Journal of Carbon Research

MDPI

Review

The Advanced Role of Carbon Quantum Dots in Nano-Food Science: Applications, Bibliographic Analysis, Safety Concerns, and Perspectives

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Abstract: Carbon quantum dots (CQDs) are innovative carbon-based nanomaterials that can be synthesized from organic and inorganic sources using two approaches: "top-down" (laser ablation, arc discharge, electrochemical, and acidic oxidation) and "bottom-up" (hydrothermal, ultrasound-assisted, microwave, and thermal decomposition). Among these, hydrothermal synthesis stands out as the best option as it is affordable and eco-friendly and can produce a high quantum yield. Due to their exceptional physical and chemical properties, CQDs are highly promising materials for diverse applications, i.e., medicine, bioimaging, and especially in food safety, which is one of the thriving fields of recent research worldwide. As an innovative sensing tool, CQDs with different surface functional groups enable them to detect food contaminants, i.e., food additives in processed food, drug residues in honey, and mycotoxins in beer and flour, based on different sensing mechanisms (IFE, PET, and FRET). This article discussed the sources, fabrication methods, advantages, and limitations of CQDs as a sensing for the detection of food contaminants. In addition, the cost-effectiveness, eco-friendliness, high quantum yield, safety concerns, and future research perspectives to enhance food quality and security were briefly highlighted. This review also explored recent advancements in CQD applications in food safety, supported by a bibliometric analysis (2014–2024) using the PubMed database.

Keywords: carbon quantum dots; carbon nanomaterials; carbon sources; food sensing; food safety; photoluminescence

Academic Editor: Camélia Matei Ghimbeu

Received: 16 November 2024
Revised: 19 December 2024
Accepted: 20 December 2024
Published: 24 December 2024

Citation: Majid, A.; Ahmad, K.; Tan, L.; Niaz, W.; Na, W.; Huiru, L.; Wang, J. The Advanced Role of Carbon Quantum Dots in Nano-Food Science: Applications, Bibliographic Analysis, Safety Concerns, and Perspectives. *C* **2025**, *11*, 1. https://doi.org/10.3390/c11010001

1. Introduction

For humans, food is one of their most basic needs. Nonetheless, eating often exposes a person to food contaminants. Food contaminants are substances that do not naturally exist in food products. These contaminants can pass into food through three main routes. First, when food is processed, naturally occurring chemicals may change into dangerous pollutants. Secondly, during processing, contaminated food may absorb contaminants from the surrounding area. Thirdly, throughout the handling, processing, washing, and disinfection stages, food may come into contact with contaminants [1]. Food contaminants can be either organic or inorganic and originate from a variety of sources, such as the environment and microorganisms [2]. Food additives, polychlorinated biphenyls (PCBs), copper, mercury, lead, mycotoxins, and drug residues such as pesticides, herbicides, fertilizers, and food preservatives are a few examples of harmful pollutants, and their toxicity depends upon different factors, i.e., age, dosage, exposure frequency, and health of the individual [3,4]. Mycotoxins are chemical compounds produced by filamentous fungi such as *Fusarium*, *Penicillium*, and *Aspergillus,* which pose short- and long-term effects on human beings. Plant-based foods frequently contain mycotoxins, which are well-known chemical risks in the food chain and are widely present in human bodies [5]. Food additives are frequently utilized in the food sector because they can prolong the shelf life and improve the appearance and odor of food. However, using food additives excessively might result in cancer, cytopathic illness, organ damage, and food poisoning [6]. These contaminants pose potential risks to food safety and processing, can cause food deterioration, result in food poisoning, and may ultimately lead to acute or severe diseases. Global consumer concern over food safety is increasing the risk of consuming unsafe food globally [7,8]. It is crucial to maintain food quality from contamination and ensure food safety, which is essential for both producers and consumers [9]. Analytical techniques, i.e., high-performance liquid chromatography (HPLC) and gas chromatography–mass spectrometry (GC-MS), can be expensive and time-consuming and requires skilled operators and rigorous sample preparation [10]. Moreover, the increasing research interest in global food safety, which is pushed by the continuous advancements in techniques and devices for accurate food analysis, has caused quantum dots (QDs) to emerge as promising contributors [11,12]. QD applications have laid the groundwork for high sensitivity, low cost, ease of use, and improved accuracy [13,14].

Carbon quantum dots (CQDs) are eco-friendly carbon-based nanomaterial with a size of 2–10 nm and quasi-spherical structures and have excellent chemical and physical properties such as strong fluorescence, good biocompatibility, excellent photobleaching resistance, and ultraviolet (UV) absorption, gaining them the attention of investigators and researchers in food-related applications [15,16]. CQDs display a significantly large surface area despite their small size. The core of CQDs contains conjugated sp^2/sp^3 hybridized carbon and the outer surface of CQDs is bounded by carbonyl and carboxyl groups, making CQDs more biocompatible and ideal for adsorbing various pollutants and metal ions; for example, CQDs can remove Cr (VI) from a water environment with efficiency of over 83.85% [16,17]. Their fluorescence properties and ability to interact with different analytes make them useful tools for detecting a wide range of substances, such as obtaining pathogens and toxins, contributing to the improvement of more efficient and consistent food safety and quality monitoring [18]. Photoluminescence is a significant optical characteristic of CQDs. The three primary luminescence mechanisms that have been found to cause fluorescence enhancement or quenching are photo-induced electron transfer (PET), the inner filter effect (IFE), and fluorescence resonance energy transfer (FRET) [19].

Atoms present on the surface of CQDs have prominent activity and can interact with other molecules or functional groups to achieve numerous chemical properties that can be exploited for different applications [20,21]. CQDs have vast characteristics depending on the precursor materials and fabrication methods [22]. The fabrication of CQDs is achieved through varied methods such as thermal decomposition, hydrothermal, laser ablation, and arc discharge, with each proposing distinct advantages [20,23]. CQDs with plenty of surface functional groups enhance their ability to identify different components in food, which could lead to new developments in food safety techniques in the future [24].

The significance of utilizing CQDs in food safety, food analysis, and the monitoring of toxic substances is becoming more effective as sensing and detection approaches [9]. CQD application in food analysis assists with the accurate and efficient identification of multiple components in complex food matrices, expediting inclusive quality assessments [22]. Furthermore, CQDs play an important role in monitoring and tracing toxic substances, offering a sensitive and targeted method to identify and detect harmful elements [25]. Many studies emphasize the effectiveness and crucial role of CQDs in advancing analytical methodologies/technologies in real-time analysis, contributing to the predominant goal of protecting public health through improved food safety practices [8]. The prospective interactions between CQDs and biological systems, as well as the long-term effects of their absorption, demand a thorough study to confirm consumer safety [7]. Bibliometrics is an effective method for describing the patterns of publishing trends in certain study domains. The two main parts of a bibliometric analysis are as follows: first, it describes how publications are distributed according to several clusters, such as subjects, fields, sources, authors, organizations, and countries; second, it is widely used to analyze trends in research and production in science, including the number of cited publications across a variety of domains. The current study presents a bibliometric analysis of the literature on "carbon quantum dots" as sensors obtained from the PubMed database.

This review article thoroughly covers the most recent research advancement on the detection mechanism of CQDs and their applications in food contaminants analysis, food safety, and harmful substance detection, with a specific emphasis on food inspection and toxicity. Furthermore, the challenges, future perspectives, and safety concerns of CQDs in fundamental research and applications were also discussed.

2. Basic Sources for Fabrication of CQDs

CQDs can be produced from organic and inorganic components, providing researchers with the flexibility to adapt CQDs for particular applications, minimizing concerns of toxicity, high stability, and excellent functionality [26].

2.1. Natural Carbon-Based Organic Precursors

Natural sources gained importance as CQDs can be derived from precursors such as fruit extracts, sugars, or other biomass materials, offering a natural and sustainable source for carbon-based nanomaterial synthesis. The functional groups of CQDs depend on the precursor materials employed and fabrication approaches and have become more important due to growing environmental concerns and production costs [27,28]. Lignin-based carbon dots (L-CDs) were prepared by Mint et al. [29] via a simple facile hydrothermal technique using H_2O_2 as an oxidizing agent and successfully applied for bio-imaging (in vitro and in vivo) applications. Devi et al. synthesized waste-derivatized CQDs from whey for selenite monitoring in water [30]. These carbon-based natural organic probes are environmentally friendly and exhibit excellent analytical characteristics, making them ideal for the food industry's rising emphasis on real-time application [31]. Despite the low cost and non-toxicity of natural sources, there are still significant challenges such as uncertain reaction mechanisms and complications caused by the existence of impurities in the optimization of CQD synthesis. In food-related applications, CQDs synthesized from these sources can assist as non-toxic and biocompatible additives for food labeling, tracing, and sensing. Their exclusive detecting properties make them valuable for enhancing food safety and quality control processes [31].

2.2. Synthetic Organic Carbon Precursors

CQDs can be sourced from synthetic organic materials such as polymers or organic ligands with tailored properties [24,27]. CQDs with high quantum yield were produced by Feng et al. [32] using ethylenediamine and thiosalicylic acid as precursors. The CQDs have a size of 2.3 nm with an excitation-independent emission wavelength of 320–440 nm. Ding et al. [32] synthesized highly luminescent carbon quantum dots (CQDs) with a mixture of o-phenylenediamine and l-glutamic acid using different ratios in four different solvents (ethanol, formamide, aqueous H_2SO_4 solution, and dimethylformamide). Multicolor (blue to red) with high color-purity emission triangular CQDs were synthesized by Yuan et al. [33] using phloroglucinol (PG) as the reagent (a triangulogen), and a quantum yield of up to 54–72% was determined with the advantages of stability, low cost, and environmental friendliness. The different organic carbon precursors used for the fabrication of CQDs and their advantages, disadvantages, and safety concerns are given in Table 1.

Table 1. Organic carbon precursors for the synthesis of CQDs and their advantages, disadvantages, and safety concerns.

Organic Source	Advantage	Disadvantage	Safety Concern	References
Sugarcane bagasse	Abundant and sustainable source Potential for energy applications	Lower quantum yield compared to some CQDs Potential risks from residual pesticides/herbicides	Potential cytotoxicity under specific conditions	[34,35]
Orange pericarp	High oxygen content, potential for catalysis Good photoluminescence quantum yield	Low nitrogen content compared to palm shells Potential for heavy metal contamination	Potential heavy metal contamination and cytotoxicity	[36,37]
Orange waste peels	Cost-effective; upcycles waste Tunable properties; potential antibacterial activity High oxygen content, potential for catalysis	Variability in properties based on orange variety Potential for heavy metal contamination	Potential heavy metal contamination and cytotoxicity trace elements and contaminants	[36,38]
Pineapple peel	Abundant and sustainable source Good photoluminescence quantum yield Cost-effective; upcycles waste	Lower stability compared to some CQDs Potential for heavy metal contamination	Potential cytotoxicity under specific conditions	[39,40]
Banana peel	Excellent biocompatibility and biodegradability Tunable properties; potential antibacterial activity Tunable properties; potential antibacterial activity	Lower stability compared to some CQDs	Potential cytotoxicity under specific conditions	[31,41]
Wheat straw	Abundant and sustainable source Potential for energy applications Cost-effective;	Limited control over size and morphology Lower biocompatibility	Potential cytotoxicity under specific conditions	[36,42]

Table 1. *Cont.*

Organic Source	Advantage	Disadvantage	Safety Concern	References
Citrus fruit peels	Diverse potential applications (sensing, catalysis, etc.) Wide variety of available citrus fruits Potential for energy applications.	Variability in properties based on citrus variety Potential for bitterness from limonene	Potential cytotoxicity under specific conditions; trace elements and contaminants	[43,44]
Cassava peels	Abundant and sustainable source Good biocompatibility and biodegradability Tunable properties; good antibacterial activity.	Lower stability compared to some CQDs Potential for heavy metal contamination	Potential cytotoxicity at specific conditions; trace elements and contaminants	[40,45]
Grapefruit peel	Good photoluminescence quantum yield, Upcycles waste Potential for sensing applications.	Limited research compared to some options Potential for heavy metal contamination	Potential cytotoxicity under specific conditions; trace elements and contaminants	[36,40]

2.3. Industrial Waste Materials

Waste from food processing, agriculture, and industrial products containing high contents of carboxyl, amino, sulfur, and hydroxyl functional groups can be excellent sources for the fabrication of CQDs and offer a wide range of potential practical uses [46,47]. Although the synthesis of CQDs from waste and by-products has been covered in recent studies, further investigation is required to completely examine potential materials as a sustainable source of CQDs due to their low cost and availability at large scale. Graphene (G) and (CQDs) are two valuable materials that can be synthesized from agricultural-based waste [16,48]. Highly fluorescent CQDs from industrial waste were synthesized by Thambiraj [34] from bagasse waste with a particle size of around 5 nm. Zhang et al. [49] synthesized high-quality biocompatible CDs from polystyrene foam waste and showed tunable emission (blue to orange) with a particle size of 3.4 nm. Huang et al. [50] used bio-refinery byproducts for the preparation of CQDs with a size distribution ranging from 2.0 to 6.0 nm, and they contained a significant proportion of blue-green fluorescence with a quantum yield (QY) of about 13%.

2.4. Inorganic Sources

Inorganic sources typically deal with heavy metal elements, like cadmium or lead, combined with metallic elements chalcogenide to produce CQDs through methods such as colloidal production [51]. Inorganic source-based CQDs are important in the context of the food industry, where the prominence of safety and regulatory compliance is paramount [52]. CQDs derived from inorganic precursors, normally related to the carbonization of materials like graphite or carbon black, offer a controlled and standardized approach to nanomaterial fabrication. These inorganic sources contribute to the advancement of CQDs with consistent size, surface properties, and purity, making them suitable for food-related applications [51]. In the food industry, inorganic-sourced CQDs can be employed for food labeling, quality control, and sensing/detection of harmful components. Their stability and unique characteristics make them valuable tools for improving food quality, enhancing shelf life, and ensuring the food supply chain is up to standards, bringing it into line with the rigorous necessities of the industry [26].

2.5. Graphitic Materials

Tohamy et al. [16] synthesized amphoteric-Janus nitrogen-doped CQDs (AJ–N–CQDs) from industrial waste and showed excellent fluorescence properties, whereas N–GQDs lack fluorescence properties because of the high concentration of Graphene (G). Agricultural waste (sugarcane bagasse) was utilized to synthesize hybrid material by Al-Kiey [47]. The synthesized electrodes demonstrated remarkable qualities for supercapacitors with a high specific capacitance of 612 F g^{-1} at 1 A g^{-1} and exhibited a retention rate (96.3%). Further CV studies showed that the synthesized electrode had a high specific capacitance of 657.1 F g^{-1} at 5 mV/s.

Xu et al. [53] prepared novel CQDs with an average size of <10 nm using high-purity graphite rods by ionic liquid-assisted electrochemical exfoliation, which offered a new avenue for research with the expanded application of innovative graphitic materials in analyte detection. A green method for producing high-quality CQDs was developed by Hu et al. [54] via selective oxidation using coal. This approach is simple, safe, green, and efficient to acquire CQDs without the emission of hazardous gases. Liu et al. [55] prepared water-soluble carbon nanoparticles (CNPs) with a particle size < 2 nm using candle soot via an oxidative acid treatment, and further purification of CNPs was performed using polyacrylamide-gel electrophoresis (PAGE). Incomplete combustion resulted in particles with larger diameters between 20 and 800 nm. Studies showed that this reaction introduces some functional groups, i.e., OH and CO_2H on the surface of CNPs, which gives the particles a hydrophilic and negatively charged appearance. Calabro et al. [56] synthesized graphene quantum dots (GQDs) from carbon nano onions utilizing two methods, i.e., chemical oxidation (CO-GQDs average diameter of 8 nm) with a thickness of two or three graphene layers and pulsed laser ablation (LA) (LA-GQDs average diameter of 6 nm) with a single layer of graphene thickness. These GQDs exhibit blue-shifted absorbance and are more uniformly sized. Inorganic carbon precursors for the synthesis of CQDs and their advantages, disadvantages, and safety concerns are given in Table 2.

Table 2. Inorganic carbon precursors used for the fabrication of CQDs and their advantages, disadvantages, and safety concerns.

Inorganic Source	Advantage	Disadvantage	Safety Concern	References
Crude soot	-Tunable photoluminescence (color emission) -Good biocompatibility and biodegradability, -Good water solubility	-Lower photoluminescence efficiency than some inorganic quantum dots QDs -Low yield, large particle size, low specific surface area, limited active reaction sites.	Harmful substances Polycyclic aromatic hydrocarbons(PAHs) toxic byproducts	[57]
Graphite electrodes, Graphite powder and cement	-High chemical stability -Wide range of potential applications -Narrow size distribution, excellent water solubility with fluorescence properties.	-Limited control over size and morphology Complicated operations and high-cost.	-May require special handling due to dust	[58,59]
Graphene oxide, Bulk F-C3N4 powder	-Tunable properties -High thermal stability -Easy operation	-Potential cytotoxicity under specific conditions -Sophisticated equipment, high energy cost	-Limited safety data; may require further research	[60,61]

Table 2. *Cont.*

Inorganic Source	Advantage	Disadvantage	Safety Concern	References
Citric acid and thiourea, Poly(ethylene glycol) and saccharide	-Homogeneous, simultaneous, and rapid heating, resulting in uniform size distribution.	-High production cost -High energy cost	-Toxic in high doses	[62,63]
Urea and sodium citrate, Melamine and EDTA	High quantum yield, with tunable PL characteristic	-Purification treatment is complicated and time-consuming	-May be harmful if inhaled	[64,65]
Carbon glassy, polyethylene glycol 200, Nanodiamond-derived carbon Nano onions	Narrow size distribution, excellent water solubility with fluorescence properties	Complicated operations and high-cost	-May be harmful if inhaled	[56,66]

3. Fabrication of CQDs

The fabrication of CQDs can be achieved via two basic approaches: bottom-up and top-down approaches. Bottom-up methods produce CQDs from molecular precursors, allowing the controlled size of particles and chemical composition. In contrast, the top-down approach involved breaking down large carbon structures into nanoscale CQDs in a broader size distribution. The choice between these methods depends on the desired application and the specific properties required for the synthesized CQDs [67], which are listed in Table 3. These essential techniques can fulfill the various demands of CQDs and their unique properties [68]. The generalized synthetic routes for the fabrication of CQDs are shown in Figure 1.

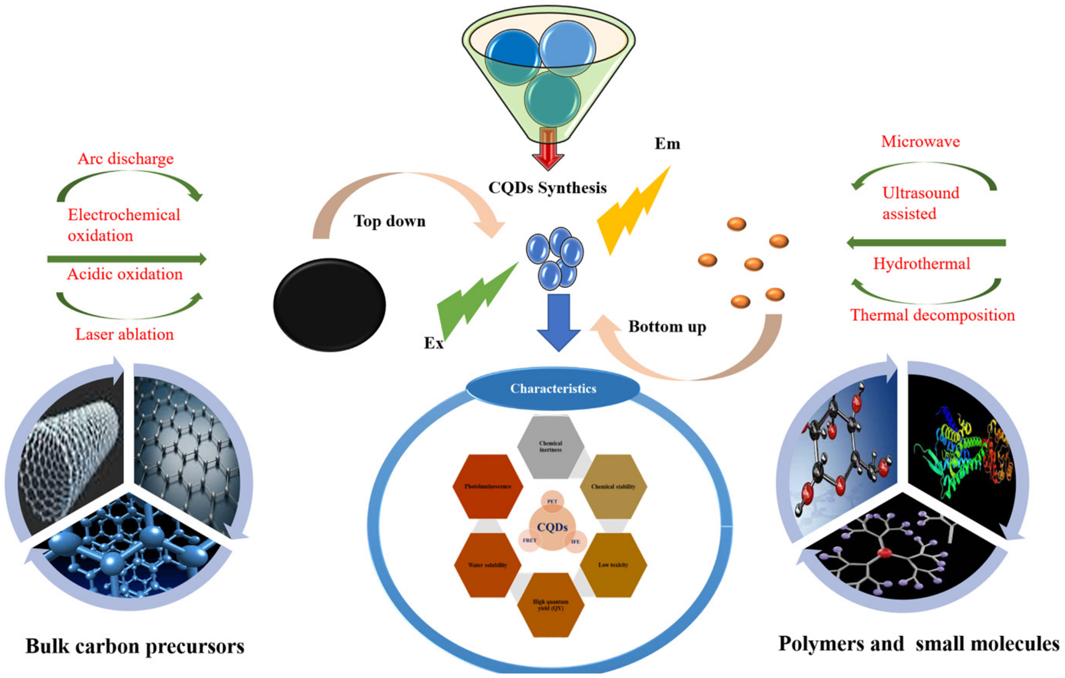

Figure 1. Two basic approaches for CQD synthesis are the bottom-up method and the top-down method.

Table 3. Synthetic routes using different precursors and properties of carbon quantum dots.

Route	Synthetic Method	Precursor	Size of CQDs	Quantum Yield (%)	Advantages	Disadvantages	Reference
Top-Down Approach	Laser Ablation	Graphite powders	1–8 nm	0.54	Controllable morphology	Low yield and difficult to scale up	[69]
		Graphene	2–5 nm	2			[70]
	Arc Discharge	SADW	1–5 nm	16	Small particle size and high oxygen content	Impurities are difficult to separate and purify, yield is very low	[71]
		Ni/Co carbon composite rod		0.016			[57]
	Acidic Oxidation	Lignin	2.4 nm	13	High yield, controllable size, and low cost	Easy to corrode	[29]
		Chinese ink	1–6 nm				[72]
Bottom-Up Approach	Hydrothermal Synthesis	Ascorbic acid	2–6 nm	13	High efficiency, Controllable size, and low cost	High temperature and time-consuming	[73]
		Dry carnation petals	2.69				[74]
	Microwave Pyrolysis	Orange juice	2–5 nm	29.30	Simple, short-time, and low cost	Not easy to control	[75]

3.1. Fabrication of CQDs by Top-Down Approach

CQDs synthesized by using a top-down approach involved the breakdown of large carbon structures into nano-scale particles. This method allows for fabrication but the resulting CQDs may show an extensive size distribution. The top-down fabrication approach is chosen based on its efficiency and suitability for specific applications requiring larger quantities of CQDs [68].

The fabrication of CQDs via a top-down approach is regularly exploited to modify large-scale carbon materials into nano-sized CQDs usually by laser ablation, discharge techniques, and acidic oxidation. The primary disadvantage of this approach is the challenge of attaining the optimal particle size and shape [76].

3.1.1. Laser Ablation

The laser ablation technique is one of the most promising approaches for synthesizing CQDs that make use of a high-intensity laser pulse to expose the surface of the target to thermo-dynamic conditions that result in high pressure and temperature. The sudden increase in heat leads to the formation of a plasma state and nanoparticles are formed by vapor crystallization. The laser beam increases the temperature of ablated particles, i.e., ions, atoms, and atom clusters, to several kelvins. Inside the cavitation bubble, they interact with liquid (from surroundings) and undergo chemical reactions. The obtained nanoparticles diffuse into the surrounding liquid, which is turned into a colloidal solution during the plasma-cooling phase, and the whole cycle is completed in 1 ms [77].

Li et al. [78] prepared CQDs using a laser ablation technique, which showed observable and controllable photoluminescence (PL) [78]. Moreover, by selecting the appropriate organic solvent during the laser ablation process, CQDs can be modified to vary their photoluminescence (PL) properties [79]. In the food industry, CQD fabrication via the laser ablation method holds promise for different applications. This advanced technique facilitates the formation of nano-scale CQDs with particular properties, such as size and surface features, which can be employed for food labeling, traceability, and quality control [77].

The accuracy offered by the laser ablation technique allows for the customization of CQDs to serve as exclusive and consistent markers for tracking and authenticating food products, addressing concerns related to food safety. Moreover, the sensing properties of CQDs synthesized through this method could offer new avenues for advanced sensing and imaging technologies in food processing and quality assurance [79].

The laser ablation fabrication technique has advantages for creating CQDs with well-organized structures, excellent water solubility, narrow size distribution, and luminous properties. However, the difficult operation, expensive cost, and labor-intensive nature limit its uses. This approach has the significant advantages of controlling particle size and having a high quantum yield. However, the disadvantage is the creation of irregular particle sizes and bubble formation.

3.1.2. Arc Discharge Synthesis

The fabrication of CQDs using the arc discharge method is gaining attention in the food industry due to its prospective applications in food safety and the quality of food products. Using this technique, a target material is vaporized and condensed into CQDs by creating a high-voltage electric arc between two electrodes. The optimum conditions of the arc discharge process allow the production of CQDs with specific features and are suitable for applications such as food labeling and detection [59].

Chemical exfoliation is an appropriate method for the fabrication of high-quality CQDs at a large scale, in which a high-purity graphite rod is used as an anode and platinum wire is used as an electrode installed into an ionic fluid or water solution [59,80]. Sikiru et al. [80] employed an arc discharge technique to synthesize CQDs from the breakdown of bulk carbon material, which included rearranging the carbon atoms as a result of the gas plasma generated in a sealed reactor, breaking down bulk carbon material at the anodic electrode powered by the gas plasma produced in a sealed reactor, and turning carbon vapors into CQDs at the cathode [80].

Although the CQDs produced using this method often have a wide range of particle sizes due to the formation of various-sized particles during the arc discharge process, these CQDs can serve as exclusive markers for the confirmation of helping to stop food deception and ensuring the viability of food products throughout the supply chain. Furthermore, the adaptability of CQDs produced by the arc discharge method opens prospects for advanced sensing technology, contributing to improved monitoring and control in the food industry. The uniformity of each particle's shape and structure is greatly enhanced by this approach. The low yield, formation of undesirable particles, and need for further purification procedures are the disadvantages of this approach [59,80].

3.1.3. Electrochemical Oxidation

CQDs can be fabricated through electrochemical techniques employing either a basic or acidic environment to cause the electrolytic reaction. Carbon source materials, such as carbon fiber, graphene, and graphite, are commonly used as electrodes to produce electrolytic cell discharge, which separates the carbon particles and produces CQDs [81]. A novel electrochemical method was developed by Deng et al. [82] for large-scale synthesizing GCQDs with purified water as an electrolyte and particle size-dependent emission colors were obtained. CQDs were fabricated by Liu et al. [83] in alkaline alcohols NaOH/EtOH from the electrochemical oxidation of graphite electrodes for ferric ion detection. Tan et al. [84] produced small uniform-sized GQDs with a distinct red fluorescence by electrochemically peeling graphite in a $K_2S_2O_8$ solution. Borna et al. [85] prepared CQDs 1–5 nm in size via electrochemical synthesis using graphite, and their study revealed that the particle size of CQDs was dependent on the current intensity, while the fluorescence intensity decreased proportionally with the increased size of the particle. CQDs with high purity, cheap cost, high yield, and controlled size can be synthesized by electrochemical oxidation; however, the tedious purification and extraction procedures are the somewhat major drawbacks of this technique [85].

3.1.4. Acidic Oxidation Method

CQDs fabricated via the acidic oxidation method, through the exfoliation of bulk carbon precursors, generate hydrophilic groups (carboxyl and hydroxyl groups) on the surfaces of CQDs, which could significantly improve fluorescence properties [86]. Small organic molecules are carbonized by strong acids (oxidizing) and break down into small sheets via controlled oxidation; however, this approach could suffer from severe circumstances and abrupt procedures.

Peng et al. [87] proposed a facile method for the fabrication of luminous CQDs using concentrated H_2SO_4 to dehydrate carbohydrates in an aqueous solution, subsequently utilizing HNO_3 to split the carbonaceous materials into individual CQDs and employing amine-terminated compounds for passivation [87].

Yang et al. (2014) [72] synthesized heteroatom-doped CQDs via acidic oxidation followed by hydrothermal reduction. A mixed solution with an appropriate ratio of HNO_3, H_2SO_4, and $NaClO_3$ was first employed to oxidize carbon nanoparticles made from Chinese ink. After that, the oxidized CQDs were treated with sodium hydrosulphide (NaHS), dimethylformamide (DMF), and sodium selenide (NaHSe) via the hydrothermal method to obtain N-CQDs, SCQDs, and Se-CQDs with adjustable photoluminescence (PL), a high quantum yield (QY), and a prolonged fluorescence lifetime. The photoluminescence (PL) of these CQDs was dependent on the surface passivation. By adjusting the starting material and nitric acid treatment period, these CQDs can have a customized emission wavelength. These CQDs can be used in life science research because of their benign nature and multicolor emission capabilities. There are numerous advantages of acidic oxidation, i.e., the bulk production of a final material with a controlled size that is easy to handle, low cost, and highly efficient. The drawback of chemical oxidation worth noting is the lack of homogeneity in size, and QDs prepared via chemical oxidation with acid are prone to corrosion and the production of waste acid compounds [72,88].

3.2. Fabrication of CQDs by Bottom-Up Approach

The fabrication of CQDs via a bottom-up approach involved building nanomaterials from molecular precursors with well-defined tailored properties, making them appropriate for numerous applications that need specific features, i.e., precise size and composition [68].

The bottom-up approach is favored when refining the characteristics of CQDs is important for optimal performance in different applications, and this approach has several benefits including the lower manufacturing temperature, porosity control, low cost, straightforward composition to produce high-surface-area nanomaterials, and molecular homogeneity of the finished product. The bottom-up method is preferred when CQD refining properties are crucial for the best results in various applications.

3.2.1. Hydrothermal Method

In the food industry, the hydrothermal technique is employed as an adaptable, simple, and eco-friendly practice for the fabrication of CQDs. The hydrothermal method is one of the most fascinating techniques for the fabrication of CQDs, in which a carbon-rich reaction precursor is placed into a Teflon-lined vessel, which involves dissolving tiny organic compounds or polymers in water or an organic solvent. The organic compounds, polymers, or natural carbon precursors are combined at a high temperature to create carbon-seeding cores, which subsequently grow into CQDs with a particle size range of 2 nm to 10 nm [89].

CQDs are fabricated by the hydrothermal method using an autoclave with external heating, usually prepared at a high temperature; for example, for the synthesis of CQDs from glucose, 15 mL of deionized H_2O, 6 mL of NH_3, and 2 g of glucose were taken, mixed into a Teflon-lined vessel, and then autoclaved at 180 °C temperature for 5 h, from which a quantum yield (QY) of the CQDs of up to 80% was reported, which is comparable to fluorescent dyes. The approach has several benefits compared to other approaches, including its cost-effectiveness, ease of synthesis, low energy use, green chemistry, and environmental friendliness. The method's shortcomings are its non-homogeneous dispersion and requirement for a lengthy reaction time [20].

3.2.2. Ultrasound-Assisted Approach

The ultrasound-assisted approach (sonochemical synthesis) utilizes cavitation from alternating waves in liquid (high and low pressure) at frequencies from 20 kHz to 100 kHz, which generates high-speed liquid jets, resulting in strong hydrodynamic shear forces that cause tiny vacuum bubbles to grow and burst. Large carbon materials are broken into nanoscale CQDs using these high-energy ultrasonic waves [90,91]. A simple facile approach was proposed by Park et al. [92] for synthesizing green carbon nanodots at a large scale with a particle size of ∼4 nm under ultrasound treatment at room temperature. Another facile and green method was reported by Li et al. [93] to synthesize fluorescent carbon nanoparticle FCNPs less than 5 nm by treating the active carbon in a hydrogen peroxide solution with ultrasonic waves in a single step. FCNPs emit photoluminescence from the visible-to-near infrared spectral range and have high hydrophilicity due to rich surface hydroxyl groups. Some major advantages of this technique include the low equipment cost and facile, non-toxic, and scalable nature, whereas its primary drawbacks are the lack of control over particle size and relatively low Φs (<10 %) [93].

3.2.3. Microwave Pyrolysis Approach

The process of microwave pyrolysis, which is an inexpensive and quick way to fabricate CQDs, has received widespread attention due to its quick synthesis and commercialization. This method utilizes microwave radiation to induce pyrolysis, a process involving the decomposition of organic compounds at elevated temperatures (the absence of oxygen). The microwave synthesis approach involves a common strategy to increase emission quantum yields using sugar moieties as a carbon source, polymeric oligomers as the reaction media, and amine compounds as surface-passivating agents and nitrogen dopants [80].

Zhu et al. [62] proposed a simple, efficient microwave pyrolysis fabrication technique to create carbon quantum dots that involved dissolving saccharide (glucose) polyethylene glycol (PEG200) in water to create a transparent solution and then heating it in a microwave oven. Excitation-dependent PL characteristics were present in the produced CQDs. First, distilled water was combined with varying amounts of the carbon precursor and reaction medium. The resulting translucent solution was then heated for a further two to ten minutes in a 500 W microwave oven. The color shifted from colorless to light yellow in less than a minute, and additionally, the appearance of a dark brown color indicated the development of CQDs. The product was separated and purified to produce fluorescent carbon quantum dots when it was cooled to room temperature [62].

This approach offers advantages like rapid heating, energy efficiency, and precise temperature control [94,95]. The microwave pyrolysis approach aligns with the industry's growing emphasis on eco-friendly practices and circular economy principles, providing a promising avenue for turning useful and environmentally friendly materials [62,96].

The CQDs created can be applied in the food sector for excellent optical function with high efficiency of detection and sensing frequency. This technique is most suitable for a scientist to synthesize CQDs because of the simple operation, optimum condition of reaction, cheap raw materials, and simple preparation method, contributing to the potential for one-step high-volume fabrication of CQDs. However, there are a few drawbacks, including the fact that it is expensive and contains dangerous microwave radiation that needs to be handled carefully.

The benefits include the quick reaction time, simple and quick synthesis process, high production of particles with adjustable sizes, and environmental friendliness. The primary drawback of the microwave approach is its high energy requirement and unpredictable reaction conditions [68].

3.2.4. Thermal Decomposition

An efficient method to fabricate CQDs is the thermal decomposition technique, which involves the decomposition of compounds by heat [97]. One of the most fascinating ways to make fluorescent CQDs is through the thermal decomposition of citric acid (CA); however, the reaction path is rather complicated and still not well understood. To prepare excellent luminous CQDs, CA was employed as the carbon source and N-(aminoethyl)-amino propyl methyl dimethoxy silane (AEAPMS) was used as the passivating agent. Furthermore, CA was neutralized with NaCl solution, heated at 200 °C for 30 min, and dialyzed to obtain the purified product. The size of the synthesized CQDs was within the 0.7 nm to 1.0 nm range. Both of these CQDs revealed that the quantum yield (QY) is dependent and independent of the photoluminescent (PL) function [20].

Ludmerczki et al. [98] investigated how the optical characteristics of absorption and emission vary as CA is thermally decomposed. To understand the overall chemical synthesis route that results in the formation of CQDs starting from the carbon precursor CA, to organosilane coating (amino functional group) and the final product, this modification was very successful in enhancing the temporal stability of the optical response. The major advantages of the thermal decomposition method include its large-scale production, cost-effectiveness, and less time-consuming nature, while the varying particle sizes and low yields are the drawbacks of this technology [98].

4. Application in Food Analysis

CQDs have better biocompatibility, are inexpensive, have good photobleaching resistance, and have more stable properties, which result in their prospective use in the food industry. Their distinctive physicochemical and optical characteristics have drawn the attention of researchers [99]. There are numerous potential applications based on CQDs for the analysis and detection of noxious substances in foodstuffs that can cause severe health problems. Table 4 lists the applications of CQD-based sensors in the food industry, such as the detection of pesticides, nutritional materials, microbial toxins, additives, and pathogenic microbes. The fabrication of a CQDs-MnO_2 detection platform based on fluorescent retrieval was efficaciously used in sensing canned vegetables, fruits, and juices [100].

Table 4. Role of CQDs and their applications in food sector contaminants.

Food Contaminant	Types of Food Compounds	Detection Mechanism	Perimeter of Detecting	Emission Wave-Length	References
Bacteria	Tap water, eggplant	Fluorescence recovery	50 nM	442 nm	[20]
Chemical	Juice samples/cabbages	Fluorescence quenching	3.4 nM	-	[101]
Phytic acid	Food	Fluorescence recovery	0.36 µmol/L	450 nm	[102]
Lemon yellow	Ice sugar, honey, and bread	Fluorescence quenching	73 nM	593 nm	[103]
Heavy metal ion	Food	Fluorescence recovery	4.2 nM	410 nm	[20]
Vitamin	Fresh fruits & vegetables	Fluorescence recovery	42 nM	441 nm	[103]
Hg^{2+}	Food (beverage)	Fluorescence quenching (Static quenching)	0.24 µM	445 nm	[104]
Methyl orange	Saffron	Fluorescence quenching (FRET)	0.77 µM	425 nm	[105]
Curcumin	Curry powder	Fluorescence quenching (IFE)	0.133 µM	445 nm	[106]
Pesticide residues	Apple	Fluorescence quenching (Electron transfer)	5 ppb	520 nm	[107]
Chlorpyrifos	Apple juice	Fluorescence	2.7 ng/mL	462 nm	[108]
Ochratoxin A	Red wine	Fluorescence recovery (Tuning aggregation/disaggregation)	13 pg/mL	-	[109]
Aflatoxin B1	Food (Peanuts & soybeans)	Fluorescence/immunoasssay	0.05 ng/mL	525 nm	[12]
Tartrazine	Food samples	Fluorescence quenching (FRET)	0.45 µmol/L	462 nm	[110]
Melamine	Milk	Fluorescence quenching(FRET)	36 nM	438 nm	[111]
Tannic acid	Food Samples	Fluorescence quenching(Electron transfer)	0.6 nmol/L	440 nm	[112]
Food additives	Pickled olives	Fluorescence quenching	252 ng/mL	435 nm	[113]

4.1. Sensing Mechanism of Functionalized CQDs in Food Analysis

The sensing approach of functionalized CQDs in food analysis represents a cutting-edge methodology that influences the unique properties of these nanomaterials for the enhanced detection and quantification of numerous analytes in food samples [100]. The functionalization of CQDs involves modifying their surface with specific functional groups, enabling selective interactions with target molecules. This surface chemistry boosts the sensitivity and specificity of the sensing platform. In food analysis, functionalized CQDs show significant capabilities [18,100].

Their fluorescence properties and ability to interact with different analytes make them useful tools for detecting a wide range of substances, including pathogens, toxins, and quality parameters in food samples, contributing to the improvement of more efficient and consistent food safety and quality monitoring systems [18]. Photoluminescence is a significant optical characteristic of CQDs. The three primary luminescence mechanisms that have been found to cause fluorescence enhancement or quenching are photo-induced electron transfer (PET), fluorescence resonance energy transfer (FRET), and the inner filter effect (IFE) [19].

If the absorption spectrum of a target substance overlaps the fluorescence ex/em spectrum of the probe, the fluorescence intensity of the probe will be quenched by the target substance, namely the IFE [114]. Photo-induced electron transfer (PET) occurs when both the electron donor and electron acceptor are excited, and when electron transfer occurs between both species, this process can result in fluorescence quenching [115].

Fluorescence resonance energy transfer (FRET) occurs due to the following reasons: (1) there is good overlap between the emission and absorption spectrum of the fluorescent probe and the quencher; and (2) there is an appropriate distance, of generally less than 100 Å, between the donor and the acceptor. If these two conditions are met, the fluorescence energy will be transferred from the donor to the acceptor, with this process known as FRET [116]. Figure 2 shows the general sensing mechanism of carbon quantum dots in food applications.

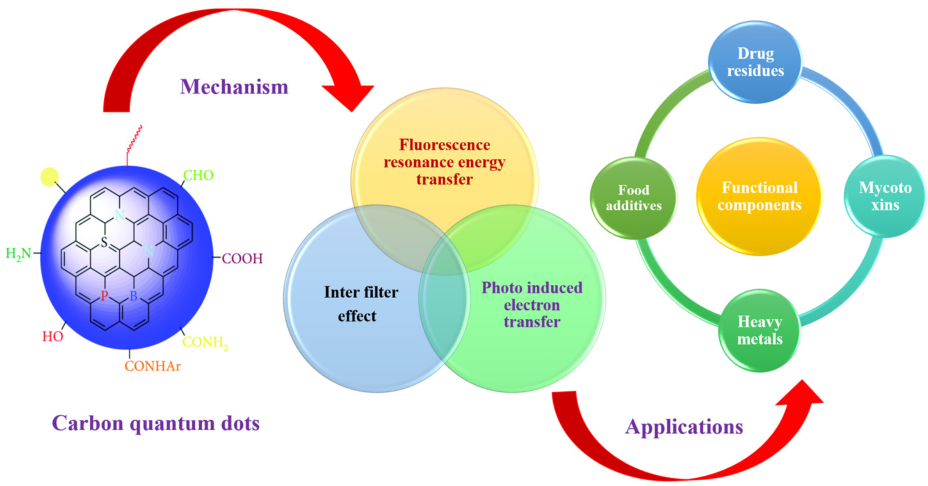

Figure 2. Summarized general sensing mechanism of CQDs in food applications.

4.2. CQDs Detecting Functional Components in Foods

CQDs have emerged as promising nanomaterials for detecting functional components in foods due to their distinctive sensing and chemical properties. These nanoscale carbon-based structures, often engineered with specific surface functionalities, show unique sensitivity and selectivity in identifying and quantifying different bioactive compounds existing in food backgrounds [117]. CQDs can be tailored to interact with specific functional groups of bioactive molecules, such as polyphenols, vitamins, and antioxidants, leading to distinct alterations in their fluorescence properties upon binding [100].

This essential sensitivity allows for the real-time analysis of functional components in food samples. Moreover, the biocompatibility of CQDs and their minimal interference with the innate composition of foods make them ideal candidates for rapid detection methods, offering a promising opportunity for advancing the analysis of functional components in diverse food products [18]. In foods that are medicinally homologous, the existence of functional components is generally regarded as the primary criterion for determining the quality of food. CQDs and certain metal ions can interact, causing the quenching of the fluorescence intensity of CQDs. Thus, the fluorescence of CQDs can be restored by adding nutrients to the solution containing certain ions. This phenomenon can therefore be used to construct a fluorescence-enhanced sensor to detect nutrients in meals. For the detection and analysis of such components, fluorescent CQDs are an efficient, practical, and accurate approach [117].

Significant pharmacological actions against viruses and bacteria are produced by chlorogenic acid, and its quantity can be used as the benchmark for assessing honey suckle quality. The strength of chlorogenic acid increases in the linear range of 0.15 to 60 mol L^{-1}, and the fluorescence of CQDs is quenched due to the inner filter effect (IFE). These CQD-based fluorescent methods not only considerably increase the detection speed but also improve the sensitivity, making them appropriate for the rapid evaluation of large numbers of honey suckle samples [118].

4.3. Sensing Toxic Food Additives

The most frequently utilized substances in the food sector are food additives as they can prolong the shelf life and improve the appearance and odor of food. However, using food additives excessively might result in cancer, cytopathic illness, organ damage, and food poisoning. Thus, it is essential to develop a quick and effective technique for the monitoring of food additives [6]. Xylitol is a type of food additive that has drawn the attention of prospective cohort studies and randomized controlled trials [119] given that, if a significant amount is ingested, it may end up in the colonic microbiota due to its poor intestinal absorption and digestion effects on body weight and glucose metabolism, as well as its potential to heighten the risk of obesity and cardiovascular events.

CQDs have emerged as versatile tools that play an excellent role in the detection of food additives within the food industry [118]. The unique properties of CQDs, like their biocompatibility, tunable fluorescence, and large surface area, make them suitable candidates for improving the functionality and safety of food products. CQDs can be employed as carriers for delivering food additives, providing controlled release, and targeted delivery [76].

As shown in Figure 3a, a highly sensitive approach developed by Carneiro et al., (2021) [113] based on fluorescence sensing, while taking into account the importance of examining chemical additives in processed food with a detection limit (LOD) 252 ng mL^{-1}, was successfully performed for five food additives (ascorbic acid, citric acid, sodium benzoate, lactic acid, and potassium sorbate). Using a dilution factor of 201, the discrimination tests were conducted using 2000 μL of FM-CD suspension and 10 μL of each additive in an aqueous solution. The first signal was measured as I_0 (emission fluorescence of FM-CD), and Signal I was measured for the FM-CD sample + additive. To create the LDA platform, the ratio of these signals (I/I_0) was calculated using the values of I and I_0, which were assessed over a spectral range of 380 to 600 nm. All the tested additives could clearly be distinguished using the suggested sensing approach of FM-CDs in conjunction with LDA algorithms; these additions were also detected in an actual sample of pickled olives. In addition, the sensing platform shows promise for prospective application in manufactured food quality control since it successfully distinguished between the five additives with 100% accuracy. Furthermore, it is imperative to highlight the exceptional sensing capabilities of FM-CDs derived from natural sources, which have the potential to yield distinct binding events with every food additive molecule [113].

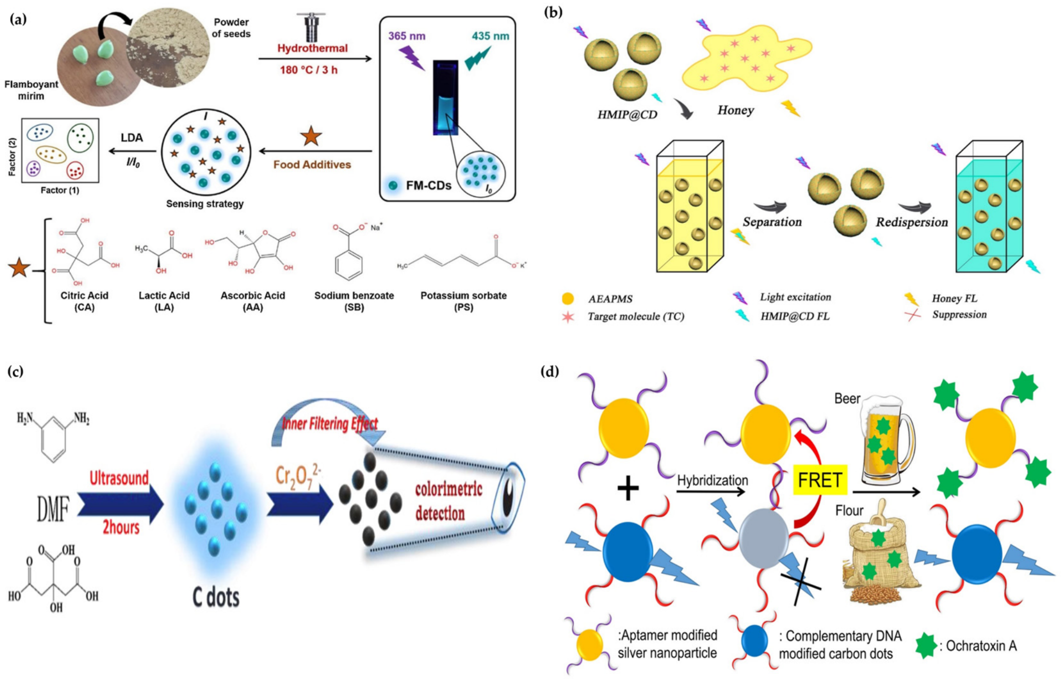

Figure 3. (**a**) Illustration of five distinct food additives shown with their fluorescence sensing strategies using the LDA approach. Reproduced from [113] ©Elsevier Science Direct. (**b**) Illustration of detection of tetracycline (TC) procedure in honey. The HMIP@CD was first dispersed in a sample of diluted honey. After adsorption, the composite was separated by centrifugation and was dispersed in (PBS) followed by fluorescence detection. Reproduced from [120] ©Elsevier Science Direct. (**c**) Schematic illustration of CDs for $Cr_2O_7^{2-}$ ions detection by fluorescence quenching through inner filter effect (IFE). Reproduced from [121] ©Elsevier Science Direct. (**d**) FRET-based fluorescence detection of ochratoxin A (OTA) in flour and beer. The absorbance spectra of Apt-AgNPs correlated with the cDNA-CD emission spectrum, promoting the FRET between AgNPs and CD and causing the energy transfer to cause the CD's fluorescence signals to vanish. Reproduced from [122] ©Elsevier Science Direct.

Moreover, the intrinsic ability of CQDs to interact with different molecules allows for proficient sensing and monitoring of food additives, confirming their proper combination and adherence to regulatory standards [76]. Furthermore, the use of CQDs can contribute to improving the stability, prolonging shelf-life, and increasing the quality of food products by preventing oxidation or degradation of sensitive additives [123]. The multifaceted role of CQDs in food additive applications emphasizes their potential to advance food technology and quality control measures in the ever-evolving landscape of the food industry [124,125].

4.4. Detection of Toxic and Harmful Drug Residues in Food

The detection of harmful and toxic drug residues in food is a serious aspect of confirming food safety and public health [126]. Advanced technologies, including innovative analytical methods utilizing sensors and nanomaterials, have improved our ability to identify and quantify contaminants in food samples [6]. Different techniques, such as mass spectrometry, chromatography, and biosensors, are employed to target a broad spectrum of toxic residues, including pesticides, heavy metals, mycotoxins, and veterinary drug residues. These methods often influence the specificity and sensitivity of biosensors, utilizing antibodies or aptamers that selectively bind to the target contaminants [127]. Moreover, nanomaterials such as CQDs can play a crucial role in intensifying signals and increasing the sensitivity of detection assays. Fast and precise analysis of toxic residues in food not only facilitates compliance with regulatory standards but also confirms the delivery of safe and healthy food products to consumers [126].

Li et al. [120] successfully synthesized molecularly imprinted polymer carbon dots (HMIP@CD) via a microwave method. The HMIP@CD absorbed the tetracycline (TC) from the diluted honey sample in less than three minutes through the charge transfer quenching. TC separated from the honey sample via centrifugation and re-dispersed the sample into the phosphate buffer solution, as shown in Figure 3b. Following the separation and re-dispersion procedure, satisfactory recovery was obtained, indicating that the technique can be used successfully to identify TC in honey samples. The fluorescence of HMIP@CD can prevent the autofluorescence of honey, which interferes with the sample. Compared to the conventional solid core MIP@CD, the HMIP@CD has several benefits, such as a large surface area, a quick adsorption rate, and high sensitivity. HMIP@CD was employed as a fluorescence detection method for TC in honey, which eliminated the problem of auto-fluorescence interference with the honey sample. This technique should enable MIP@CD to be extended for the detection of numerous analytes in complex samples with auto-fluorescence interference [120].

The unique capacity of MIPs to recognize compounds is frequently utilized to concentrate, purify, and isolate minute target molecules of veterinary drug and pesticide residues in food. An excellent fluorescent, room-temperature ionic liquid-sensitized CQD sensing probe (RTIL-SCQDs-MIPs) was successfully designed to track the pesticide lambda-cyhalothrin (LC) in tea and vegetable samples with a limit of detection of 0.5 g kg^{-1} [128]. It is known that the detection and sensing performance can be considerably improved by using S-doped CQDs with RTIL sensing probes. According to the interactions between the host and the guest mechanism, the MIP-based outer material is significant in the detection of analyte LC in foods [129].

To improve the detection of organophosphorus pesticide residues, magnetic molecularly imprinted polymer (MMIP) microspheres functionalized with vinyl phosphate (VPA) were created and coupled with CQDs for fluorescence detection [130]. The MMIP-CQDs@VPA fluorescence sensor was used to detect triazophos in vegetables (cucumbers) with a lower limit of detection of 0.0015 mmol L^{-1} and was proven to have excellent reproducibility, sensitivity, and accuracy. Metallic nanoparticles (NPs), such as AgNPs and AuNPs, are excellent carriers for electrochemical sensing because they have a low energy transfer resistance and large surface area. For more precise and sensitive detection of acetamiprid (pesticides) in cucumber, tomato, and cabbage samples, an exceptional fluorescent aptasensor made of AuNPs and CQDs was developed [36].

4.5. Sensing for Toxic Heavy Metal Ions

CQDs have gained attention as efficient and sensitive sensing platforms for the detection of metal ions in food items, playing an essential role in confirming food safety. The optimal properties of CQDs, such as the large surface area, fluorescence, and excellent biocompatibility, make them suitable for designing highly efficient sensors for monitoring metal ions [18,131]. Heavy metal ions like Hg^{2+}, Pb^{2+}, Cr^{6+}, As^{3+}, Cu^{2+}, Fe^{3}, and Fe^{2+} are known as contaminants and play an important role in the contamination of the environment, notably in food [132].

Notwithstanding efforts to limit the environmental contamination caused by these metals, people consume a few micrograms of Cd^{2+} and Pb^{2+} daily, even in developed countries. Recent research has shown that exposure to high concentrations of Cd^{2+} and Pb^{2+} in human beings can cause neurodegeneration and neurological problems [133]. When functionalized or modified with specific ligands, CQDs can selectively interact with different heavy metal ions, leading to distinct changes in their fluorescence intensity or emission wavelength. This interaction forms the basis of a sensitive and quick detection method, often with low detection confines [18].

The versatility of CQDs facilitates the effective simultaneous determination of multiple ions in complex food matrices and can monitor the levels of contaminants, such as Hg^{2+}, Pb^{2+}, Cr^{6+}, As^{3+}, Cu^{2+}, Fe^{3+}, and Fe^{2+}, contributing to the overall safety and quality assurance of food products consumed by the public. The application of CQDs in heavy metal ion sensing showcases their potential as innovative tools in the field of food product investigation [132]. As a result, it is critical to detect heavy metal ions accurately and promptly in food. These heavy metals enter the body of a human through the food chain.

Qiao et al. [121] used the carbon precursors citric acid (CA) and 1,3-phenylenediamine (1,3 PD) to produce water-soluble carbon dots (CDs), as illustrated in Figure 3c. Carbon dots were a good choice for an on-site nano platform, with two modes for the detection of $Cr_2O_7{}^{2-}$ at the trace level, and the fluorescence of CDs can be remarkably quenched by the presence of chromate due to the inner filter effect. Furthermore, the results showed that carbon dots respond to $Cr_2O_7{}^{2-}$ in a very selective and sensitive manner, whereby the color changes achieved linearity of 0 to 140 nM with recoveries ranging from 95% to 105% and 96% to 98% in the drinking and Zhujiang River water samples, respectively. This further demonstrated that ion-selective recognition is feasible in real-time analysis because of its practicality, quick response, and precise detection. Further real water and river samples were tested for $Cr_2O_7{}^{2-}$ concentrations to assess the analytical capabilities of this nano-platform [121].

In addition, Pizarro et al. [134] prepared an electrochemical sensor using glassy carbon electrode-modified GQDs for the simultaneous detection of Cd^{2+} and Pb^{2+} in seafood. The ratiometric fluorescence based on novel CQDs for the efficient determination of glutathione and Cu^{2+} was successfully synthesized. [134]. The fluorescent CQDs were produced utilizing citric acid and o-phenylenediamine (OPD) through a one-pot simple hydrothermal method. The oxidation product, 2,3-diamino phenazine, was produced when the oxidation reaction occurred between Cu^{2+} and OPD, the fluorescence of CQDs was quenched at 446 nm, and a new distinct peak appeared at 562 nm. This ratiometric sensing technique demonstrated increased sensitivity to Cu^{2+} in the range of 0.25–10.0 mol L^{-1}, with a limit of detection of 0.076 mol L^{-1} [135].

Similarly, He et al. [136] synthesized ratiometric CdTe quantum dots and graphite carbon nitride (GCNN) fluorescent sensing probes to detect Cu^{2+} in drinks. Cu^{2+} quenched the CdTe QDs' yellow fluorescence when exposed to a UV lamp. The pink-yellow color of GCNN shifted to blue at the same time [136].

4.6. Sensing of Mycotoxins Through CQDs

Mycotoxins are chemical compounds produced by filamentous fungi such as Fusarium, Penicillium, and Aspergillus. These substances have the potential to have several detrimental short- and long-term effects on human beings. Plant-based foods frequently contain mycotoxins, which are well-known chemical risks in the food chain and are widely present in human bodies [5]. Recent studies of prolonged exposure to mycotoxins and their possible link to the development of neurological disorders like Parkinson's or Alzheimer's due to neurotoxicity repercussions have increased our understanding of the effects of mycotoxins on the nervous system [137].

The application of CQDs in sensing mycotoxins represents a significant advancement in ensuring the quality and safety of products within the food industry [116]. CQDs exhibit unique optical properties and surface functionality and provide an innovative solution for mycotoxin detection in different food backgrounds. Functionalized CQDs can be tailored to selectively bind to specific mycotoxins, inducing measurable changes in their fluorescence characteristics [18].

Aflatoxin (AF) was categorized as an exceedingly hazardous cancerogenic substance that contaminates lentils, cereals grain, oil, and their products, posing a major threat to human health. Fluorescent carbon quantum dots–duplicate molecularly imprinted polymers (CQDs-DMIPs) were employed as a pretreatment for the specific identification and quantification of aflatoxin B1 (AFB1) in peanuts, together with HPLC detection [138]. The high toxicity of aflatoxin B1 was determined using a duplicate template of 5, 7-dimethoxy coumarin compared to solid-phase extraction (SPE-HPLC) combined with UV, which achieved a high enrichment factor of 71-fold with a LOD 118 ng L^{-1} [18].

Wang et al. [122] developed a facile, highly efficient method for detecting ochratoxin A in flour and beer based on nitrogen-doped carbon dots (N-CDs) as an energy donor and DNA and MCH (6-mercapto-1-hexanol)-modified silver nanoparticles as an energy acceptor in the FRET system as shown in Figure 3d. This method has three advantages: (1) nitrogen-doped CDs produced in a single step without requiring complex nanoparticle modification allow for the acquisition of increased fluorescence intensity; (2) using MCH as an assistance molecule, OTA detection was completed in less than 30 min; and (3) a wide linear range was obtained, which could detect OTA in actual agricultural samples and provide solutions for food safety issues. This tailored interaction facilitates the sensitive and rapid detection of mycotoxins, offering a more efficient alternative to traditional methods. The use of CQDs in mycotoxin sensing holds great promise for real-time monitoring, early detection, and quality control in the food industry, thereby mitigating the potential health hazards associated with mycotoxin contamination in food products [122].

5. Safety Concerns and Challenges

CQDs have exclusive properties, e.g., their sensitivity and surface functionality, which make them valuable tools for detecting contaminants and pollutants in food products. Carbon quantum dots can be modified in their surfaces, which makes them useful in food analysis [139]. CQDs provide the real-time monitoring of pathogens, allergens, and toxins in foodstuffs, contributing to the prevention of foodborne illnesses. Moreover, the exclusive fluorescence properties of CQDs help in the sensitive and selective detection of specific biomolecules, supporting the identification of allergens or adulterants [99]. By incorporating CQDs into food safety measures, the industry can address health concerns, boost consumer confidence, and contribute to the inclusive well-being of the public through the delivery of safe and healthy food [52].

CQDs assume an essential role in improving safety measures within the food industry when utilized as carriers for food products. CQDs' distinctive characteristics, including their biocompatibility, stability, and surface properties, make them ideal for improving the safe delivery of food additives or bioactive compounds [140]. Acting as carriers, CQDs can facilitate the controlled release and targeted delivery of important constituents, reducing the risk of undesired interactions or side effects [52]. Additionally, their ability to prevent the oxidation or degradation of sensitive compounds increases the overall safety and shelf-life of food products [18]. By using CQDs as carriers, the food industry not only confirms the proficient delivery of functional constituents but also addresses safety concerns related to the stability and integrity of the delivered components, contributing to making safer and higher-quality food items [141]. The following important safety concerns and challenges should be considered for the CQD-based sensing platform:

(1) The sensitivity and selectivity of the CQDs can be constrained by the complexity of the food matrix. To fabricate CQDs with the appropriate characteristics, it is important to obtain safe raw materials and create environmentally friendly additives [8,22].
(2) Currently, all approaches focus on sensing a single analyte, and few studies have been conducted on the simultaneous detection of several targets in a single sample. CQDs, compared to semiconductor QDs, have a low fluorescent quantum yield (QY), and further research is necessary to fully understand their luminescent or fluorescent mechanism. In addition, investigating their lifespan and degrading processes is necessary to potentially widen their applications in the industry [15,27].
(3) For food packaging, the particle size of nanomaterials is a crucial factor that needs to be confirmed as safe and stable throughout its shelf life, sensitive to the target analyte, and non-destructive, especially when used in conjunction with packaged goods. In addition to accurately determining the quality of the packed food, the fabrication and size of CQDs must be maintained to keep the food quality high over time [7,25].
(4) Materials used in nanosensors to make them multifunctional and multireactive must be made safe. Before implementing new food-sensing technologies, it is best to carefully consider how nanomaterial-based sensors affect socioeconomic and human health issues. We must be aware that the toxicity of carbon quantum dots increases due to the oxidative stress caused by the relative oxygen species leading to the poisoning of food [3].

6. Bibliometric Analysis and Future Perspectives

A bibliometric analysis is an organized analysis framework of many articles on a particular topic. This provides knowledge on both current and future-oriented topics, including research trends, journals, co-authorship networks, co-citations, bibliographic coupling, the creation of new fields and subjects, and the evolution of new fields over time [142]. In this study, the purpose of the bibliometric analysis was to examine and assess published works from 2014 to 2024 that generally addressed the potential uses of CQDs in food from the PubMed scientific database. In bibliometric research, keyword co-occurrence analysis is a potent technique for examining the connections and trends among keywords in a particular field of study [143]. Overlay visualization and network visualization maps of author keyword co-occurrence are shown in Figure 4a,b, respectively, from the period of 2014 to 2024. By presenting and discerning the co-occurrence patterns, researchers can identify closely associated and commonly studied concepts. This information can guide future research directions, collaborations, and grant funding decisions by highlighting prevailing research interests and potential areas of scientific advancement regarding carbon-based quantum dots. These networks may be used to assess how revolutionary a piece of research is in the subject under consideration.

The bibliographic analysis on CQDs reveals that a growing number of publications emphasized their importance and potential in food safety applications, particularly in the detection of food contaminates, and highlighted the eco-friendly synthesis of CQDs from both natural and synthetic sources, showing their versatility and effectiveness in various food matrices. Additionally, CQDs exhibit photoluminescent properties, which further research should strive to fully understand. The sensing mechanism of CQDs, as well as the longevity and degradation process of CQDs, should also be addressed to ensure their effectiveness over time in real-time analysis. To make carbon quantum dots more commercially viable for use in food-based applications, it should be imperative to find low-cost methods for fabrication on a large scale. Thermal or pyrolysis methods may restrict the widespread usage of brown-colored CQDs in a range of food analyses. For this problem, novel non-thermal technologies can be used to handle the large-scale production of CQDs. From a synthesis perspective, sustainability issues such as the recyclability, reusability, environmental pollution, and toxicity of CQDs should be taken into account while developing new synthesis techniques and desired materials. More work and efforts are required, in particular, to produce green carbon precursors for the eco-friendly synthesis of CQDs.

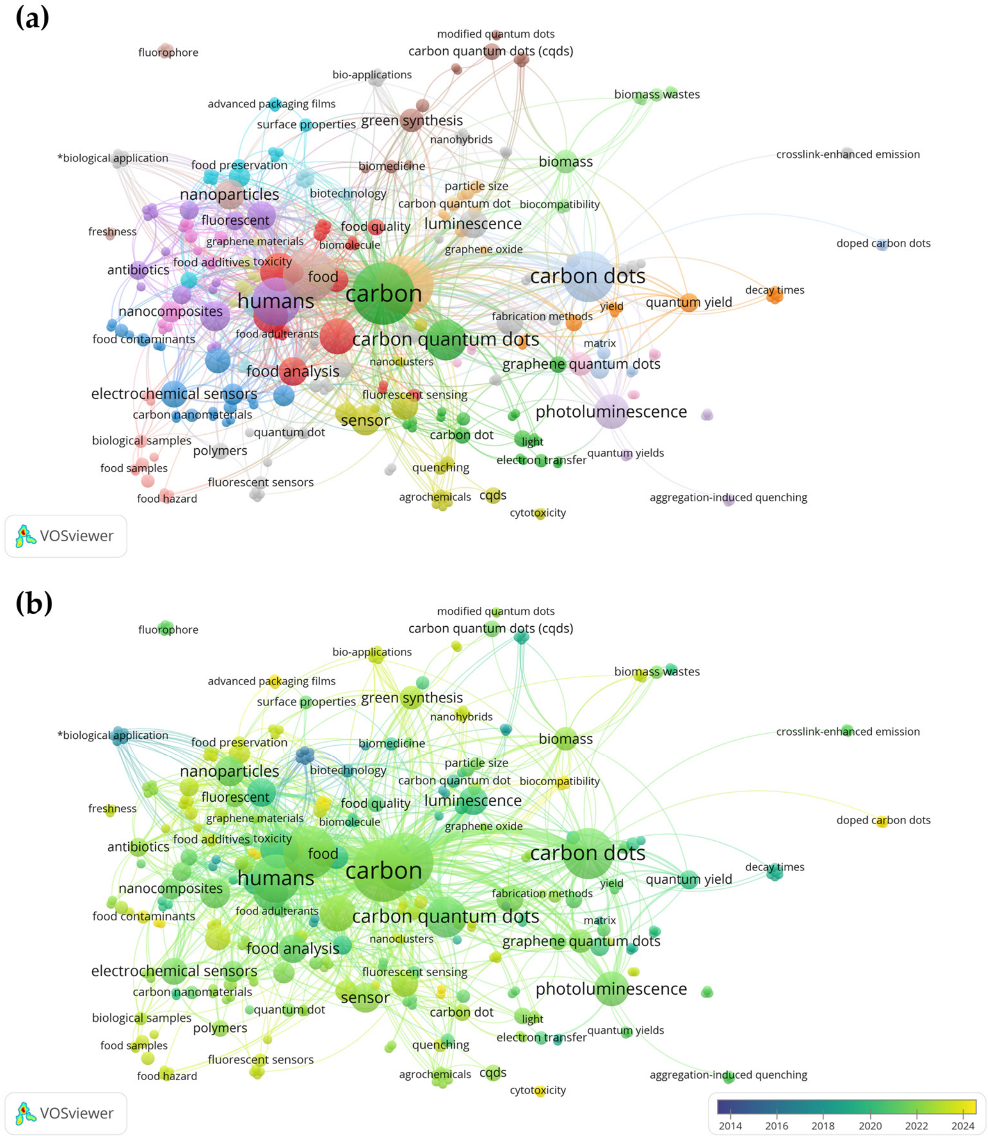

Figure 4. (**a**) The keywords are shown as colored nodes in the network visualization, and the connections between them are shown as edges. This can assist in determining the groups of relevant keywords and the degree of correlation between them. (**b**) The overlay visualization compares different sets of data, such as the co-occurrence of keywords providing an overlay visualization map from 2014 to 2024.

The use of carbon dots at the nanoscale to identify dangerous food additives used to lengthen the shelf life of foods is still not widespread. The practical application of carbon quantum dots for the detection of additives during packing materials must therefore be demonstrated using realistic food samples. Further research should determine the effects of composition, charge, and functional groups on CQDs made from various polymers. Previous scientific studies have demonstrated that the impurity of CQD in samples results in a situation where a significant amount of by-products, such as oligomers and carbon particles, would result. These issues cause CQD applications in food investigation and food safety detection to move at a slower pace. From a detection perspective, future research is required to accomplish the simultaneous determination of numerous pollutants and to stop various contaminants from interfering with one another.

Additionally, there is a need for greater study on carbon QD sensors with low detection limits. Concerning the application's perspective, before detection, complicated food samples require several pre-treatment procedures. As a result, it can be difficult to perform analysis without pre-treatment, and future studies should be improved or omit the pre-treatment step to allow the practical use of these CQDs-based detection approaches. Additionally, while taking into account more food sample blends, more exceptional results should be attained for the more effective detection of trace analytes in food and its products with high specificity and sensitivity.

Great efforts should be made in this regard to improve the sensitivity and selectivity of CQDs-based detectors for the simultaneous detection of multiple analytes in food. Carbon quantum dots are small nanoparticles that can enter the human body by skin inhalation because of their nano size and dimensions, which can have a severe impact on our health. The exceptional applications of CQDs have fascinated researchers and energized them to use nanotechnology in the field of food sciences. Additional CQD-based mixes and high-quality CQDs should be developed to boost their exceptional features in the field of food research as a result of the rapid growth of nanofood technology. Therefore, synthesized CQDs from food waste could have a bright future in food safety and food quality.

7. Conclusions

In conclusion, CQDs are emerging as versatile nanomaterials with remarkable potential across various fields, especially for food safety. CQDs can be synthesized from diverse carbon-rich organic and inorganic sources. Waste from food, agriculture, and industry contains a high content of carboxyl, amino, sulfur, and hydroxyl functional groups, which can be excellent sources for the fabrication of CQDs and offer a wide range of potential practical uses. Environmentally friendly CQDs possess unique physical and chemical properties and enable the efficient detection of food contaminants introduced during processing and packaging. Among fabrication methods, green hydrothermal synthesis attracts attention for its cost-effectiveness, eco-friendliness, and high quantum yield. The functionalized surfaces of CQDs make them highly effective in sensing applications, ensuring food quality and safety. The primary luminescence mechanisms that have been found to cause fluorescence enhancement or quenching are photo-induced electron transfer (PET), fluorescence resonance energy transfer (FRET), and the inner filter effect (IFE). CQDs offer numerous advantages over semiconductor QDs but have a low fluorescent quantum yield (QY), and further research is necessary to fully understand their luminescent or fluorescent mechanisms. For food packaging, the particle size of nanomaterials is a crucial factor that needs to be confirmed as safe and stable throughout its shelf life, as the toxicity of carbon quantum dots increases due to oxidative stress caused by the relative oxygen species, leading to the poisoning of food.

This review highlights the recent advancements in CQDs for food safety, while the limitations have also been addressed to ensure their practical implementation. We also provided bibliometric insights into a decade of research progress (2014–2024). Future efforts should focus on overcoming the current challenges to fully harness CQDs' potential in ensuring global food security. To enable their increased use in the field of food sensing, it is necessary to investigate their lifespan and degradation processes. Moreover, the surface functionalization of carbon dots using certain chemical ligands is a promising approach toward the development of nanoprobes capable of targeting diverse species.

Author Contributions: A.M.: conceptualization, writing—original draft, visualization. K.A.: writing—review and editing, visualization. L.T.: validation, review and editing, assisted in the whole manuscript preparation. W.N. (Waqas Niaz): writing—review and editing. W.N. (Wang Na): visualization and revision. L.H.: editing and revision. J.W.: supervision, validation, funding acquisition. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (No. 41876078) and the Open Fund of Key Laboratory of Marine Ecological Environment Science and Engineering, Ministry of Natural Resources (No. MESE-2019-06).

Data Availability Statement: Data are available ypon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Wu, M.M.H.; Liao, B.; Xia, I.F.; Luk, P.K.H.; Wong, K.; Kwok, K.W.H. Food emulsifiers increase toxicity of food contaminants in three human GI tract cell lines. *Food Chem. Toxicol.* **2024**, *185*, 114499. [CrossRef] [PubMed]
2. Bharagava, R.N.; Saxena, G.; Mulla, S.I. Introduction to Industrial Wastes Containing Organic and Inorganic Pollutants and Bioremediation Approaches for Environmental Management. In *Bioremediation of Industrial Waste for Environmental Safety*; Springer: Singapore, 2020; pp. 1–18. [CrossRef]
3. Bizzo, W.A.; Figueiredo, R.A.; De Andrade, V.F. Characterization of Printed Circuit Boards for Metal and Energy Recovery after Milling and Mechanical Separation. *Materials* **2014**, *7*, 4555–4566. [CrossRef]
4. Siddhuraju, P.; Makkar, H.; Becker, K. The effect of ionising radiation on antinutritional factors and the nutritional value of plant materials with reference to human and animal food. *Food Chem.* **2002**, *78*, 187–205. [CrossRef]
5. Gallardo-Ramos, J.A.; Marín-Sáez, J.; Sanchis, V.; Gámiz-Gracia, L.; García-Campaña, A.M.; Hernández-Mesa, M.; Cano-Sancho, G. Simultaneous detection of mycotoxins and pesticides in human urine samples: A 24-h diet intervention study comparing conventional and organic diets in Spain. *Food Chem. Toxicol.* **2024**, *188*, 114650. [CrossRef] [PubMed]
6. Yue, X.Y.; Zhou, Z.J.; Wu, Y.M.; Li, Y.; Li, J.C.; Bai, Y.H.; Wang, J.L. Application Progress of Fluorescent Carbon Quantum Dots in Food Analysis. *Chin. J. Anal. Chem.* **2020**, *48*, 1288–1296. [CrossRef]
7. Azman, N.H.; Khairul, W.M.; Sarbon, N.M. A comprehensive review on biocompatible film sensor containing natural extract: Active/intelligent food packaging. *Food Control.* **2022**, *141*, 109189. [CrossRef]
8. Atta, O.M.; Manan, S.; Shahzad, A.; Ul-Islam, M.; Ullah, M.W.; Yang, G. Biobased materials for active food packaging: A review. *Food Hydrocoll.* **2022**, *125*, 107419. [CrossRef]
9. Jeddi, M.Z.; Boon, P.E.; Cubadda, F.; Hoogenboom, R.; Mol, H.; Verhagen, H.; Sijm, D.T. A vision on the 'foodture' role of dietary exposure sciences in the interplay between food safety and nutrition. *Trends Food Sci. Technol.* **2022**, *120*, 288–300. [CrossRef]
10. Li, Y.; Hu, Z.; He, L. An approach to develop binary chromatographic fingerprints of the total alkaloids from Caulophyllum robustum by high performance liquid chromatography/diode array detector and gas chromatography/mass spectrometry. *J. Pharm. Biomed. Anal.* **2007**, *43*, 1667–1672. [CrossRef]
11. Li, X.; Wang, C.; Li, P.; Sun, X.; Shao, Z.; Xia, J.; Liu, Q.; Shen, F.; Fang, Y. Beer-derived nitrogen, phosphorus co-doped carbon quantum dots: Highly selective on–off-on fluorescent probes for the detection of ascorbic acid in fruits. *Food Chem.* **2023**, *409*, 135243. [CrossRef] [PubMed]
12. Wang, G.; Zhang, S.; Cui, J.; Gao, W.; Rong, X.; Lu, Y.; Gao, C. Novel highly selective fluorescence sensing strategy for Mercury(II) in water based on nitrogen-doped carbon quantum dots. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2023**, *286*, 122010. [CrossRef] [PubMed]
13. Gong, C.; Fan, Y.; Zhao, H. Recent advances and perspectives of enzyme-based optical biosensing for organophosphorus pesticides detection. *Talanta* **2022**, *240*, 123145. [CrossRef] [PubMed]
14. Clancy, A.J.; Bayazit, M.K.; Hodge, S.A.; Skipper, N.T.; Howard, C.A.; Shaffer, M.S.P. Charged Carbon Nanomaterials: Redox Chemistries of Fullerenes, Carbon Nanotubes, and Graphenes. *Chem. Rev.* **2018**, *118*, 7363–7408. [CrossRef]
15. Rao, R.; Pint, C.L.; Islam, A.E.; Weatherup, R.S.; Hofmann, S.; Meshot, E.R.; Wu, F.; Zhou, C.; Dee, N.; Amama, P.B.; et al. Carbon Nanotubes and Related Nanomaterials: Critical Advances and Challenges for Synthesis toward Mainstream Commercial Applications. *ACS Nano* **2018**, *12*, 11756–11784. [CrossRef] [PubMed]
16. Tohamy HA, S.; El-Sakhawy, M.; Kamel, S. Microwave-assisted synthesis of amphoteric fluorescence carbon quantum dots and their chromium adsorption from aqueous solution. *Sci. Rep.* **2023**, *13*, 11306. [CrossRef] [PubMed]

17. Tohamy, H.A.S. Fluorescence 'Turn-on' Probe for Chromium Reduction, Adsorption and Detection Based on Cellulosic Nitrogen-Doped Carbon Quantum Dots Hydrogels. *Gels* **2024**, *10*, 296. [CrossRef]
18. Pan, M.; Xie, X.; Liu, K.; Yang, J.; Hong, L.; Wang, S. Fluorescent Carbon Quantum Dots—Synthesis, Functionalization and Sensing Application in Food Analysis. *Nanomaterials* **2020**, *10*, 930. [CrossRef]
19. Ni, P.; Chen, C.; Jiang, Y.; Zhang, C.; Wang, B.; Lu, Y.; Wang, H. A fluorescent assay for alkaline phosphatase activity based on inner filter effect by in-situ formation of fluorescent azamonardine. *Sens. Actuators B Chem.* **2020**, *302*, 127145. [CrossRef]
20. Sun, Y.; Zhang, M.; Bhandari, B.; Yang, C. Recent Development of Carbon Quantum Dots: Biological Toxicity, Antibacterial Properties and Application in Foods. *Food Rev. Int.* **2022**, *38*, 1513–1532. [CrossRef]
21. Cao, N.; Zhao, F.; Zeng, B. A novel self-enhanced electrochemiluminescence sensor based on PEI-CdS/Au@SiO2@RuDS and molecularly imprinted polymer for the highly sensitive detection of creatinine. *Sens. Actuators B Chem.* **2020**, *306*, 127591. [CrossRef]
22. Sendão, R.M.S.; Esteves da Silva, J.C.G.; Pinto da Silva, L. Applications of Fluorescent Carbon Dots as Photocatalysts: A Review. *Catalysts* **2023**, *13*, 179. [CrossRef]
23. Ahmad, K.; Khan, S.; Yasin, M.T.; Hussain, S.; Ahmad, R.; Ahmad, N.; Ahmed, M.; Ghani, A.; Faheem, M.; Ullah, H.; et al. Enhanced starch hydrolysis by α-amylase using copper oxide nanowires. *Appl. Nanosci.* **2021**, *11*, 2059–2071. [CrossRef]
24. Yadav, R.; Vikas Lahariya, V.; Tanwar, M.; Kumar, R.; Das, A.; Sadhana, K. A study on the photophysical properties of strong green-fluorescent N-doped carbon dots and application for pH sensing. *Diam. Relat. Mater.* **2023**, *139*, 110411. [CrossRef]
25. Mantashloo, R.; Bahar, S. Synthesis of magnetic graphene quantum dots based molecularly imprinted polymers for fluorescent determination of quercetin. *Microchem. J.* **2023**, *185*, 108233. [CrossRef]
26. Gao, R.; Kodaimati, M.S.; Yan, D. Recent advances in persistent luminescence based on molecular hybrid materials. *Chem. Soc. Rev.* **2021**, *50*, 5564–5589. [CrossRef] [PubMed]
27. Ghosh, S.; Ghosh, A.; Ghosh, G.; Marjit, K.; Patra, A. Deciphering the Relaxation Mechanism of Red-Emitting Carbon Dots Using Ultrafast Spectroscopy and Global Target Analysis. *J. Phys. Chem. Lett.* **2021**, *12*, 8080–8087. [CrossRef]
28. Shilpi, S.; Thakur, A. A Review of the Application of Carbon Quantum Dots. *AIP Conf. Proc.* **2023**, *2535*, 030006.
29. Myint, A.A.; Rhim, W.K.; Nam, J.M.; Kim, J.; Lee, Y.W. Water-soluble, lignin-derived carbon dots with high fluorescent emissions and their applications in bioimaging. *J. Ind. Eng. Chem.* **2018**, *66*, 387–395. [CrossRef]
30. Devi, P.; Kaur, G.; Thakur, A.; Kaur, N.; Grewal, A.; Kumar, P. Waste derivitized blue luminescent carbon quantum dots for selenite sensing in water. *Talanta* **2017**, *170*, 49–55. [CrossRef] [PubMed]
31. Nguyen, T.N.; Le, P.A.; Phung, V.B.T. Facile green synthesis of carbon quantum dots and biomass-derived activated carbon from banana peels: Synthesis and investigation. *Biomass Convers. Biorefinery* **2022**, *12*, 2407–2416. [CrossRef]
32. Ding, H.; Wei, J.S.; Zhang, P.; Zhou, Z.Y.; Gao, Q.Y.; Xiong, H.M. Solvent-Controlled Synthesis of Highly Luminescent Carbon Dots with a Wide Color Gamut and Narrowed Emission Peak Widths. *Small* **2018**, *14*, 1800612. [CrossRef]
33. Yuan, F.; Yuan, T.; Sui, L.; Wang, Z.; Xi, Z.; Li, Y.; Li, X.; Fan, L.; Tan, Z.; Chen, A.; et al. Engineering triangular carbon quantum dots with unprecedented narrow bandwidth emission for multicolored LEDs. *Nat. Commun.* **2018**, *9*, 2249. [CrossRef]
34. Thambiraj, S.; Shankaran, D.R. Green synthesis of highly fluorescent carbon quantum dots from sugarcane bagasse pulp. *Appl. Surf. Sci.* **2016**, *390*, 435–443. [CrossRef]
35. Kasinathan, K.; Samayanan, S.; Marimuthu, K.; Yim, J.H. Green synthesis of multicolour fluorescence carbon quantum dots from sugarcane waste: Investigation of mercury (II) ion sensing, and bio-imaging applications. *Appl. Surf. Sci.* **2022**, *601*, 154266. [CrossRef]
36. Sadegh Hassani, S.; Daraee, M.; Navazani, S.h.; Rahimi, F. Carbon-based Quantum Dots from Food Waste: Synthesis to Application in Food Safety. *Quantum Dots Bioanal. Chem. Med.* **2023**, *22*, 275–306. [CrossRef]
37. Tolou-Shikhzadeh-Yazdi, S.; Shakibapour, N.; Hosseini, S.; Mokaberi, P.; Malaekeh-Nikouei, B.; Chamani, J. High-efficient synthesis of carbon quantum dots from orange pericarp as fluorescence turn-on probes for Ca^{2+} and Zn^{2+} ion detection and their application in trypsin activity characterization. *Iran. J. Basic Med. Sci.* **2023**, *26*, 190–199. [CrossRef] [PubMed]
38. Olmos-Moya, P.M.; Velazquez-Martinez, S.; Pineda-Arellano, C.; Rangel-Mendez, J.R.; Chazaro-Ruiz, L.F. High added value functionalized carbon quantum dots synthetized from orange peels by assisted microwave solvothermal method and their performance as photosensitizer of mesoporous TiO2 photoelectrodes. *Carbon* **2022**, *187*, 216–229. [CrossRef]
39. Vandarkuzhali, S.A.A.; Natarajan, S.; Jeyabalan, S.; Sivaraman, G.; Singaravadivel, S.; Muthusubramanian, S.; Viswanathan, B. Pineapple Peel-Derived Carbon Dots: Applications as Sensor, Molecular Keypad Lock, and Memory Device. *ACS Omega* **2018**, *3*, 12584–12592. [CrossRef] [PubMed]
40. Kumar, H.; Bhardwaj, K.; Sharma, R.; Nepovimova, E.; Kuča, K.; Dhanjal, D.S.; Verma, R.; Bhardwaj, P.; Sharma, S.; Kumar, D. Fruit and Vegetable Peels: Utilization of High Value Horticultural Waste in Novel Industrial Applications. *Molecules* **2020**, *25*, 2812. [CrossRef]

41. Wu, C.; Zhou, T.; Gao, Z.; Li, M.; Zhou, Q.; Zhao, W. Sensitive and smartphone-assisted visual detection of oxytetracycline by a ratiometric fluorescence sensor based on nitrogen-doped carbon quantum dots from banana peel cooperating with europium. *Microchem. J.* **2023**, *194*, 109283. [CrossRef]
42. Shi, J.; Zhou, Y.; Ning, J.; Hu, G.; Zhang, Q.; Hou, Y.; Zhou, Y. Prepared carbon dots from wheat straw for detection of Cu2+ in cells and zebrafish and room temperature phosphorescent anti-counterfeiting. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2022**, *281*, 121597. [CrossRef]
43. Šafranko, S.; Goman, D.; Stanković, A.; Medvidović-Kosanović, M.; Moslavac, T.; Jerković, I.; Jokić, S. An Overview of the Recent Developments in Carbon Quantum Dots—Promising Nanomaterials for Metal Ion Detection and (Bio)Molecule Sensing. *Chemosensors* **2021**, *9*, 138. [CrossRef]
44. Ezati, P.; Priyadarshi, R.; Rhim, J.W. Prospects of sustainable and renewable source-based carbon quantum dots for food packaging applications. *Sustain. Mater. Technol.* **2022**, *33*, e00494. [CrossRef]
45. Jorn-Am, T.; Supchocksoonthorn, P.; Pholauyphon, W.; Manyam, J.; Chanthad, C.; Paoprasert, P. Quasi-Solid, Bio-Renewable Supercapacitors Based on Cassava Peel and Cassava Starch and the Use of Carbon Dots as Performance Enhancers. *Energy Fuels* **2022**, *36*, 7865–7877. [CrossRef]
46. Kumar, J.V.; Rhim, J.W. Fluorescent carbon quantum dots for food contaminants detection applications. *J. Environ. Chem. Eng.* **2024**, *12*, 111999. [CrossRef]
47. Al Kiey, S.A.; Tohamy, H.A.S. Sustainable energy harvesting: Manganese oxide-decorated carbon quantum dots derived from agriculture for high-performance supercapacitors. *J. Energy Storage* **2024**, *101*, 113758. [CrossRef]
48. de Oliveira, B.P.; da Silva Abreu, F.O.M. Carbon quantum dots synthesis from waste and by-products: Perspectives and challenges. *Mater. Lett.* **2021**, *282*, 128764. [CrossRef]
49. Zhang, R.; Liu, Y.; Yu, L.; Li, Z.; Sun, S. Preparation of high-quality biocompatible carbon dots by extraction, with new thoughts on the luminescence mechanisms. *Nanotechnology* **2013**, *24*, 225601. [CrossRef] [PubMed]
50. Huang, C.; Dong, H.; Su, Y.; Wu, Y.; Narron, R.; Yong, Q. Synthesis of Carbon Quantum Dot Nanoparticles Derived from Byproducts in Bio-Refinery Process for Cell Imaging and In Vivo Bioimaging. *Nanomaterials* **2019**, *9*, 387. [CrossRef]
51. Omran, B.A.; Whitehead, K.A.; Baek, K.H. One-pot bioinspired synthesis of fluorescent metal chalcogenide and carbon quantum dots: Applications and potential biotoxicity. *Colloids Surf. B Biointerfaces* **2021**, *200*, 111578. [CrossRef] [PubMed]
52. Sharma, A.S.; Ali, S.; Sabarinathan, D.; Murugavelu, M.; Li, H.; Chen, Q. Recent progress on graphene quantum dots-based fluorescence sensors for food safety and quality assessment applications. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 5765–5801. [CrossRef] [PubMed]
53. Xu, Z.; Yu, J.; Liu, G. Fabrication of carbon quantum dots and their application for efficient detecting Ru(bpy)32+ in the solution. *Sens. Actuators B Chem.* **2013**, *181*, 209–214. [CrossRef]
54. Hu, S.; Wei, Z.; Chang, Q.; Trinchi, A.; Yang, J. A facile and green method towards coal-based fluorescent carbon dots with photocatalytic activity. *Appl. Surf. Sci.* **2016**, *378*, 402–407. [CrossRef]
55. Liu, H.; Ye, T.; Mao, C. Fluorescent Carbon Nanoparticles Derived from Candle Soot. *Angew. Chem.* **2007**, *119*, 6593–6595. [CrossRef]
56. Calabro, R.L.; Yang, D.S.; Kim, D.Y. Liquid-phase laser ablation synthesis of graphene quantum dots from carbon nano-onions: Comparison with chemical oxidation. *J. Colloid Interface Sci.* **2018**, *527*, 132–140. [CrossRef]
57. Xu, X.; Ray, R.; Gu, Y.; Ploehn, H.J.; Gearheart, L.; Raker, K.; Scrivens, W.A. Electrophoretic Analysis and Purification of Fluorescent Single-Walled Carbon Nanotube Fragments. *J. Am. Chem. Soc.* **2004**, *126*, 12736–12737. [CrossRef] [PubMed]
58. Sun, Y.P.; Zhou, B.; Lin, Y.; Wang, W.; Fernando, K.A.S.; Pathak, P.; Meziani, M.J.; Harruff, B.A.; Wang, X.; Wang, H.; et al. Quantum-sized carbon dots for bright and colorful photoluminescence. *J. Am. Chem. Soc.* **2006**, *128*, 7756–7757. [CrossRef]
59. Yatom, S.; Bak, J.; Khrabryi, A.; Raitses, Y. Detection of nanoparticles in carbon arc discharge with laser-induced incandescence. *Carbon* **2017**, *117*, 154–162. [CrossRef]
60. Nair, R.V.; Thomas, R.T.; Sankar, V.; Muhammad, H.; Dong, M.; Pillai, S. Rapid, Acid-Free Synthesis of High-Quality Graphene Quantum Dots for Aggregation Induced Sensing of Metal Ions and Bioimaging. *ACS Omega* **2017**, *2*, 8051–8061. [CrossRef]
61. Wang, N.; Fan, H.; Sun, J.; Han, Z.; Dong, J.; Ai, S. Fluorine-doped carbon nitride quantum dots: Ethylene glycol-assisted synthesis, fluorescent properties, and their application for bacterial imaging. *Carbon* **2016**, *109*, 141–148. [CrossRef]
62. Zhu, H.; Wang, X.; Li, Y.; Wang, Z.; Yang, F.; Yang, X. Microwave synthesis of fluorescent carbon nanoparticles with electrochemiluminescence properties. *Chem. Commun.* **2009**, *34*, 5118–5120. [CrossRef] [PubMed]
63. Li, H.; Shao, F.Q.; Huang, H.; Feng, J.J.; Wang, A.J. Eco-friendly and rapid microwave synthesis of green fluorescent graphitic carbon nitride quantum dots for vitro bioimaging. *Sens. Actuators B Chem.* **2016**, *226*, 506–511. [CrossRef]
64. Zhou, J.; Yang, Y.; Zhang, C.Y. A low-temperature solid-phase method to synthesize highly fluorescent carbon nitride dots with tunable emission. *Chem. Commun.* **2013**, *49*, 8605–8607. [CrossRef] [PubMed]
65. Fan, X.; Feng, Y.; Su, Y.; Zhang, L.; Lv, Y. A green solid-phase method for preparation of carbon nitride quantum dots and their applications in chemiluminescent dopamine sensing. *RSC Adv.* **2015**, *5*, 55158–55164. [CrossRef]

66. Doñate-Buendia, C.; Torres-Mendieta, R.; Pyatenko, A.; Falomir, E.; Fernández-Alonso, M.; Mínguez-Vega, G. Fabrication by Laser Irradiation in a Continuous Flow Jet of Carbon Quantum Dots for Fluorescence Imaging. *ACS Omega* **2018**, *3*, 2735–2742. [CrossRef]
67. Yang, S.; Li, Y.; Chen, L.; Wang, H.; Shang, L.; He, P.; Dong, H.; Wang, G.; Ding, G. Fabrication of Carbon-Based Quantum Dots via a "Bottom-Up" Approach: Topology, Chirality, and Free Radical Processes in "Building Blocks". *Small* **2023**, *19*, 2205957. [CrossRef] [PubMed]
68. Kagdada, H.L.; Bhojani, A.K.; Singh, D.K. An Overview of Nanomaterials: History, Fundamentals, and Applications. In *Nanomaterials: Advances and Applications*; Springer: Singapore, 2023; pp. 1–26. [CrossRef]
69. Hu, S.-L.; Niu, K.-Y.; Sun, J.; Yang, J.; Zhao, N.-Q.; Du, X.-W. One-step synthesis of fluorescent carbon nanoparticles by laser irradiation. *J. Mater. Chem.* **2009**, *19*, 484–488. [CrossRef]
70. Russo, P.; Liang, R.; Jabari, E.; Marzbanrad, E.; Toyserkani, E.; Zhou, Y.N. Single-step synthesis of graphene quantum dots by femtosecond laser ablation of graphene oxide dispersions. *Nanoscale* **2016**, *8*, 8863–8877. [CrossRef] [PubMed]
71. Chao-Mujica, F.J.; Garcia-Hernández, L.; Camacho-López, S.; Camacho-López, M.A.; Contreras, D.R.; Pérez-Rodríguez, A.; Peña-Caravaca, J.P.; Darias-Gonzalez, J.G.; Hernandez-Tabares, L.; de Fuentes, O.A.; et al. Carbon quantum dots by submerged arc discharge in water: Synthesis, characterization, and mechanism of formation. *J. Appl. Phys.* **2021**, *129*, 163301. [CrossRef]
72. Yang, S.; Sun, J.; Li, X.; Zhou, W.; Wang, Z.; He, P.; Ding, G.; Xie, X.; Kang, Z.; Jiang, M. Large-scale fabrication of heavy doped carbon quantum dots with tunable-photoluminescence and sensitive fluorescence detection. *J. Mater. Chem. A* **2014**, *2*, 8660–8667. [CrossRef]
73. Shabbir, H.; Tokarski, T.; Ungor, D.; Wojnicki, M. Eco Friendly Synthesis of Carbon Dot by Hydrothermal Method for Metal Ions Salt Identification. *Materials* **2021**, *14*, 7604. [CrossRef]
74. Du, F.; Cheng, Z.; Wang, G.; Li, M.; Lu, W.; Shuang, S.; Dong, C. Carbon Nanodots as a Multifunctional Fluorescent Sensing Platform for Ratiometric Determination of Vitamin B2and "turn-Off" Detection of pH. *J. Agric. Food Chem.* **2021**, *69*, 2836–2844. [CrossRef] [PubMed]
75. Magdy, G.; Belal, F.; Elmansi, H. Rapid microwave-assisted synthesis of nitrogen-doped carbon quantum dots as fluorescent nanosensors for the spectrofluorimetric determination of palbociclib: Application for cellular imaging and selective probing in living cancer cells. *RSC Adv.* **2023**, *13*, 4156–4167. [CrossRef]
76. Nazari, Z.; Hadi Nematollahi, M.; Zareh, F.; Pouramiri, B.; Mehrabani, M. An Electrochemical Sensor Based on Carbon Quantum Dots and Ionic Liquids for Selective Detection of Dopamine. *ChemistrySelect* **2023**, *8*, e202203630. [CrossRef]
77. Shorgar, N.; Bhati, I.; Jhalora, P. Laser ablation synthesis of quantum dots. *Quantum Dots Fundam. Synth. Appl.* **2023**, 53–75. [CrossRef]
78. Li, X.; Wang, H.; Shimizu, Y.; Pyatenko, A.; Kawaguchi, K.; Koshizaki, N. Preparation of carbon quantum dots with tunable photoluminescence by rapid laser passivation in ordinary organic solvents. *Chem. Commun.* **2010**, *47*, 932–934. [CrossRef] [PubMed]
79. Latha, B.D.; Soumya, K.; More, N.; Mounika, C.; Guduru, A.T.; Singh, G.; Kapusetti, G. Fluorescent carbon quantum dots for effective tumor diagnosis: A comprehensive review. *Biomed. Eng. Adv.* **2023**, *5*, 100072. [CrossRef]
80. Sikiru, S.; Oladosu, T.L.; Kolawole, S.Y.; Mubarak, L.A.; Soleimani, H.; Afolabi, L.O.; Oluwafunke Toyin, A.O. Advance and prospect of carbon quantum dots synthesis for energy conversion and storage application: A comprehensive review. *J. Energy Storage* **2023**, *60*, 106556. [CrossRef]
81. Niu, C.; Yao, Z.; Jiang, S. Synthesis and application of quantum dots in detection of environmental contaminants in food: A comprehensive review. *Sci. Total Environ.* **2023**, *882*, 163565. [CrossRef]
82. Deng, J.; Lu, Q.; Li, H.; Zhang, Y.; Yao, S. Large scale preparation of graphene quantum dots from graphite oxide in pure water via one-step electrochemical tailoring. *RSC Advances* **2015**, *5*, 29704–29707. [CrossRef]
83. Liu, M.; Xu, Y.; Niu, F.; Gooding, J.J.; Liu, J. Carbon quantum dots directly generated from electrochemical oxidation of graphite electrodes in alkaline alcohols and the applications for specific ferric ion detection and cell imaging. *Analyst* **2016**, *141*, 2657–2664. [CrossRef] [PubMed]
84. Tan, X.; Li, Y.; Li, X.; Zhou, S.; Fan, L.; Yang, S. Electrochemical synthesis of small-sized red fluorescent graphene quantum dots as a bioimaging platform. *Chem. Commun.* **2015**, *51*, 2544–2546. [CrossRef]
85. Borna, S.; Sabzi, R.E.; Pirsa, S. Synthesis of carbon quantum dots from apple juice and graphite: Investigation of fluorescence and structural properties and use as an electrochemical sensor for measuring Letrozole. *J. Mater. Sci. Mater. Electron.* **2021**, *32*, 10866–10879. [CrossRef]
86. Shen, P.; Xia, Y. Synthesis-modification integration: One-step fabrication of boronic acid functionalized carbon dots for fluorescent blood sugar sensing. *Anal. Chem.* **2014**, *86*, 5323–5329. [CrossRef] [PubMed]
87. Peng, H.; Travas-Sejdic, J. Simple aqueous solution route to luminescent carbogenic dots from carbohydrates. *Chem. Mater.* **2009**, *21*, 5563–5565. [CrossRef]

88. Ray, S.C.; Saha, A.; Jana, N.R.; Sarkar, R. Fluorescent carbon nanoparticles: Synthesis, characterization, and bioimaging application. *J. Phys. Chem. C* **2009**, *113*, 18546–18551. [CrossRef]
89. Anwar, S.; Ding, H.; Xu, M.; Hu, X.; Li, Z.; Wang, J.; Liu, L.; Jiang, L.; Wang, D.; Dong, C.; et al. Recent Advances in Synthesis, Optical Properties, and Biomedical Applications of Carbon Dots. *ACS Appl. Bio Mater.* **2019**, *2*, 2317–2338. [CrossRef] [PubMed]
90. Theerthagiri, J.; Madhavan, J.; Lee, S.J.; Choi, M.Y.; Ashokkumar, M.; Pollet, B.G. Sonoelectrochemistry for energy and environmental applications. *Ultrason. Sonochemistry* **2020**, *63*, 104960. [CrossRef]
91. Wang, R.; Lu, K.Q.; Tang, Z.R.; Xu, Y.J. Recent progress in carbon quantum dots: Synthesis, properties and applications in photocatalysis. *J. Mater. Chem. A* **2017**, *5*, 3717–3734. [CrossRef]
92. Park, S.Y.; Lee, H.U.; Park, E.S.; Lee, S.C.; Lee, J.W.; Jeong, S.W.; Kim, C.H.; Lee, Y.-C.; Huh, Y.S.; Lee, J. Photoluminescent green carbon nanodots from food-waste-derived sources: Large-scale synthesis, properties, and biomedical applications. *ACS Appl. Mater. Interfaces* **2014**, *6*, 3365–3370. [CrossRef]
93. Li, H.; He, X.; Liu, Y.; Yu, H.; Kang, Z.; Lee, S.T. Synthesis of fluorescent carbon nanoparticles directly from active carbon via a one-step ultrasonic treatment. *Mater. Res. Bull.* **2011**, *46*, 147–151. [CrossRef]
94. Jhonsi, M.A. Carbon Quantum Dots for Bioimaging. In *State of the Art in Nano-Bioimaging*; IntechOpen: London, UK, 2018. [CrossRef]
95. Otoni, C.G.; Azeredo, H.M.C.; Mattos, B.D.; Beaumont, M.; Correa, D.S.; Rojas, O.J. The Food–Materials Nexus: Next Generation Bioplastics and Advanced Materials from Agri-Food Residues. *Adv. Mater.* **2021**, *33*, 2102520. [CrossRef] [PubMed]
96. Suriapparao, D.V.; Tejasvi, R. A review on role of process parameters on pyrolysis of biomass and plastics: Present scope and future opportunities in conventional and microwave-assisted pyrolysis technologies. *Process Saf. Environ. Prot.* **2022**, *162*, 435–462. [CrossRef]
97. Zhou, X.; Zhao, S.; Zhang, J.; Xiang, G.; Jiang, S.; Li, L.; Wang, Y.; Li, Y.; Jing, C.; Yao, L.; et al. FA+ and Mn^{2+} codoped CsPbCl3 perovskite quantum dots with super thermal stability. *Ceram. Int.* **2023**, *49*, 1002–1008. [CrossRef]
98. Ludmerczki, R.; Mura, S.; Carbonaro, C.M.; Mandity, I.M.; Carraro, M.; Senes, N.; Garroni, S.; Granozzi, G.; Calvillo, L.; Marras, S.; et al. Carbon Dots from Citric Acid and its Intermediates Formed by Thermal Decomposition. *Chem. —A Eur. J.* **2019**, *25*, 11963–11974. [CrossRef]
99. Desai, M.L.; Ravani, A.G. Carbon dots in food analysis. *Carbon Dots Anal. Chem. Detect. Imaging* **2023**, 293–303. [CrossRef]
100. Manzoor, S.; Dar, A.H.; Dash, K.K.; Pandey, V.K.; Srivastava, S.; Bashir, I.; Khan, S.A. Carbon dots applications for development of sustainable technologies for food safety: A comprehensive review. *Appl. Food Res.* **2023**, *3*, 100263. [CrossRef]
101. Nagarajan, D.; Gangadharan, D.; Venkatanarasimhan, S. Synthetic strategies toward developing carbon dots via top-down approach. *Carbon Dots Anal. Chem. Detect. Imaging* **2023**, 1–13. [CrossRef]
102. Abdelhamid, H.N. Carbon dots for electrochemical analytical methods. *Carbon Dots Anal. Chem. Detect. Imaging* **2023**, 77–86. [CrossRef]
103. Yang, X.; Feng, M.; Zhang, X.; Huang, Y. Co,N,S co-doped hollow carbon with efficient oxidase-like activity for the detection of Hg^{2+} and Fe^{3+} ions. *Microchem. J.* **2023**, *187*, 108383. [CrossRef]
104. Fu, W.-J.; Peng, Z.-X.; Dai, Y.; Yang, Y.-F.; Song, J.-Y.; Sun, W.; Ding, B.; Gu, H.-W.; Yin, X.-L. Highly fluorescent N doped C-dots as sensor for selective detection of Hg2+ in beverages. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2022**, *265*, 120392. [CrossRef]
105. Mir, T.G.; Shukla, S.; Malik, A.Q.; Singh, J.; Kumar, D. Microwave-assisted synthesis of N-doped carbon quantum dots for detection of methyl orange in saffron. *Chem. Pap.* **2023**, *77*, 3641–3649. [CrossRef]
106. Yu, C.; Zhuang, Q.; Cui, H.; Li, L.; Ding, Y.; Lin, J.; Duan, Y. A Fluorescent "Turn-off" Probe for the Determination of Curcumin Using Upconvert Luminescent Carbon Dots. *J. Fluoresc.* **2020**, *30*, 1469–1476. [CrossRef] [PubMed]
107. 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]
108. 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 fluorometric sensor for the detection of chlorpyrifos. *Microchem. J.* **2022**, *172*, 106953. [CrossRef]
109. Zhang, Y.; Wang, S.; Zhang, Y.; Pang, G.; Guo, S. Tuning the Aggregation/Disaggregation Behavior of Graphene Quantum Dots by Structure-Switching Aptamer for High-Sensitivity Fluorescent Ochratoxin A Sensor. *Anal. Chem.* **2017**, *89*, 1704–1709. [CrossRef]
110. Li, Q.; Du, H.; Li, J.; Deng, J.; Wang, R.; Chen, Y. Sulfur-rich carbon quantum dots based on Alternanthera philoxeroides and thiourea for the detection of tartrazine. *J. Mater. Sci. Mater. Electron.* **2022**, *33*, 12808–12818. [CrossRef]
111. Dai, H.; Shi, Y.; Wang, Y.; Sun, Y.; Hu, J.; Ni, P.; Li, Z. A carbon dot based biosensor for melamine detection by fluorescence resonance energy transfer. *Sens. Actuators B Chem.* **2014**, *202*, 201–208. [CrossRef]

112. Sistani, S.; Shekarchizadeh, H. Fabrication of fluorescence sensor based on molecularly imprinted polymer on amine-modified carbon quantum dots for fast and highly sensitive and selective detection of tannic acid in food samples. *Anal. Chim. Acta* **2021**, *1186*, 339122. [CrossRef]
113. Carneiro, S.; Holanda, M.; Cunha, H.; Oliveira, J.; Pontes, S.; Cruz, A.; Fechine, L.; Moura, T.; Paschoal, A.; Zambelli, R.; et al. Highly sensitive sensing of food additives based on fluorescent carbon quantum dots. *J. Photochem. Photobiol. A Chem.* **2021**, *411*, 113198. [CrossRef]
114. Han, Z.; Long, Y.; Pan, S.; Liu, H.; Yang, J.; Hu, X. Efficient one-pot synthesis of carbon dots as a fluorescent probe for the selective and sensitive detection of rifampicin based on the inner filter effect. *Anal. Methods* **2018**, *10*, 4085–4093. [CrossRef]
115. Peng, H.L.; Callender, R. Mechanism for Fluorescence Quenching of Tryptophan by Oxamate and Pyruvate: Conjugation and Solvation-Induced Photoinduced Electron Transfer. *J. Phys. Chem. B* **2018**, *122*, 6483–6490. [CrossRef]
116. Pal, C.A.; Lingamdinne, L.P.; Chang, Y.Y.; Koduru, J.R. Carbon dots as adsorbents for removal of toxic chemicals. *Carbon Dots Anal. Chem. Detect. Imaging* **2023**, 161–180. [CrossRef]
117. Borges, L.P.S.L.; de Carvalho, K.M.B.; da Costa, T.H.M. Usual dietary intake, physical activity, weight loss, and body composition after five years of Roux-en-Y gastric bypass. *Int. J. Obes.* **2023**, *47*, 263–272. [CrossRef] [PubMed]
118. Kainth, S.; Maity, B.; Shetti, N.P.; Basu, S.; Kakarla, R.R. Dual emissive carbon dots: Synthesis strategies, properties and its ratiometric sensing applications. *Nano-Struct. Nano-Objects* **2023**, *33*, 100931. [CrossRef]
119. Bellanco, A.; Celcar, Š.; Martínez-Cuesta, M.C.; Requena, T. The food additive xylitol enhances the butyrate formation by the child gut microbiota developed in a dynamic colonic simulator. *Food Chem. Toxicol.* **2024**, *187*, 114605. [CrossRef]
120. Li, H.; Zhao, L.; Xu, Y.; Zhou, T.; Liu, H.; Huang, N.; Ding, J.; Li, Y.; Ding, L. Single-hole hollow molecularly imprinted polymer embedded carbon dot for fast detection of tetracycline in honey. *Talanta* **2018**, *185*, 542–549. [CrossRef] [PubMed]
121. Qiao, G.; Lu, D.; Tang, Y.; Gao, J.; Wang, Q. Smart choice of carbon dots as a dual-mode onsite nanoplatform for the trace level detection of Cr2O72-. *Dye. Pigment.* **2019**, *163*, 102–110. [CrossRef]
122. Wang, C.; Tan, R.; Chen, D. Fluorescence method for quickly detecting ochratoxin A in flour and beer using nitrogen doped carbon dots and silver nanoparticles. *Talanta* **2018**, *182*, 363–370. [CrossRef]
123. Gong, Y.; Zhao, J. Small Carbon Quantum Dots, Large Photosynthesis Enhancement. *J. Agric. Food Chem.* **2018**, *66*, 9159–9161. [CrossRef] [PubMed]
124. 61 Sharma, S.; Umar, A.; Sood, S.; Mehta, S.K.; Kansal, S.K. Photoluminescent C-dots: An overview on the recent development in the synthesis, physiochemical properties and potential applications. *J. Alloys Compd.* **2018**, *748*, 818–853. [CrossRef]
125. Yang, M.; de Albuquerque, J.C.; Silva, E.D.; Silva, M.L. On the critical cases of linearly coupled Choquard systems. *Appl. Math. Lett.* **2019**, *91*, 1–8. [CrossRef]
126. Han, Y.; Yang, W.; Luo, X.; He, X.; Yu, Y.; Li, C.; Tang, W.; Yue, T.; Li, Z. Cu^{2+}-Triggered Carbon Dots with Synchronous Response of Dual Emission for Ultrasensitive Ratiometric Fluorescence Determination of Thiophanate-Methyl Residues. *J. Agric. Food Chem.* **2019**, *67*, 12576–12583. [CrossRef]
127. Lang, Y.; Zhang, B.; Cai, D.; Tu, W.; Zhang, J.; Shentu, X.; Ye, Z.; Yu, X. Determination Methods of the Risk Factors in Food Based on Nanozymes: A Review. *Biosensors* **2022**, *13*, 69. [CrossRef] [PubMed]
128. Song, P.; Zhang, L.; Long, H.; Meng, M.; Liu, T.; Yin, Y.; Xi, R. A multianalyte fluorescent carbon dots sensing system constructed based on specific recognition of Fe(III) ions. *RSC Adv.* **2017**, *7*, 28637–28646. [CrossRef]
129. Zhou, Y.; Liu, Y.; Li, Y.; He, Z.; Xu, Q.; Chen, Y.; Street, J.; Guo, H.; Nelles, M. Multicolor carbon nanodots from food waste and their heavy metal ion detection application. *RSC Adv.* **2018**, *8*, 23657–23662. [CrossRef] [PubMed]
130. Gedda, G.; Lee, C.Y.; Lin, Y.C.; Wu, H.F. Green synthesis of carbon dots from prawn shells for highly selective and sensitive detection of copper ions. *Sens. Actuators B Chem.* **2016**, *224*, 396–403. [CrossRef]
131. Xu, Y.; Fan, Y.; Zhang, L.; Wang, Q.; Fu, H.; She, Y. A novel enhanced fluorescence method based on multifunctional carbon dots for specific detection of Hg2+ in complex samples. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2019**, *220*, 117109. [CrossRef] [PubMed]
132. Zou, C.; Liu, Z.; Wang, X.; Liu, H.; Yang, M.; Huo, D.; Hou, C. A paper-based visualization chip based on nitrogen-doped carbon quantum dots nanoprobe for Hg(II) detection. *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* **2022**, *265*, 120346. [CrossRef]
133. Pozdnyakova, N.; Krisanova, N.; Pastukhov, A.; Dudarenko, M.; Tarasenko, A.; Borysov, A.; Kalynovska, L.; Paliienko, K.; Borisova, T. Multipollutant reciprocal neurological hazard from smoke particulate matter and heavy metals cadmium and lead in brain nerve terminals. *Food Chem. Toxicol.* **2024**, *185*, 114449. [CrossRef]
134. Pizarro, J.; Segura, R.; Tapia, D.; Navarro, F.; Fuenzalida, F.; Jesús Aguirre, M. Inexpensive and green electrochemical sensor for the determination of Cd(II) and Pb(II) by square wave anodic stripping voltammetry in bivalve mollusks. *Food Chem.* **2020**, *321*, 126682. [CrossRef] [PubMed]
135. Ghataty, D.S.; Amer, R.I.; Amer, M.A.; Abdel Rahman, M.F.; Shamma, R.N. Green Synthesis of Highly Fluorescent Carbon Dots from Bovine Serum Albumin for Linezolid Drug Delivery as Potential Wound Healing Biomaterial: Bio-Synergistic Approach, Antibacterial Activity, and In Vitro and Ex Vivo Evaluation. *Pharmaceutics* **2023**, *15*, 234. [CrossRef] [PubMed]

136. He, K.; Zhan, X.; Liu, L.; Ruan, X.; Wu, Y. Ratiometric Fluorescent Paper-Based Sensor Based on CdTe Quantum Dots and Graphite Carbon Nitride Hybrid for Visual and Rapid Determination of Cu^{2+} in Drinks. *Photochem. Photobiol.* **2020**, *96*, 1154–1160. [CrossRef]
137. Mitchell, C.T.; Bridgeman, L.; Moyano-López, C.; Penalva-Olcina, R.; Juan, C.; Juan-García, A. Study of cytotoxicity in neuroblastoma cell line exposed to patulin and citrinin. *Food Chem. Toxicol.* **2024**, *186*, 114556. [CrossRef] [PubMed]
138. Liu, L.; Mi, Z.; Hu, Q.; Li, C.; Li, X.; Feng, F. Green synthesis of fluorescent carbon dots as an effective fluorescence probe for morin detection. *Anal. Methods* **2019**, *11*, 353–358. [CrossRef]
139. John, V.L.; Nair, Y.; Vinod, T.P. Doping and Surface Modification of Carbon Quantum Dots for Enhanced Functionalities and Related Applications. *Part. Part. Syst. Charact.* **2021**, *38*, 2100170. [CrossRef]
140. Luo, X.; Han, Y.; Chen, X.; Tang, W.; Yue, T.; Li, Z. Carbon dots derived fluorescent nanosensors as versatile tools for food quality and safety assessment: A review. *Trends Food Sci. Technol.* **2020**, *95*, 149–161. [CrossRef]
141. Shaik, S.A.; Sengupta, S.; Varma, R.S.; Gawande, M.B.; Goswami, A. Syntheses of N-Doped Carbon Quantum Dots (NCQDs) from Bioderived Precursors: A Timely Update. *ACS Sustain. Chem. Eng.* **2021**, *9*, 3–49. [CrossRef]
142. Mandal, S. Elucidating carbon dot research coupled with bibliometric analysis. *Next Res.* **2024**, *1*, 100051. [CrossRef]
143. Umar, E.; Ikram, M.; Haider, J.; Nabgan, W.; Haider, A.; Imran, M.; Nazir, G. A state-of-the-art review on carbon quantum dots: Prospective, advances, zebrafish biocompatibility and bioimaging in vivo and bibliometric analysis. *Sustain. Mater. Technol.* **2023**, *35*, e00529. [CrossRef]