(CN)$_6$ system with an excellent linear response ($R^2 = 0.9971$) and was further applied for the determination of tannic acid in a red wine sample. The recovery of 98.9–102.1% was obtained, demonstrating its reliability and application potential in real sample analysis. Recently, the aggregated N,S-CDs as a dual-excitation ratiometric fluorescent probe have proven to be an effective approach for the quantitative determination of chlorogenic acid [184]. Apart from dual excitation, Liu et al. (2021) observed the dual-color fluorescence emission of ultraviolet and red light when detecting 4-nitrophenol using CDs@PDA [226]. The detection limits obtained for the ultraviolet and red-light emission were 3.44 µM and 7.29 µM, respectively. In addition, 2,4,6-trinitrophenol has been detected using the fluorescence method with a detection limit of 0.11 µM in the concentration range of 0.3–3.3 µM [72]. The possible mechanism for fluorescence quenching of N-CDs by 2,4,6-trinitrophenol is explained by the electrostatic interaction or hydrogen bonding that occurs between the nitrogen groups of CDs and phenolic group of 2,4,6-trinitrophenol. To be exact, the electrostatic interactions occur when a large number of nitro groups with electron-withdrawing characteristics on benzene interact with nitrogen-containing functional groups of CDs. Hence, it can be concluded that nitro groups play a vital role in fluorescent quenching.

4.3. Pesticides

Pesticides are chemical compounds that are used to kill pests. Generally, there are six classes of pesticides according to their target species, i.e., insecticides, herbicides, rodenticides, bactericides, fungicides, and larvicides. The largest and most widely used in crop protection are insecticides [244]; however, they are classified as an extremely toxic class of chemical compounds by the World Health Organization (WHO).

Organophosphorus (OP) compounds, such as methyl parathion [121,138], paraoxon-ethyl [137], dichlorvos [245], malathion [245], ethion [245], paraoxon [154,155,211], chloropyrifos [63,96,246], methyl-paraoxon [180], diazinon [50,62], and quinalphos [247], are widely reported insecticides in the development of CD-based optical sensors. Oddly, most OP pesticides are always selected as inhibitors for sensors based on enzyme activity. According to Hou et al. (2016), dichlorvos can inhibit the activity of acetyl cholinesterase (AChE), which can turn the fluorescence of CDs off again [245], which is similar to the detection of paraoxon [155]. However, in a study of Lin et al. (2017), only OP of chlorpyrifos effectively inhibited H$_2$O$_2$ production by destroying the acetylcholinesterase activity, thereby increasing the fluorescence of C-dots after being initially turned off by Fe$^{3+}$ [96]. Moreover, the proposed sensor exhibits a low selectivity against OP. Therefore, a new facile fluorescence probing based on novel N-doped carbon dots and methyl parathion hydrolase (MPH) was developed to detect methyl parathion selectively [138]. The use of MPH in this study helps to degrade OP compounds and has many advantages over other enzymes, such as less background noise and high turnover number, which is favourable for sensitive detection.

Another class of insecticide is carbamates. Li and co-workers have been devoted to detecting carbaryl in the presence of acetylcholinesterase (ACh) and choline oxidase (ChOx) by using N-CQDs, S-CQDs, and co-doped N, S-CQD-based photoluminescence sensors [209]. The results demonstrated that high sensitivity originates from the N and S dopants, which offer stronger capacities to adsorb hydrogen peroxide (H$_2$O$_2$) and generate local states to trap hot electrons, promoting the electron transfer to H$_2$O$_2$, and thus resulting in the strong quenching of the CQD fluorescence.

Apart from the insecticide organophosphate, insecticides neonicotinoids and organochlorine have become a target pesticide. Mandal et al. (2019) have reported a simple fluorescence-based method using CDs for the detection of commonly used insecticides, such as imidacloprid and lindane [246]. The fluorescence emission of the CDs was found to be enhanced in the presence of the increasing concentration of imidacloprid; however, the emission was quenched in the presence of lindane. The interactions between CDs and insecticides were mainly driven by the high reactive -NO$_2$ and -NH groups in imidacloprid that directly bind...
to the surface functionality amino groups of CDs and by the H-bond or week ionic interaction or covalent binding between the free surface groups of the CDs and lindane, followed by the substitution reaction. In addition, the researchers also expanded the potential of CDs in sensing unclassified pesticides, namely tetradifon [246]. The leaving groups (-Cl) of tetradifon were found to possess strong covalent binding with the surface amine group of the CDs with a high affinity. Nonetheless, the results showed that tetradifon has a higher detection limit than imidacloprid, but offers a lower detection limit than lindane. This phenomenon can be attributed to the binding affinity of all the different target pesticides. Their binding affinity can be arranged in the following decreasing order: imidacloprid > tetradifon > lindane.

Until 2021, the fluorescence response of CDs towards herbicides [50,60,213,220,246] and fungicides [73,182,183] has also been explored. It is reported that with increasing concentrations of herbicides, i.e., atrazine [213], pretialchlor [60], glyphosate [50], and fungicide thiophanate methyl [183], this has resulted in an increase in PL emission intensity (turn-on). This fluorescence ‘turn-on’ model was dynamic quenching, whereas, when the concentrations of trifluralin [220], pyrimethanil [182], and isoprothiolane [73] were increased, the fluorescence emission of CDs was found to decrease, leading to static quenching. Supchocksoonthorn et al. (2021) suggested that the fluorescent quenching is closely related to the inner filter effect, due to the π-π interaction between the large aromatic core of the CDs and anilinopyrimidine unit of pyrimethanil and between their polar functional groups [182].

Furthermore, as an improvement to the method with a single fluorescence signal, Zhu et al. (2022) developed a new type of CD-functionalized core-shell nanospheres as a ratiometric fluorescence to detect λ-cyhalothrin (LC), a typical pyrethroid insecticide. Figure 8 shows the main binding reactions in the preparation of the CD-functionalized core-shell nanospheres. Here, silica nanoparticles play a role in preventing the contact between m-CDs and the dispersion solvent so the m-CDs could act as a reliable reference background; o-CDs act as a fluorescence signal; 3-aminopropytriethoxy silane (APTES) as a functional monomer to connect with LC through hydrogen bonding; ionic liquids (IL) as a cationic surfactant, which are attached to the system by electrostatic interaction to enhance the fluorescence of the core-shell nanospheres; and tetraethyl orthosilicate (TEOS) is used to form a layer of imprinted silicon shell on the surface of m-CDs@SiO₂. Inspired by the role of the materials, these newly formed core-shell nanospheres managed to achieve lower detection limits, excellent reusability, and better precision than those of other methods reported in this work [230]. All the proposed CD-based optical sensors for the detection of pesticides are tabulated orderly in Table 12.

![Figure 8. Schematic diagram of binding reactions of the prepared CD-functionalized core-shell nanospheres for detection of λ-cyhalothrin.](image-url)
Table 12. Summary of the developed optical sensors for pesticides detection.

| Pesticide                        | Material                 | Optical Sensor       | Range of Detection            | Limit of Detection | Linear Correlation Coefficient | Year  | Reference |
|----------------------------------|--------------------------|----------------------|-----------------------------|--------------------|-------------------------------|-------|-----------|
| Methyl parathion                 | Tyr-CDs                  | Fluorescent          | \(1.0 \times 10^{-6} - 1.0 \times 10^{-4} \) M | \(4.8 \times 10^{-11} \) M | 0.997                         | 2015  | [121]     |
| Paraoxon-ethyl                   | CDs                      | Fluorescent          | 0.5–8.0 nM                  | 0.22 µM            | 0.9974                        | 2016  | [137]     |
| Dichlorvos, malathion, ethion    | CDs/Cu(II)/AChE/ATChCl   | Fluorescent          | 6 nM–0.6 nM                 | 3.8 µM             | 0.998                         | 2016  | [245]     |
| Carbaryl                         | N,S co-doped CQDS        | Photoluminescent     | 0.00030313–3.131 µM         | 0.02485 µM         | -                             | 2016  | [209]     |
| Paraoxon                         | CQDs                     | Fluorescent          | 0.1817–181.7 nM             | 0.1817 nM          | 0.9941                        | 2017  | [211]     |
| Chlorpyrifos                     | Fe-modified CDs          | Fluorescent          | 0.028523–2.8523 µM          | 0.00145 µM         | 0.9943                        | 2017  | [96]      |
| Atrazine                         | N-CQDs                   | Fluorescent          | 0–1.817 µM                  | 0.00145 µM         | 0.993                         | 2018  | [154]     |
| Pretillachlor                    | CDs                      | Fluorescent          | 5.7 µM–61.5 µM              | 2.9 µM             | 0.9847                        | 2019  | [60]      |
| Diazinon                         | CDs                      | Fluorescent          | 0.8214 nM–16.43 µM          | 0.8214 nM          | -                             | 2020  | [50]      |
| Glyphosate                       | CDs                      | Fluorescent          | 1.4787 nM–29.574 µM         | 0.01183 µM         | -                             | 2020  | [213]     |
| Amicarbazon                      | CDs                      | Fluorescent          | 1.036 nM–20.72 µM           | 0.02072 nM         | -                             | 2020  | [62]      |
| Methyl-paraoxon                  | B,N-CDs                  | Fluorescent          | 0.1–15 µM                   | 0.1 µM             | 0.9967                        | 2020  | [180]     |
| Diazinon                         | CDs                      | Fluorescent          | 0.02–10 µM                  | 0.01 µM            | 0.9727                        | 2020  | [62]      |
| Trifluralin                      | Ca-modified CDs          | Fluorescent          | 7.89 µM                     | 0.96 µM            | 0.92                           | 2020  | [220]     |
| Quinalphos                       | OPCD@Uio-66-NH₂          | Fluorescent          | 0.05–100.0 µM               | 0.00599 µM         | 0.9959                        | 2021  | [247]     |
| Chlorpyrifos                     | TEF-CDS                  | Fluorescent          | 0.01–50.0 µM                | 0.0057 µM          | 0.9965                        | 2021  | [63]      |
| Pyrimethanil                     | CDs                      | Fluorescent          | 0.5–75 µM                   | 14 nM              | 0.9907                        | 2021  | [182]     |
| Thiophanate methyl               | SCDs/Hg²⁺                 | Fluorescent          | 0.05–2.0 µM                 | 7.6 nM             | 0.9988                        | 2021  | [183]     |
| Isoprothiolane                   | CDs                      | Fluorescent          | 1 mM–0.05 µM                | 11.58 nM           | 0.9921                        | 2021  | [73]      |
| A-Cyhalothrin                    | CD-functionnalized core-shell nanospheres | Ratiometric fluorescence | 3.045–456.8 nM             | 0.146 nM           | 0.988                         | 2022  | [230]     |
| Chlorpyrifos                     | J-CQDs                   | Fluorescent          | 57.05–513.4 nM              | 7.701 nM           | 0.993                         | 2022  | [41]      |

Where Tyr-CDs: L-tyrosine methyl ester functionalized carbon dots, CDs/Cu(II)/AChE/ATChCl: carbon dots/copper ion/acyticholinesterase/acyethylcholine, BChE-ATCh-MnO₂-CDs: butyrylcholinesterase-acyethylcholine-manganese dioxide- carbon dots, N-doped CDs-MPH: nitrogen-doped carbon dots and methyl parathion hydrolase, B,N-CDs: boron and nitrogen-doped carbon dots, Ca-modified CDs: calcium-modified carbon dots, OPCD@Uio-66-NH₂: carbon dots derived from orthophenylenediamine incorporated Uio-66-NH₂, TEF-CDs: carbon dots from Tagetes erecta flower, SCDs/Hg²⁺: sulfur-doped carbon dots/mercury ions, J-CQDs: Jatropha-carbon quantum dots.

4.4. Explosive Compounds

Military-grade explosives such as trinitrotoluene (TNT), dinitroaniline (DNT), are still a major worldwide concern in terms of terror threat and environmental impact. The only method that detects explosive compounds using CDs is a fluorescent sensor. For instance, Zhang et al. (2015) used N-rich CDs for 2,4,6-trinitrotoluene determination [120]. Apparently, TNT is a typical electron deficient nitro compound, which can selectively interact with amine group on CDs, leading to charge transfer from fluorescent CDs to the aromatic rings of TNT and consequently quenching the fluorescence emission of CDs strongly.

Dai and co-workers found that fluorescence sensors are well suited for detecting nitroaromatic compounds, such as 2,4-dinitrotoluene (DNT), as they can quench the emission.
of the excited species [132]. In this work, static quenching occurred with an increasing concentration of DNT, as CDs formed stable charge-transfer complexes with DNT molecules. Considering that the selectivity of those sensors were relatively low because some metal ions or other structure analogy can quench those fluorescent nanoparticles, Xu et al. introduced molecularly imprinted polymers (MIPs) to improve the selectivity [131]. However, this causes poor sensitivity because of the highly cross-linked nature of MIPs. Therefore, a novel strategy using periodic mesoporous silica particles as the imprinting matrix and using amino-CDs directly as a “functional monomer” was proposed to improve the sensitivity of M-MIPs@CDs.

In addition, Campos et al. (2016) first demonstrated the fluorometric sensing of 4-chloro-2,6-dinitroaniline in an aqueous solution using carbon quantum dots coated with PAMAM-NH$_2$ [208]. The presence of amine groups in the PAMAM-NH$_2$ dendrimer results in the enhanced fluorescence intensity and quantum yield from 3.94% to 6.93%. Moreover, it is interesting that with an increase in pH starting from 2.25, the fluorescence intensity increases drastically and then become constant from pH 6 to 11. The reason for the constant fluorescence intensity may be due to the buffering effect of the surface groups (–COOH and –NH$_2$ mainly).

Next, a selective and sensitive detection of TNT explosive residues based on CD-modified optical sensors has been developed and rapidly elevating until 2022 [99,139,196,214,248]. The research concluded that the possible mechanism for TNT detection corresponds to the Jackson–Meisenheimer (JM) complex. Particularly, functionalizing CDs with amino groups can selectively form a JM complex with typical electron-deficient groups in TNT via charge transfer during a nucleophilic aromatic substitution reaction, which consequently causes fluorescence quenching. In addition, the selectivity of the sensor against TNT was investigated by Devi’s group [214]. The proposed sensor showed high selectivity for TNT over other weaker Lewis acids, such as dinitrotoluene (DNT), 2,4-dinitrotoluic acid (TA), nitrobenzene (NB), and p-nitrophenol (NP). It can be concluded that the JM complex formed by TNT is more stabilized due to more resonance structures; more nitro groups on the TNT aromatic ring than that formed by DNT, TA, NB, and NP.

All the proposed CD-based optical sensors for the detection of explosive compounds are tabulated orderly in Table 13.

Table 13. Summary of the developed optical sensors for explosive compound detection.

| Explosive Compound | Material | Optical Sensor | Range of Detection | Limit of Detection | Linear Correlation Coefficient | Year | Reference |
|--------------------|----------|----------------|--------------------|-------------------|-------------------------------|------|-----------|
| 2,4,6-Trinitrotoluene | N-rich CNDs | Fluorescent | 10 nM–1.5 μM | 1 nM | - | 2015 | [120] |
| 2,4-Dinitrotoluene | Amine-functionalized CDs | Fluorescent | 1 mM–50 mM | 1 mM | - | 2016 | [132] |
| Trinitrotoluene | M-MIPs@CDs | Fluorescent | - | 17 nM | - | 2016 | [131] |
| 4-Chloro-2,6-dinitroaniline | CQDs@PAMAM-NH$_2$ | Fluorescent | 1.0 × 10$^{-5}$–6.0 × 10$^{-5}$ M | 2 μM | 0.994 | 2016 | [208] |
| 2,4,6-Trinitrotoluene | Ethylenediamine-modified CDs | Fluorescent | - | 0.213 μM | 0.997 | 2017 | [139] |
| Trinitrotoluene | Nitrogen-doped CQD | Fluorescent | 4.4 nM–26.4 μM | 0.03258 μM | 0.9993 | 2018 | [214] |
| Trinitrotoluene | CDs capped with EDA | Fluorescent | 44.03–220.14 nM | 57.24 nM | 0.95457 | 2018 | [99] |
| Trinitrotoluene | CDs (in the presence of nitric acid) capped with EDA | Fluorescent | 44.03–220.14 nM | 48.43 nM | 0.9752 | 2018 | [99] |
| 4-Chloro-2,6-dinitroaniline | PEI-CQDs | Fluorescent | 0–38.17 μM | 0.4094 μM | 0.9979 | 2022 | [196] |

Where N-rich CNDs: nitrogen-rich carbon nanodots, M-MIPs@CDs: mesoporous structured molecularly imprinted polymers capped carbon dots, CQDs@PAMAM-NH$_2$: carbon quantum dots functionalized with amine groups by PAMAM dendrimer, EDA: ethylenediamine, CDs and Fe@SiO$_2$-NH$_2$: carbon dots and the magnetism of amino-functionalized magnetic core-shell nanomaterial, PEI-CQDs: polyethyleneimine capped carbon quantum dots.
5. Concluding Remarks

An enormous research effort has been devoted to the development of CDs using green and chemical precursors. The reason behind the interest in this fabrication is its fluorescent properties that make it continuously competitive to produce bright and high-quality CDs. This paper has presented the recent progress in the field of CDs, focusing on the green and chemical precursors and fluorescent properties. To the best of our knowledge, this is the first review paper that highlights each of the precursors used in the CDs with the values of the fluorescence quantum yield.

Among the available green precursors, CDs produced by plants are the most popular source because it is a more stable and straightforward process to scale up. For instance, the CDs synthesized from leaves, i.e., *Calotropis procera* leaves, without any addition of surface passivation have the highest quantum yield of 71.95% under the hydrothermal carbonization process, as shown in Figure 9a. It can be observed that the leaves have shown great potential as carbon sources due to their carbon-, hydrogen-, oxygen-, nitrogen-rich composition, which can eliminate the need of surface-chemical passivating agents. Other factors that contributed to the excellent photoluminescence properties include (i) heteroatom doping, such as sulfur, nitrogen, phosphorus, and boron; (ii) heating temperature and time; (iii) type and ratio of solvent; and (iv) pH of media. Even so, the quantum yields obtained from the green precursors were still low compared to the chemical precursors, as depicted in Figure 9b. It was shown that the thermal pyrolysis treatment of sodium citrate dihydrate and urea led to green fluorescence CDs with a quantum yield as high as 93%. As expected, CDs synthesized from acid reagents possess higher quantum yields due to the existence of carboxyl groups. The greater the number of carboxyl groups in the carbon source, the more amino groups of urea that will conjugate onto the surface of CDs.

![Figure 9](image_url)

Figure 9. Quantum yields of the CDs based on (a) green precursors and (b) chemical precursors.

Although the highest quantum yield results have been achieved using chemical precursors (acid reagents), the high toxicity of this precursor may hinder their potential for diverse applications. Therefore, future development should firstly focus on synthesizing CDs from green precursors, particularly plant parts and waste products. In addition, it is highly necessary to fabricate green precursors consisting of hydroxyl, carboxyl and amino groups to avoid the use of toxic chemical passivating agents. Furthermore, this will allow for the development of high-quality and non-toxicity CDs, finally paving the way towards their practical application in various fields.

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References

1. Atchudan, R.; Edison, T.N.J.I.; Perumal, S.; Vinodh, R.; Sundramoorthy, A.K.; Babu, R.S.; Lee, Y.R. Leftover Kiwi Fruit Peel-Derived Carbon Dots as a Highly Selective Fluorescent Sensor for Detection of Ferric Ion. *Chemosensors* 2021, 9, 166. [CrossRef]

2. Carbonaro, C.M.; Corpino, R.; Salis, M.; Mocci, F.; Thakkar, S.V.; Olla, C.; Ricci, P.C. On the Emission Properties of Carbon Dots: Reviewing Data and Discussing Models. *C–J. Carbon Res.* 2019, 5, 60. [CrossRef]

3. Shi, W.; Song, S.; Zhang, H. Hydrothermal Synthetic Strategies of Inorganic Semiconducting Nanostructures. *Chem. Soc. Rev.* 2013, 42, 5714–5743. [CrossRef]

4. Li, L.; Dong, T. Photoluminescence Tuning in Carbon Dots: Surface Passivation or/and Functionalization, Heteroatom Doping. *J. Mater. Chem. C* 2018, 6, 7944–7970. [CrossRef]

5. Jorns, M.; Pappas, D. A Review of Fluorescent Carbon Dots, Their Synthesis, Physical and Chemical Characteristics, and Applications. *Nanomaterials* 2021, 11, 1448. [CrossRef]

6. Long, C.; Jiang, Z.; Shangguan, J.; Qing, T.; Zhang, P.; Feng, B. Applications of Carbon Dots in Environmental Pollution Control: A Review. *Chem. Eng. J.* 2021, 406, 126848. [CrossRef]

7. Sharma, V.; Tiwari, P.; Kaur, N.; Mobin, S.M. Optical Nanosensors Based on Fluorescent Carbon Dots for the Detection of Water Contaminants: A Review. *Environ. Chem. Lett.* 2021, 19, 3229–3241. [CrossRef]

8. Kurian, M.; Paul, A. Recent Trends in the Use of Green Sources for Carbon Dot Synthesis—A Short Review. *Carbon Trends* 2021, 3, 100032. [CrossRef]

9. Sahu, S.; Behera, B.; Maiti, T.K.; Mohapatra, S. Simple One-Step Synthesis of Highly Luminescent Carbon Dots from Orange Juice: Application as Excellent Bio-Imaging Agents. *Chem. Commun.* 2012, 48, 8835–8837. [CrossRef]

10. Zhou, J.; Sheng, Z.; Han, H.; Zou, M.; Li, C. Facile Synthesis of Fluorescent Carbon Dots Using Watermelon Peel as a Carbon Source. *Mater. Lett.* 2012, 66, 222–224. [CrossRef]

11. Du, F.; Zhang, M.; Li, X.; Li, J.; Jiang, X.; Li, Z.; Hua, Y.; Shao, G.; Jin, J.; Shao, Q.; et al. Economical and Green Synthesis of Bagasse-Derived Fluorescent Carbon Dots for Biomedical Applications. *Nanotechnology* 2014, 25, 315702. [CrossRef]

12. Tyagi, A.; Tripathi, K.M.; Singh, N.; Choudhary, S.; Gupta, R.K. Green Synthesis of Carbon Quantum Dots from Lemon Peel Waste: Applications in Sensing and Photocatalysis. *RSC Adv.* 2016, 6, 72423–72432. [CrossRef]

13. Edison, T.N.J.I.; Atchudan, R.; Shim, J.J.; Kalimuthu, S.; Ahn, B.C.; Lee, Y.R. Turn-off Fluorescence Sensor for the Detection of Ferric Ion in Water Using Green Synthesized N-Doped Carbon Dots and Its Bio-Imaging. *J. Photochem. Photobiol. B Biol.* 2016, 158, 235–242. [CrossRef]

14. Shi, J.; Ni, G.; Tu, J.; Jin, X.; Peng, J. Green Synthesis of Fluorescent Carbon Dots for Sensitive Detection of Fe²⁺ and Hydrogen Peroxide. *J. Nanopart. Res.* 2017, 19, 209. [CrossRef]

15. Zhao, J.; Huang, M.; Zhang, L.; Zou, M.; Chen, D.; Huang, Y.; Zhao, S. Unique Approach to Develop Carbon Dot-Based Nanohybrid Near-Infrared Ratiometric Fluorescent Sensor for the Detection of Mercury Ions. *Anal. Chem.* 2017, 89, 8044–8049. [CrossRef]

16. Su, A.; Wang, D.; Shu, X.; Zhong, Q.; Chen, Y.; Liu, J.; Wang, Y. Synthesis of Fluorescent Carbon Quantum Dots from Dried Lemon Peel for Determination of Carmine in Drinks. *Chem. Res. Chin. Univ.* 2018, 34, 164–168. [CrossRef]

17. Ding, H.; Ji, Y.; Wei, J.S.; Gao, Q.Y.; Zhou, Z.Y.; Xiong, H.M. Facile Synthesis of Red-Emitting Carbon Dots from Pulp-Freeze Lemon Juice for Bioimaging. *J. Mater. Chem. B* 2017, 5, 5272–5277. [CrossRef]

18. Chatzimitakos, T.; Kasouni, A.; Sygellou, L.; Avgерopoulos, A.; Troganis, A.; Stalikas, C. Two of a kind but different: Luminescent Carbon Quantum Dots from Citrus Peels for Iron and Tartrazine Sensing and Cell Imaging. *Talanta* 2017, 175, 305–312. [CrossRef]

19. Gharat, P.M.; Pal, H.; Dutta Choudhury, S. Photophysics and Luminescence Quenching of Carbon Dots Derived from Lemon Juice and Glycerol. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* 2019, 209, 14–21. [CrossRef]

20. Schneider, E.M.; Bärtisch, A.; Stark, W.J.; Grass, R.N. Safe One-Pot Synthesis of Fluorescent Carbon Quantum Dots from Lemon Juice for a Hands-On Experience of Nanotechnology. *J. Chem. Educ.* 2019, 96, 540–545. [CrossRef]

21. Tadesse, A.; RamaDevi, D.; Battu, G.; Basavaiah, K. Facile Green Synthesis of Fluorescent Carbon Quantum Dots from Citrus Lemon Juice for Live Cell Imaging. *Asian J. Nanosci. Mater.* 2018, 1, 36–46.

22. Lu, M.; Duan, Y.; Song, Y.; Tan, J.; Zhou, L. Green Preparation of Versatile Nitrogen-Doped Carbon Quantum Dots from Watermelon Juice for Cell Imaging, Detection of Fe³⁺ Ions and Cysteine, and Optical Thermometry. *J. Mol. Liq.* 2018, 269, 766–774. [CrossRef]

23. Rajendran, K.; Rajendiran, N. Bluish Green Emitting Carbon Quantum Dots Synthesized from Jackfruit (Artocarpus Heterophyllus) and Its Sensing Applications of Hg (II) and Cr (VI) Ions. *Mater. Res. Express* 2018, 5, 24008. [CrossRef]

24. Ahmadian-Fard-Fini, S.; Salavati-Niasari, M.; Ghanbari, D. Hydrothermal Green Synthesis of Magnetic Fe₃O₄–Carbon Dots by Lemon and Grape Fruit Extracts and as a Photoluminescence Sensor for Detecting of E. Coli Bacteria. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* 2018, 203, 481–493. [CrossRef]
25. Anindita, F.; Darmawan, N.; Mas'Ud, Z.A. Fluorescence Carbon Dots from Durian as an Eco-Friendly Inhibitor for Copper Corrosion. **AIP Conf. Proc.** 2018, 127208. [CrossRef]

26. Carvalho, J.; Santos, L.R.; Germino, J.C.; Terezo, A.J.; Moreto, J.A.; Quites, F.J.; Freitas, R.G. Hydrothermal Synthesis to Water-Stable Luminescent Carbon Dots from Acerola Fruit for Photoluminescent Composites Preparation and Its Application as Sensors. **Mater. Res.** 2019, 22, 1–8. [CrossRef]

27. Fatahi, Z.; Esfandiari, N.; Ehtesabi, H.; Bagheri, Z.; Ranjbar, Z.; Latifi, H. Physicochemical and Cytotoxicity Analysis of Green Synthesis Carbon Dots for Cell Imaging. **EXCLI J.** 2019, 18, 454–466. [CrossRef]

28. Tadesse, A.; Hagos, M.; Ramadevi, D.; Basavaiah, K.; Belachew, N. Fluorescent-Nitrogen-Doped Carbon Quantum Dots Derived from Citrus Lemon Juice: Green Synthesis for Highly Luminescent Carbon Quantum Dots from Lemon Juice. **ACS Omega** 2020, 5, 3889–3898. [CrossRef]

29. Monte-Filho, S.S.; Andrade, S.I.E.; Lima, M.B.; Araujo, M.C.U. Synthesis of Highly Fluorescent Carbon Dots from Lemon Juice for Determination of Riboflavin in Multivitamin/Mineral Supplements. **J. Pharm. Anal.** 2019, 9, 209–216. [CrossRef]

30. Hoan, B.T.; Tam, P.D.; Pham, V.H. Green Synthesis of Highly Luminescent Carbon Quantum Dots from Lemon Juice. **J. Nanotechnol.** 2019, 2019, 2852816. [CrossRef]

31. Jayaweera, S.; Yin, K.; Ng, W.J. Nitrogen-Doped Durian Shell Derived Carbon Dots for Inner Filter Effect Mediated Sensing of Tetracycline and Fluorescent Ink. **J. Fluoresc.** 2019, 29, 221–229. [CrossRef]

32. Hashemi, F.; Heidari, F.; Mohajeri, N.; Mahmoodzadeh, F.; Zarghami, N. Fluorescence Intensity Enhancement of Green Carbon Dots: Synthesis, Characterization and Cell Imaging. **Photochem. Photobiol.** 2020, 96, 1032–1040. [CrossRef]

33. Mukthi, H.; Sharath, R.; Kottam, N.; Smriti, S.P.; Samrat, K.; Ankitha, P. Green Synthesis of Carbon Dots and Evaluation of Its Pharmacological Activities. **Bionanoscience** 2020, 10, 731–744. [CrossRef]

34. Zhang, Q.; Liang, J.; Zhao, L.; Wang, Y.; Zheng, Y.; Wu, Y.; Jiang, L. Synthesis of Novel Fluorescent Carbon Quantum Dots From *Rosa roxburghii* for Rapid and Highly Selective Detection of O-Nitrophenol and Cellular Imaging. **Front. Chem.** 2020, 8, 1–9. [CrossRef]

35. Gudimella, K.K.; Appidi, T.; Wu, H.F.; Battula, V.; Jogdand, A.; Rengan, A.K.; Gedda, G. Sand Bath Assisted Green Synthesis of Carbon Dots from Citrus Fruit Peels for Free Radical Scavenging and Cell Imaging. **Colloids Surf. B Biointerfaces** 2021, 197, 111362. [CrossRef]

36. Atchudan, R.; Jebakumar Immanuel Edison, T.N.; Shannugam, M.; Perumal, S.; Somanathan, T.; Lee, Y.R. Sustainable Synthesis of Carbon Quantum Dots from Banana Peel Waste Using Hydrothermal Process for in Vivo Bioimaging. **Phys. E Low-Dimens. Syst. Nanostruct.** 2021, 126, 114417. [CrossRef]

37. Ghereghlou, M.; Esmaeili, A.A.; Darroudi, M. Green Synthesis of Fluorescent Carbon Dots from *Elaeagnus angustifolia* and Its Application as Tartrazine Sensor. **J. Fluoresc.** 2021, 31, 185–193. [CrossRef]

38. Ashok Varman, G.; Kalanidhi, K.; Nagaraj, P. Green Synthesis of Fluorescent Carbon Dots from Canon Ball Fruit for Sensitive Detection of Fe³⁺ and Catalytic Reduction of Textile Dyes. **Dyes Pigment.** 2022, 119, 110101. [CrossRef]

39. Vijeata, A.; Chaudhary, S.; Chaudhary, G.R. Fluorescent Carbon Dots from Indian Bael Patra as Effective Sensing Tool to Detect Perilous Food Colorant. **Food Chem.** 2022, 373, 131492. [CrossRef]

40. Atchudan, R.; Edison, T.N.J.I.; Perumal, S.; Vinodh, R.; Sundramoorthy, A.K.; Babu, R.S.; Lee, Y.R. Morus Nigra-Derived Hydrophilic Carbon Dots for the Highly Sensitive and Effective Detection of Ferric Ion in Aqueous Media and Human Colon Cancer Cell Imaging. **Colloids Surf. A Physicochem. Eng. Asp.** 2022, 635, 128073. [CrossRef]

41. Chandra, S.; Bano, D.; Sahoo, K.; Kumar, D.; Kumar, V.; Kumar Yadav, P.; Hadi Hasan, S. Synthesis of Fluorescent Carbon Quantum Dots from Jatropha Fruits and Their Application in Fluorimetric Sensor for the Detection of Chlorpyrifos. **Microchem. J.** 2022, 172, 106953. [CrossRef]

42. Qu, Y.; Yu, L.; Zhu, B.; Chai, F.; Su, Z. Green Synthesis of Carbon Dots by Celery Leaves for Use as Fluorescent Paper Sensors for the Detection of Nitrophenols. **New J. Chem.** 2020, 44, 1500–1507. [CrossRef]

43. Yin, B.; Deng, J.; Peng, X.; Long, Q.; Zhao, J.; Lu, Q.; Chen, Q.; Li, H.; Tang, H.; Zhang, Y.; et al. Green Synthesis of Carbon Dots with Down- and up-Conversion Fluorescent Properties for Sensitive Detection of Hypochlorite with a Dual-Readout Assay. **Analyst** 2013, 138, 6551–6557. [CrossRef]

44. Thota, S.P.; Thota, S.M.; Manoj, K.S.; Muthukumar, V.S.S.; Venketesh, S.; Vadlanii, P.V.; Belliraj, S.K. Facile One-Pot Hydrothermal Synthesis of Stable and Biocompatible Fluorescent Carbon Dots from Lemon Grass Herb. **IET Nanobiotechnol.** 2018, 12, 127–132. [CrossRef]

45. Miao, H.; Wang, L.; Zhao, Y.; Zhou, Z.; Yang, X. Label-Free Fluorimetric Detection of CEA Using Carbon Dots Derived from Tomato Juice. **Biosens. Bioelectron.** 2016, 86, 83–89. [CrossRef]

46. Liu, Y.; Liu, Y.; Park, M.; Park, S.J.; Zhang, Y.; Akanda, M.R.; Park, B.Y.; Kim, H.Y. Green Synthesis of Fluorescent Carbon Dots from Carrot Juice for Use in Vitro Cellular Imaging. **Carbon Lett.** 2017, 21, 61–67. [CrossRef]

47. Liu, W.; Diao, H.; Chang, H.; Wang, H.; Li, T.; Wei, W. Green Synthesis of Carbon Dots from Rose-Heart Radish and Application for Fe³⁺ Detection and Cell Imaging. **Sens. Actuators B Chem.** 2017, 241, 190–198. [CrossRef]

48. Vasimalai, N.; Vilas-Boas, V.; Gallo, J.; Cerqueira, M.d.F.; Menéndez-Miranda, M.; Costa-Fernández, J.M.; Diéguez, L.; Espiña, B.; Fernández-Argüelles, M.T. Green Synthesis of Fluorescent Carbon Dots from Spices for in Vitro Imaging and Tumour Cell Growth Inhibition. **Beilstein J. Nanotechnol.** 2018, 9, 530–544. [CrossRef]
75. Chauhan, P.; Chaudhary, S.; Kumar, R. Biogenic Approach for Fabricating Biocompatible Carbon Dots and Their Application in Colorimetric and Fluorometric Sensing of Lead Ion. J. Clean. Prod. 2021, 279, 123639. [CrossRef]

76. Wang, C.; Xu, J.; Zhang, R.; Zhao, W. Facile and Low-Energy-Consumption Synthesis of Dual-Functional Carbon Dots from Corus Walleter Leaves for Detection of p-Nitrophenol and Photocatalytic Degradation of Dyes. Colloids Surf. A Physicochem. Eng. Asp. 2022, 640, 128531. [CrossRef]

77. Ge, G.; Li, L.; Chen, M.; Wu, X.; Yang, Y.; Wang, D.; Zuo, S.; Zeng, Z.; Xiong, W.; Guo, C. Green Synthesis of Nitrogen–Doped Carbon Dots from Fresh Tea Leaves for Selective Fe$^{3+}$ Ions Detection and Cellular Imaging. Nanomaterials 2022, 12, 986. [CrossRef]

78. Krishnaiah, P.; Atchudan, R.; Perumal, S.; Salama, E.S.; Lee, Y.R.; Jeon, B.H. Utilization of Waste Biomass of Poa Pratensis for Outright Green Synthesis of Fluorescent Carbon Dots and Its Application in Detection of Mn$^{2+}$ and Fe$^{3+}$. Chemosphere 2022, 286, 131764. [CrossRef]

79. Tan, X.W.; Romainor, A.N.B.; Chin, S.F.; Ng, S.M. Carbon Dots Production via Pyrolysis of Sago Waste as Potential Probe for Metal Ions Sensing. J. Anal. Pyrolysis 2014, 105, 157–165. [CrossRef]

80. Ang, W.L.; Boon Mee, C.A.L.; Sambudi, N.S.; Mohammad, A.W.; Leo, C.P.; Mahmoudi, E.; Benamor, A. Microwave-Assisted Conversion of Palm Kernel Shell Biomass Waste to Photoluminescent Carbon Dots. Sci. Rep. 2020, 10, 21199. [CrossRef]

81. Monday, Y.N.; Abdullah, J.; Yusof, N.A.; Rashid, S.A.; Shueb, R.H. Facile Hydrothermal and Solvothermal Synthesis and Characterization of Nitrogen-Doped Carbon Dots from Palm Kernel Shell Precursor. Appl. Sci. 2021, 11, 1630. [CrossRef]

82. Liu, S.; Liu, Z.; Li, Q.; Xia, H.; Yang, W.; Wang, R.; Li, Y.; Zhao, H.; Tian, B. Facile Synthesis of Carbon Dots from Wheat Straw for Colorimetric and Fluorescent Detection of Fluoride and Cellular Imaging. Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 2021, 246, 118964. [CrossRef] [PubMed]

83. Ramanan, V.; Thiyagarajan, S.K.; Raji, K.; Suresh, R.; Sekar, R.; Ramamurthy, P. Outright Green Synthesis of Fluorescent Carbon Dots from Eutrophic Algal Blooms for in Vitro Imaging. ACS Sustain. Chem. Eng. 2016, 4, 4724–4731. [CrossRef]

84. Moonrinta, S.; Jannongsong, S.; Sampattavanich, S.; Kladsomboon, S.; Sajomsang, W.; Paoprasert, P. Synthesis of Biocompatible Carbon Dots from Yogurt and Gas Vapor Sensing. IOP Conf. Ser. Mater. Sci. Eng. 2018, 378, 012005. [CrossRef]

85. Pacquiao, M.R.; de Luna, M.D.G.; Thongsai, N.; Kladsomboon, S.; Paoprasert, P. Highly Fluorescent Carbon Dots from Enokitake Mushroom as Multi-Faceted Optical Nanomaterials for Cr$^{6+}$ and VOC Detection and Imaging Applications. Appl. Surf. Sci. 2018, 453, 192–203. [CrossRef]

86. Plácido, J.; Bustamante-López, S.; Meissner, K.E.; Kelly, D.E.; Kelly, S.L. Microalgae Biochar-Derived Carbon Dots and Their Application in Heavy Metal Sensing in Aqueous Systems. Sci. Total Environ. 2019, 656, 531–539. [CrossRef]

87. Zulfajri, M.; Liu, K.C.; Pu, Y.H.; Rasool, A.; Dayalan, S.; Huang, G.G. Utilization of Carbon Dots Derived from Volvariella Volvacea Mushroom for a Highly Sensitive Detection of Fe$^{3+}$ and Pb$^{2+}$ Ions in Aqueous Solutions. Chemosensors 2020, 8, 47. [CrossRef]

88. Chauhan, P.; Saini, J.; Chaudhary, S.; Bhasin, K.K. Sustainable Synthesis of Carbon Dots from Agarose Waste and Prospective Application in Sensing of L-Aspartic Acid. Mater. Res. Bull. 2021, 134, 111113. [CrossRef]

89. Shen, C.; Dong, C.; Cheng, L.; Shi, X.; Bi, H. Fluorescent Carbon Dots from Shehuannella onoedensis MR–1 for Hg$^{2+}$ and Tetracycline Detection and Selective Fluorescence Imaging of Gram–Positive Bacteria. J. Environ. Chem. Eng. 2022, 10, 107020. [CrossRef]

90. Hu, Y.; Yang, J.; Tian, J.; Jia, L.; Yu, J.S. Waste Frying Oil as a Precursor for One-Step Synthesis of Sulfur-Doped Carbon Dots with PH-Sensitive Photoluminescence. Carbon 2014, 77, 775–782. [CrossRef]

91. Zhang, C.; Xiao, Y.; Ma, Y.; Li, B.; Liu, Z.; Lu, C.; Liu, X.; Wei, Y.; Zhu, Z.; Zhang, Y. Algae Biomass as a Precursor for Synthesis of Nitrogen-and Sulphur-Co-Doped Carbon Dots: A Better Probe in Arabidopsis Guard Cells and Root Tissues. J. Photochem. Photobiol. B Biol. 2017, 174, 315–322. [CrossRef] [PubMed]

92. Ramanan, V.; Siddaiah, B.; Raji, K.; Ramamurthy, P. Green Synthesis of Multifunctionalized, Nitrogen-Doped, Highly Fluorescent Carbon Dots from Waste Expanded Polystyrene and Its Application in the Fluorimetric Detection of Au$^{3+}$ Ions in Aqueous Media. ACS Sustain. Chem. Eng. 2018, 6, 1627–1638. [CrossRef]

93. Konwar, A.; Baruah, U.; Deka, M.J.; Hussain, A.A.; Haque, S.R.; Pal, A.R.; Chowdhury, D. Tea-Carbon Dots-Reduced Graphene Oxide: An Efficient Conducting Coating Material for Fabrication of an E-Textile. ACS Sustain. Chem. Eng. 2017, 5, 11645–11651. [CrossRef]

94. Su, R.; Wang, D.; Liu, M.; Yan, J.; Wang, J.X.; Zhan, Q.; Pu, Y.; Foster, N.R.; Chen, J.F. Subgram-Scale Synthesis of Biomass Derived-Fluorescent Carbon Dots in Subcritical Water for Bioimaging, Sensing, and Solid-State Patterning. ACS Omega 2018, 3, 13211–13218. [CrossRef]

95. Xue, H.; Yan, Y.; Hou, Y.; Li, G.; Hao, C. Novel Carbon Quantum Dots for Fluorescent Detection of Phenol and Insights into the Mechanism. New J. Chem. 2018, 42, 11485–11492. [CrossRef]

96. Lin, B.; Yan, Y.; Guo, M.; Cao, Y.; Yu, Y.; Zhang, T.; Huang, Y.; Wu, D. Modification-Free Carbon Dots as Turn-on Fluorescence Probe for Detection of Organophosphorus Pesticides. Food Chem. 2018, 245, 1176–1182. [CrossRef]

97. Kumar, A.; Kumar, A.; Sahu, S.K.; Kumar, S. Synthesis of Green Fluorescent Carbon Quantum Dots Using Waste Polyolefins Residue for Cu$^{2+}$ Ion Sensing and Live Cell Imaging. Sens. Actuators B Chem. 2018, 254, 197–205. [CrossRef]

98. Aji, M.P.; Wati, A.L.; Priyanto, A.; Karunawan, J.; Nuryadin, B.W.; Wibowo, E.; Marvoto, P. Sulhadi Polymer Carbon Dots from Plastics Waste Upcycling. Environ. Nanotechnol. Monit. Manag. 2018, 9, 136–140. [CrossRef]

99. Devi, S.; Gupta, R.K.; Paul, A.K.; Kumar, V.; Sachdev, A.; Gopinath, P.; Tyagi, S. Ethylenediamine Mediated Luminescence Enhancement of Pollutant Derivatized Carbon Quantum Dots for Intracellular Trinitrotoluene Detection: Soot to Shine. RSC Adv. 2018, 8, 32684–32694. [CrossRef]
100. Feng, X.; Zhang, Y. A Simple and Green Synthesis of Carbon Quantum Dots from Coke for White Light-Emitting Devices. RSC Adv. 2019, 9, 33789–33793. [CrossRef]

101. Hu, Y.; Gao, Z.; Yang, J.; Chen, H.; Han, L. Environmentally Benign Conversion of Waste Polyethylene Terephthalate to Fluorescent Carbon Dots for “on-off-on” Sensing of Ferric and Pyrophosphate Ions. J. Colloid Interface Sci. 2019, 538, 481–488. [CrossRef] [PubMed]

102. Gunjal, D.B.; Gurav, Y.M.; Gore, A.H.; Naik, V.M.; Waghmare, R.D.; Patil, C.S.; Sohn, D.; Ambhule, P.V.; Shejwal, R.V.; Kolekar, G.B. Nitrogen Doped Waste Tea Residue Derived Carbon Dots for Selective Quantification of Tetracycline in Urine and Pharmaceutical Samples and Yeast Cell Imaging Application. Opt. Mater. 2019, 98, 109484. [CrossRef]

103. Gunjal, D.B.; Naik, V.M.; Waghmare, R.D.; Patil, C.S.; Shejwal, R.V.; Gore, A.H.; Kolekar, G.B. Sustainable Carbon Nanodots Synthesised from Kitchen Derived Waste Tea Residue for Highly Selective Fluorimetric Recognition of Free Chlorine in Acidic Water: A Waste Utilization Approach. J. Taiwan Inst. Chem. Eng. 2019, 95, 147–154. [CrossRef]

104. Irmania, N.; Dehvari, K.; Gedda, G.; Tseng, P.J.; Chang, J.Y. Manganese-Doped Green Tea-Derived Carbon Quantum Dots as a Targeted Dual Imaging and Photodynamic Therapy Platform. J. Biomed. Mater. Res. Part B Appl. Biomater. 2020, 108, 1616–1625. [CrossRef] [PubMed]

105. Niu, Q.; Gao, K.; Lin, Z.; Wu, W. Amine-Capped Carbon Dots as a Nanosensor for Sensitive and Selective Detection of Picric Acid. Nanomaterials 2020, 10, 1255. [CrossRef] [PubMed]

106. Chen, B.B.; Liu, Z.X.; Zou, H.Y.; Huang, C.Z. Highly Selective Detection of 2,4,6-Trinitrophenol by Using Newly Developed Terbium-Doped Blue Carbon Dots. Analyst 2013, 141, 2676–2681. [CrossRef]

107. Dong, Y.; Pang, H.; Yang, H.B.; Guo, C.; Shao, J.; Chi, Y.; Li, C.M.; Yu, T. Carbon-Based Dots Co-Doped with Nitrogen and Sulfur for High Quantum Yield and Excitation-Independent Emission. Angew. Chem. Int. Ed. 2013, 52, 7800–7804. [CrossRef] [PubMed]

108. Niu, Q.; Gao, K.; Lin, Z.; Wu, W. Amine-Capped Carbon Dots as a Nanosensor for Sensitive and Selective Detection of Picric Acid in Aqueous Solution via Electrostatic Interaction. Anal. Methods 2013, 5, 6228–6233. [CrossRef]

109. Ahmed, G.H.G.; Laínó, R.B.; Calzón, J.A.G.; García, M.E.D. Highly Fluorescent Carbon Dots as Nanoprobes for Sensitive and Selective Determination of 4-Nitrophenol in Surface Waters. Microchem. Acta 2015, 182, 51–59. [CrossRef]

110. Zhang, H.; Chen, Y.; Liang, M.; Xu, L.; Qi, S.; Chen, H.; Chen, X. Solid-Phase Synthesis of Highly Fluorescent Nitrogen-Doped Carbon Dots for Sensitive and Selective Probing Ferric Ions in Living Cells. Anal. Chem. 2014, 86, 9846–9852. [CrossRef] [PubMed]

111. Zhao, L.; Geng, F.; Di, F.; Guo, L.H.; Wan, B.; Yang, Y.; Zhang, H.; Sun, G. Polyamine-Functionalized Carbon Nanodots: A Novel Chemiluminescence Probe for Selective Detection of Iron(III) Ions. RSC Adv. 2014, 4, 45768–45771. [CrossRef]

112. Zhang, R.; Chen, N. Manganese-Doped Carbon Quantum Dots: Facile Synthesis and Application as a “Turn-off” Fluorescent Probe for Detection of Hg2+ Ions. Biosens. Bioelectron. 2013, 55, 83–90. [CrossRef]

113. Zhang, P.; Xue, Z.; Luo, D.; Yu, W.; Guo, Z.; Wang, T. Dual-Peak Electrogenerated Chemiluminescence of Carbon Dots for Iron Ions Detection. Anal. Chem. 2014, 86, 5620–5623. [CrossRef]

114. Zheng, L.; Han, Y.; Zhu, J.; Zhai, Y.; Dong, S. Simple and Sensitive Fluorescent and Electrochemical Trinitrotoluene Sensors Based on Aqueous Carbon Dots. Anal. Chem. 2017, 89, 2033–2036. [CrossRef]

115. Hou, J.; Dong, J.; Zhu, H.; Teng, X.; Ai, S.; Mang, M. A Simple and Sensitive Fluorescent Sensor for Methyl Parathion Based on L-Tyrosine Methyl Ester Functionalized Carbon Dots. Biosens. Bioelectron. 2015, 68, 20–26. [CrossRef] [PubMed]

116. Cui, X.; Zhu, H.; Wu, J.; Hou, Y.; Wang, P.; Wang, Z.; Yang, M. A Fluorescent Biosensor Based on Carbon Dots-Labeled Oligodeoxyribonucleotide and Graphene Oxide for Mercury (II) Detection. Biosens. Bioelectron. 2015, 63, 506–512. [CrossRef] [PubMed]

117. Wang, B.; Song, A.; Feng, L.; Ruan, H.; Li, H.; Dong, S.; Hao, J. Tunable Amphiphilicity and Multifunctional Applications of Ionic-Liquid-Modified Carbon Quantum Dots. ACS Appl. Mater. Interfaces 2015, 7, 6919–6925. [CrossRef] [PubMed]

118. Liu, L.; Feng, F.; Paau, M.C.; Hu, Q.; Liu, Y.; Chen, Z.; Choic, M.M.F. Carbon Dots Isolated from Chromatographic Fractions for Sensing Applications. RSC Adv. 2015, 5, 106838–106847. [CrossRef]

119. Li, L.; Yu, B.; You, T. Nitrogen and Sulfur Co-Doped Carbon Dots for Highly Selective and Sensitive Detection of Hg (II) Ions. Biosens. Bioelectron. 2015, 74, 263–269. [CrossRef]
126. Wang, Y.; Kim, S.H.; Feng, L. Highly Luminescent N, S-Co-Doped Carbon Dots and Their Direct Use as Mercury(II) Sensor. *Anal. Chem. Acta* **2015**, *890*, 134–142. [CrossRef]

127. Liu, Y.; Liao, M.; He, X.; Liu, X.; Kou, X.; Xiao, D. One-Step Synthesis of Highly Luminescent Nitrogen-Doped Carbon Dots for Selective and Sensitive Detection of Mercury(II) Ions and Cellular Imaging. *Anal. Sci.* **2015**, *31*, 971–977. [CrossRef]

128. Hou, Y.; Lu, Q.; Deng, J.; Li, H.; Zhang, Y. One-Pot Electrochemical Synthesis of Functionalized Fluorescent Carbon Dots and Their Selective Sensing for Mercury. *Anal. Chim. Acta* **2015**, *866*, 69–74. [CrossRef]

129. Wang, J.; Zhang, P.; Huang, C.; Liu, G.; Leung, K.C.F.; Wáng, Y.Y.J. High Performance Photoluminescent Carbon Dots for in vitro and in vivo Bioimaging: Effect of Nitrogen Doping Ratios. *Langmuir* **2015**, *31*, 8063–8073. [CrossRef]

130. Schneider, J.; Reckmeier, C.J.; Xiong, Y.; Von Seekendorff, M.; Susha, A.S.; Kasak, P.; Rogach, A.L. Molecular Fluorescence in Citric Acid-Based Carbon Dots. *J. Phys. Chem. C* **2016**, *121*, 2014–2022. [CrossRef]

131. Xu, S.; Lu, H. Mesoporous Structured MIPS@CDs Fluorescence Sensor for Highly Sensitive Detection of TNT. *Biosens. Bioelectron.* **2016**, *85*, 950–956. [CrossRef][PubMed]

132. Dai, J.; Zambrana, M.; Fidalgo, M.; Dai, J.; Zambrana, M. Amino-Functionalized Fluorescent Carbon Dots for Chemical Sensing Jirging. *MRS Adv.* **2016**, *1*, 1365–1370. [CrossRef]

133. He, J.; Zhang, H.; Zou, J.; Liu, Y.; Zhuang, J.; Xiao, Y.; Lei, B. Carbon Dots-Based Fluorescent Probe for “off-on” Sensing of Hg(II) and I-. *Biosens. Bioelec.* **2016**, *79*, 531–535. [CrossRef][PubMed]

134. Zhao, Z.; Zhang, J.; Wang, Y.; Chen, L.; Zhang, Y. Hydrothermal Synthesis of Fluorescent Nitrogen-Doped Carbon Quantum Dots from Ascorbic Acid and Valine for Selective Determination of Picric Acid in Water Samples. *Int. J. Environ. Anal. Chem.* **2016**, *96*, 1402–1413. [CrossRef]

135. He, G.; Xu, M.; Shu, M.; Li, X.; Yang, Z.; Zhang, L.; Su, Y.; Hu, N.; Zhang, Y. Rapid Solid-Phase Microwave Synthesis of Highly Photoluminescent Nitrogen-Doped Carbon Dots for Fe(III) Detection and Cellular Bioimaging. *Nanotechnology* **2016**, *27*, 395706. [CrossRef]

136. Fan, Y.Z.; Zhang, Y.; Li, N.; Liu, S.G.; Liu, T.; Li, N.B.; Luo, H.Q. A Facile Synthesis of Water-Soluble Carbon Dots as a Label-Free Fluorescent Probe for Rapid, Selective and Sensitive Detection of Picric Acid. *Sens. Actuators B Chem.* **2017**, *240*, 949–955. [CrossRef]

137. Chang, M.M.F.; Ginjom, I.R.; Ng, S.M. Single-Shot “Turn-off” Optical Probe for Rapid Detection of Paraoxon-Ethyl Pesticide on Vegetable Utilising Fluorescence Carbon Dots. *Sens. Actuators B Chem.* **2017**, *242*, 1050–1056. [CrossRef]

138. Song, W.; Zhang, H.J.; Liu, Y.H.; Liu, Y.; Ren, C.L.; Chen, H.L. A New Fluorescence Probing Strategy for the Detection of Parathion-Methyl Based on N-Doped Carbon Dots and Methyl Parathion Hydrolase. *Chin. Chem. Lett.* **2017**, *28*, 1675–1680. [CrossRef]

139. Tian, X.; Peng, H.; Li, Y.; Yang, C.; Zhou, Z.; Wang, Y. Highly Sensitive and Selective Paper Sensor Based on Carbon Quantum Dots for Visual Detection of TNT Residues in Groundwater. *Sens. Actuators B Chem.* **2017**, *243*, 1002–1009. [CrossRef]

140. Liu, T.; Cui, Z.W.; Zhou, J.; Wang, Y.; Zou, Z.G. Synthesis of Pyridinic-Rich N, S Co-Doped Carbon Quantum Dots as Effective Enzyme Mimics. *Nanoscale Res. Lett.* **2017**, *12*, 375. [CrossRef]

141. Liu, H.; Zhang, Y.; Liu, J.H.; Hou, P.; Zhou, J.; Huang, C.Z. Preparation of Nitrogen-Doped Carbon Dots with High Quantum Yield from: Bombyx Mori Silk for Fe(III) Ions Detection. *RSC Adv.* **2017**, *7*, 50584–50590. [CrossRef]

142. Liu, Y.; Liu, Y.; Lee, J.; Lee, J.H.; Park, M.; Kim, H.Y. Rational Designed Strategy to Dispel Mutual Interference of Mercuric and Ferric Ions towards Robust, PH- Stable Carbon Nanodots. *Analyst* **2017**, *142*, 1149–1156. [CrossRef][PubMed]

143. Zhang, H.; Weng, Y.; Zheng, L.; Yao, B.; Weng, W.; Lin, X. Nitrogen-Doped Carbon Quantum Dots as Fluorescent Probe for “off-on” Detection of Mercury Ions, L-Cysteine and Iodate Ions. *J. Colloid Interface Sci.* **2017**, *506*, 373–378. [CrossRef][PubMed]

144. Tian, Z.; Zhang, X.; Li, D.; Zhou, D.; Jing, P.; Shen, D.; Su, S.; Zboril, R.; Rogach, A.L. Full-Color Inorganic Carbon Dot Phosphors for White-Light-Emitting Diodes. *Adv. Opt. Mater.* **2017**, *5*, 1700416. [CrossRef]

145. Thongsai, N.; Nagae, Y.; Hirai, T.; Takahara, A.; Uchiyama, T.; Kamitani, K.; Paoprasert, P. Multifunctional Nitrogen-Doped Carbon Dots from Maleic Anhydride and Tetraethylenepentamine via Pyrolysis for Sensing, Adsorbance, and Imaging Applications. *Sens. Actuators B Chem.* **2017**, *253*, 1026–1033. [CrossRef]

146. Huang, Y.; Cheng, Z. Simple and Green Synthesis of Boron-, Sulfur-, and Nitrogen-Co-Doped Carbon Dots as Fluorescent Probe for Selective and Sensitive Detection of Sunset Yellow. *Nano* **2017**, *12*, 1750123. [CrossRef]

147. Du, Q.; Zheng, J.; Wang, J.; Yang, Y.; Liu, X. The Synthesis of Fluorescent Carbon Dots for Warm White LEDs. *RSC Adv.* **2018**, *8*, 19585–19595. [CrossRef]

148. Chen, L.; Zhang, J. Carbon Dots with Tunable Photoluminescence Properties. In Proceedings of the 2nd International Conference of Theoretical and Applied Nanoscience and Nanotechnology, Niagara Falls, ON, Canada, 10–12 June 2018; pp. 1–6. [CrossRef]

149. Yu, T.; Wang, H.; Guo, C.; Zhai, Y.; Yang, J.; Yuan, J. A Rapid Microwave Synthesis of Green-Emissive Carbon Dots with Solid-State Fluorescence and PH-Sensitive Properties. *R. Soc. Open Sci.* **2018**, *5*, 180245. [CrossRef]

150. Ren, G.; Yu, L.; Zhu, B.; Tang, M.; Chai, F.; Wang, C.; Su, Z. Orange Emissive Carbon Dots for Colorimetric and Fluorescent Sensing of 2,4,6-Trinitrophenol by Fluorescence Conversion. *RSC Adv.* **2018**, *8*, 16095–16102. [CrossRef]

151. Zhang, L.; Chang, J.; Su, R.; Huang, R.; Qi, W.; He, Z. Carbon Dots and Quantum Dots-Based Nanohybrid as a Ratiometric Fluorescent Probe for Fe(III) and Phytic Acid Sensing. *Chem. Eng. Trans.* **2018**, *70*, 2065–2070. [CrossRef]

152. Ma, Y.; Mei, J.; Bai, J.; Chen, X.; Ren, L. Ratiometric Fluorescent Nanosensor Based on Carbon Dots for the Detection of Mercury Ion. *Mater. Res. Express* **2018**, *5*, 055605. [CrossRef]
205. Hu, Y.; Yang, J.; Jia, L.; Yu, J.S. Ethanol in Aqueous Hydrogen Peroxide Solution: Hydrothermal Synthesis of Highly Photoluminescent Carbon Dots as Multifunctional Nanosensors. *Carbon* 2015, 93, 999–1007. [CrossRef]

206. Zou, W.S.; Ji, Y.J.; Wang, X.F.; Zhao, Q.C.; Zhang, J.; Shao, Q.; Liu, J.; Wang, F.; Wang, Y.Q. Insecticide as a Precursor to Prepare Highly Bright Carbon Dots for Patterns Printing and Bioimaging: A New Pathway for Making Poison Profitable. *Chem. Eng. J.* 2016, 294, 323–332. [CrossRef]

207. Wu, Z.; Feng, M.; Chen, X.; Tang, X. N-Dots as a Photoluminescent Probe for the Rapid and Selective Detection of Hg²⁺ and Ag⁺ in Aqueous Solution. *J. Mater. Chem. B* 2016, 4, 2086–2089. [CrossRef]

208. Campos, B.B.; Contreras-Cáceres, R.; Bandosz, T.J.; Jiménez-Jiménez, J.; Rodríguez-Castellón, E.; Esteves da Silva, J.C.G.; Algarra, M. Carbon Dots as Fluorescent Sensor for Detection of Explosive Nitrocompounds. *Carbon* 2016, 106, 171–178. [CrossRef]

209. Li, H.; Sun, C.; Vijayaraghavan, R.; Zhou, F.; Zhang, X.; MacFarlane, D.R. Long Lifetime Photoluminescence in N, S Co-Doped Carbon Quantum Dots from an Ionic Liquid and Their Applications in Ultrasensitive Detection of Pesticides. *Carbon* 2016, 104, 33–39. [CrossRef]

210. Liu, X.; Pang, J.; Xu, F.; Zhang, X. Simple Approach to Synthesize Amino-Functionalized Carbon Dots by Carbonization of Chitosan. *Sci. Rep.* 2016, 6, 31100. [CrossRef]

211. Wu, X.; Song, Y.; Yan, X.; Zhou, C.; Ma, Y.; Du, D.; Lin, Y. Carbon Quantum Dots as Fluorescence Resonance Energy Transfer Sensors for Organophosphate Pesticides Determination. *Biosens. Bioelectron.* 2017, 94, 292–297. [CrossRef]

212. Wu, P.; Li, W.; Wu, Q.; Liu, Y.; Liu, S. Hydrothermal Synthesis of Nitrogen-Doped Carbon Quantum Dots from Microcrystalline Cellulose for the Detection of Fe³⁺ Ions in an Acidic Environment. *RSC Adv.* 2017, 7, 44144–44153. [CrossRef]

213. Mohapatra, S.; Bera, M.K.; Das, R.K. Rapid “Turn-on” Detection of Atrazine Using Highly Luminescent N-Doped Carbon Quantum Dot. *Sens. Actuators B Chem.* 2018, 263, 459–468. [CrossRef]

214. Devi, S.; Gupta, R.K.; Paul, A.K.; Tyagi, S. Waste Carbon Paper Derivatized Carbon Quantum Dots/(3-Aminopropyl)Triethoxysilane Based Fluorescent Probe for Trinitrotoluene Detection. *Mater. Res. Express* 2019, 6, 1–12. [CrossRef]

215. Feng, Y.; Tan, L.; Tang, Q.; Zhong, W.; Yang, X. Synthesis of Carbon Dots from PEG6000 and Papain for Fluorescent and Doxycycline Sensing. *Nano* 2018, 13, 1–9. [CrossRef]

216. Siddique, A.B.; Pramanick, A.K.; Chatterjee, S.; Ray, M. Amorphous Carbon Dots and Their Remarkable Ability to Detect 2,4,6-Trinitrophenol. *Sci. Rep.* 2018, 8, 9770. [CrossRef]

217. Zhao, D.; Liu, X.; Wei, C.; Qu, Y.; Xiao, X.; Cheng, H. One-Step Synthesis of Red-Emitting Carbon Dots: Via a Solvothermal Method and Its Application in the Detection of Methylene Blue. *RSC Adv.* 2019, 9, 29533–29540. [CrossRef]

218. Fang, J.; Zhuo, S.; Zhu, C. Fluorescent Sensing Platform for the Detection of P-Nitrophenol Based on Cu-Doped Carbon Dots. *Opt. Mater. 2019, 97, 109396. [CrossRef]*

219. Xu, Y.; Yan, L.; Yue, M.; Yu, Y. Green Hydrothermal Synthesis of Fluorescent Carbon Dots from Glucose and Taurine for Fe³⁺ and PH Sensing. *Nano* 2019, 14, 1950014. [CrossRef]

220. Gogoi, J.; Chowdhury, D. Calcium-Modified Carbon Dots Derived from Polyethylene Glycol: Fluorescence-Based Detection of Trifluralin Herbicide. *J. Mater. Sci.* 2020, 55, 11597–11608. [CrossRef]

221. Saravanan, A.; Maruthapandi, M.; Das, P.; Ganguly, S.; Margel, S.; Luong, J.H.T.; Gedanken, A. Applications of N-Doped Carbon Dots as Antimicrobial Agents, Antibiotic Carriers, and Selective Fluorescent Probes for Nitro Explosives. *ACS Appl. Bio Mater.* 2020, 3, 8023–8031. [CrossRef]

222. Tammin, S.K.; Yang, Y. Highly Sensitive and Selective Detection of 4-Nitrophenol, and on-off Fluorescence Sensor for Cr (VI) and Ascorbic Acid Detection by Glucosamine Derived n-Doped Carbon Dots. *J. Photochem. Photobiol. A Chem.* 2020, 387, 112134. [CrossRef]

223. Houdová, D.; Soto, J.; Castro, R.; Rodrigues, J.; Soledad Pino-González, M.; Petković, M.; Bandosz, T.J.; Algarra, M. Chemically Heterogeneous Carbon Dots Enhanced Cholesterol Detection by MALDI TOF Mass Spectrometry. *J. Colloid Interface Sci.* 2021, 591, 373–383. [CrossRef] [PubMed]

224. Hu, Y.; Gao, Z.; Luo, J. Fluorescence Detection of Malachite Green in Fish Tissue Using Red Emissive Se,N,Cl-Doped Carbon Dots. *Food Chem.* 2021, 335, 127677. [CrossRef] [PubMed]

225. Mohammadi, S.; Mohammadi, S.; Salimi, A. A 3D Hydrogel Based on Chitosan and Carbon Dots for Sensitive Fluorescence Detection of MicroRNA-21 in Breast Cancer Cells. *Talanta* 2021, 224, 121895. [CrossRef] [PubMed]

226. Liu, Q.; Zhao, F.; Shi, B.; Changli, L. Mussel-Inspired Polydopamine-Encapsulated Carbon Dots with Dual Emission for Detection of 4-Nitrophenol and Fe³⁺. *Luminescence* 2021, 36, 431–442. [CrossRef]

227. Bisauriya, R.; Antonaroli, S.; Ardivi, M.; Angelucci, F.; Ricci, A.; Pizzoferrato, R. Tuning the Sensing Properties of N and S Co-Doped Carbon Dots for Colorimetric Detection of Copper and Cobalt in Water. *Sensors* 2022, 22, 2487. [CrossRef]

228. Ezati, P.; Rhein, J.W.; Molaei, R.; Priyadarshi, R.; Roy, S.; Min, S.; Kim, Y.H.; Lee, S.G.; Han, S. Preparation and Characterization of B, S, and N-Doped Glucose Carbon Dots: Antibacterial, Antifungal, and Antioxidant Activity. *Sustain. Mater. Technol.* 2022, 32, e00397. [CrossRef]

229. Kong, B.; Yang, T.; Cheng, F.; Qian, Y.; Li, C.; Zhan, L.; Li, Y.; Zou, H.; Huang, C. Carbon Dots as Nanocatalytic Medicine for Anti-Inflammation Therapy. *J. Colloid Interface Sci.* 2022, 611, 545–553. [CrossRef]

230. Zhu, X.; Han, L.; Liu, H.; Sun, B. A Smartphone-Based Ratiometric Fluorescent Sensing System for on-Site Detection of Pyrethroids by Using Blue-Green Dual-Emission Carbon Dots. *Food Chem.* 2022, 379, 132154. [CrossRef]
231. Fen, Y.W.; Yunus, W.M.M.; Yusof, N.A. Surface Plasmon Resonance Optical Sensor for Detection of Pb\(^{2+}\) Based on Immobilized P-Tert-Butylcalix[4]Arene-Tetrakis in Chitosan Thin Film as an Active Layer. Sens. Actuators B Chem. 2012, 171, 287–293. [CrossRef]

232. Daniyal, W.M.E.M.M.; Fen, Y.W.; Abdullah, J.; Sadrolhosseini, A.R.; Saleviter, S.; Omar, N.A.S. Exploration of Surface Plasmon Resonance for Sensing Copper Ion Based on Nanocrystalline Cellulose-Modified Thin Film. Opt. Express 2018, 26, 34880. [CrossRef]

233. Anas, N.A.A.; Fen, Y.W.; Omar, N.A.S.; Ramdzan, N.S.M.; Daniyal, W.M.E.M.M.; Saleviter, S.; Zainudin, A.A. Optical Properties of Chitosan/Hydroxyl-Functionalized Graphene Quantum Dots Thin Film for Potential Optical Detection of Ferric (III) Ion. Opt. Laser Technol. 2019, 120, 105724. [CrossRef]

234. Daniyal, W.M.E.M.M.; Fen, Y.W.; Anas, N.A.A.; Omar, N.A.S.; Ramdzan, N.S.M.; Nakajima, H.; Mahdi, M.A. Enhancing the Sensitivity of a Surface Plasmon Resonance-Based Optical Sensor for Zinc Ion Detection by the Modification of a Gold Thin Film. RSC Adv. 2019, 9, 41729–41736. [CrossRef] [PubMed]

235. Ramdzan, N.S.M.; Fen, Y.W.; Omar, N.A.S.; Anas, N.A.A.; Liew, J.Y.C.; Daniyal, W.M.E.M.M.; Hashim, H.S. Detection of Mercury Ion Using Surface Plasmon Resonance Spectroscopy Based on Nanocrystalline Cellulose/Poly(3,4-Ethylenedioxythiophene) Thin Film. Measurement 2021, 182, 109728. [CrossRef]

236. Omar, N.A.S.; Irmawati, R.; Fen, Y.W.; Abdullah, J.; Daud, N.F.M.; Daniyal, W.M.E.M.M.; Mahdi, M.A. A Sensing Approach for Manganese Ion Detection by Carbon Dots Nanocomposite Thin Film-based Surface Plasmon Resonance Sensor. Optik 2021, 243, 167435. [CrossRef]

237. Mustapha Kamil, Y.; Al-Rekabi, S.H.; Abu Bakar, M.H.; Fen, Y.W.; Mohammed, H.A.; Halip, N.H.M.; Alresheedi, M.T.; Mahdi, M.A. Arsenic Detection Using Surface Plasmon Resonance Sensor with Hydrous Ferric Oxide Layer. Photonic Sens. 2021, 12, 220306. [CrossRef]

238. Gonçalves, H.M.R.; Duarte, A.J.; Esteves da Silva, J.C.G. Optical Fiber Sensor for Hg(II) Based on Carbon Dots. Biosens. Bioelectron. 2010, 26, 1302–1306. [CrossRef]

239. Sun, X.; Li, G.; Yin, Y.; Zhang, Y.; Li, H. Carbon Quantum Dot-Based Fluorescent Vesicles and Chiral Hydrogels with Biosurfactant and Biocompatible Small Molecule. Soft Matter 2018, 14, 6983–6993. [CrossRef]

240. Wang, X.; Guo, H.; Wu, N.; Xu, M.; Zhang, L.; Yang, W. A Dual-Emission Fluorescence Sensor Constructed by Encapsulating Double Carbon Dots in Zeolite Imidazole Frameworks for Sensing Pb\(^{2+}\). Colloids Surf. A Physicochem. Eng. Asp. 2021, 615, 126218. [CrossRef]

241. Jia, M.; Peng, L.; Yang, M.; Wei, H.; Zhang, M.; Wang, Y. Carbon Dots with Dual Emission: A Versatile Sensing Platform for Rapid Assay of Cr (VI). Carbon 2021, 182, 42–50. [CrossRef]

242. Hashim, H.S.; Fen, Y.W.; Omar, N.A.S.; Fauzi, N.I.M.; Daniyal, W.M.E.M.M. Recent Advances of Priority Phenolic Compounds Detection Using Phenol Oxidases-Based Electrochemical and Optical Sensors. Meas. J. Int. Meas. Confed. 2021, 184, 109855. [CrossRef]

243. Babar, D.G.; Garje, S.S. Nitrogen and Phosphorus Co-Doped Carbon Dots for Selective Detection of Nitro Explosives. ACS Omega 2020, 5, 2710–2717. [CrossRef] [PubMed]

244. Fauzi, N.I.M.; Fen, Y.W.; Omar, N.A.S.; Hashim, H.S. Recent Advances on Detection of Insecticides Using Optical Sensors. Sensors 2021, 21, 3856. [CrossRef] [PubMed]

245. Hou, J.; Dong, G.; Tan, Z.; Lu, J.; Wang, Q.; Ai, S.; Wang, M. A Sensitive Fluorescent Sensor for Selective Determination of Dichlorvos Based on the Recovered Fluorescence of Carbon Dots-Cu(II) System. Food Chem. 2016, 202, 81–87. [CrossRef] [PubMed]

246. Mandal, P.; Sahoo, D.; Sarkar, P.; Chakraborty, K.; Das, S. Fluorescence Turn-on and Turn-off Sensing of Pesticides by Carbon Dot-Based Sensor. New J. Chem. 2019, 43, 12137–12151. [CrossRef]

247. Bera, M.K.; Behera, L.; Mohapatra, S. A Fluorescence Turn-down-up Detection of Cu\(^{2+}\) and Pesticide Quinalphos Using Carbon Quantum Dot Integrated UiO-66-NH\(_2\). Colloids Surf. A Physicochem. Eng. Asp. 2021, 624, 126792. [CrossRef]

248. Liu, Y.; Zhou, Q.; Wu, Y.; Li, S.; Sun, Y.; Sheng, X.; Zhan, Y.; Zhao, J.; Guo, J.; Zhou, B. Sensitive Detection of 2,4,6-Trinitrotoluene Utilizing Fluorescent Sensor from Carbon Dots and Reusable Magnetic Core-Shell Nanomaterial. Talanta 2021, 233, 122498. [CrossRef]