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Overview of Biomass Hydrothermal Techniques for Carbon Quantum Dots Synthesis: Mini Review

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Abstract
The aim of this study is to provide a comprehensive overview of various biomass hydrothermal techniques used in the synthesis of carbon quantum dots (CQDs), as well as to identify recent developments in this field. Careful literature search methods were employed to gather information related to biomass hydrothermal techniques and CQD synthesis, applying inclusion and exclusion criteria to select articles that align with the research focus. Data analysis approaches were used to organize and present relevant information. The main findings of this review encompass a range of hydrothermal techniques used in CQD synthesis, including diverse biomass feedstocks and process parameters influencing the final outcomes. Furthermore, the review also reveals recent advancements in CQD applications, such as in photocatalysis, biomedicine, and optoelectronics. The findings of this review have significant implications for further development in CQD synthesis using biomass hydrothermal techniques, with the potential application of this technology in various high-tech fields, including renewable energy, biomedicine, and sensing. Overall, this review provides an in-depth understanding of recent advancements in biomass hydrothermal techniques for CQD synthesis, highlighting the substantial potential of this research in supporting innovation across various application domains.

Keywords: *Biomass hydrothermal techniques, CQDs, synthesis, applications*

1. Introduction

Carbon quantum dots (CQDs), nanometer-sized carbon-based materials, have garnered significant attention in the realm of nanotechnology due to their unique properties and wide-ranging applications (1). These properties include exceptional photoluminescence, biocompatibility, chemical stability, and low toxicity, rendering them promising candidates for various fields such as optoelectronics, bioimaging, sensing, catalysis, and drug delivery (2). The synthesis of CQDs has been predominantly achieved through bottom-up and top-down approaches, each offering distinct advantages and challenges.

The exploration of efficient and sustainable methods for synthesizing CQDs is imperative to meet the growing demand for advanced nanomaterials with tailored properties. Biomass, comprising organic matter derived from plants, animals, and microorganisms, has emerged as a promising precursor for CQD synthesis due to its abundance, renewability, and diverse chemical composition (3). Biomass hydrothermal techniques, which involve subjecting biomass-derived precursors to high-temperature and high-pressure conditions in an aqueous environment, offer a greener and more cost-effective alternative to conventional synthesis methods (4). The utilization of biomass as a precursor not only addresses environmental concerns associated with conventional carbon sources but also introduces unique chemical functionalities into the resulting CQDs, thereby expanding their potential applications.

This review aims to provide a comprehensive and systematic exploration of biomass hydrothermal techniques for CQD synthesis, encompassing both bottom-up and top-down approaches. Specifically, it seeks to elucidate the underlying mechanisms and key parameters governing the formation of CQDs via biomass hydrothermal methods. Additionally, the review aims to evaluate the advantages and limitations of biomass-derived precursors in tailoring the properties and functionalities of CQDs. Furthermore, it endeavors to delineate the diverse applications facilitated by biomass-derived CQDs across various fields, ranging from optoelectronics to biomedicine.

Adopting a systematic approach, this review amalgamates and synthesizes pertinent literature on biomass hydrothermal techniques for CQD synthesis. The inclusion and exclusion criteria are defined a priori to ensure the selection of studies that meet the scope and objectives of the review. Both bottom-up methods, which involve the controlled assembly of molecular precursors to form CQDs, and top-down strategies, which entail the fragmentation of larger carbonaceous materials into nanoscale entities, are meticulously explored and analyzed (5). Additionally, the review discusses various factors influencing the synthesis process, such as precursor selection, reaction conditions, and post-treatment methods.

By synthesizing current research endeavors, this review aims to provide insights into the state-of-the-art in biomass hydrothermal synthesis of CQDs, thereby fostering a deeper understanding of the synthesis mechanisms and structure-property relationships governing these nanostructures. Moreover, it endeavors to elucidate the distinct advantages offered by biomass-derived precursors in tailoring CQD properties and functionalities, thereby elucidating their potential for diverse applications spanning from optoelectronics to biomedicine.

2. Biomass Hydrothermal Techniques for CQD Synthesis

Biomass hydrothermal techniques provide an eco-friendly and adaptable route for CQD synthesis, utilizing the diverse chemical composition of biomass-derived materials. This section explores both bottom-up and top-down methodologies utilized in CQD synthesis. In bottom-up approaches, molecular precursors sourced from biomass constituents such as carbohydrates and lignin undergo hydrothermal treatment, resulting in CQD formation through carbonization and fragmentation processes. Precursor selection and reaction conditions play pivotal roles in determining the size, morphology, and optical properties of the produced CQDs. Conversely, top-down strategies involve the fragmentation and exfoliation of larger biomass-derived carbonaceous materials, followed by subsequent treatments to tailor CQD properties.

The utilization of biomass as a precursor offers several advantages, including its abundance, renewability, and chemical diversity, which allow for the incorporation of heteroatoms and functional groups into the resulting CQDs. Moreover, biomass hydrothermal techniques operate under mild conditions and utilize water as a solvent, minimizing environmental impact and waste generation. However, challenges such as batch-to-batch variations, scalability issues, and the need for further elucidation of reaction mechanisms underscore the necessity for ongoing research and optimization efforts in biomass hydrothermal CQD synthesis.

3. Synthesis of CQDs from Biological Waste

Recent research has underscored the significance of synthesizing carbon quantum dots (CQDs) from various biomass wastes, as extensively detailed in Table 1. These findings reflect sustained interest in the development of promising carbon materials, particularly in the context of sustainability and waste reduction. Table 1 presents synthesis data of CQDs through hydrothermal methods, encompassing a variety of carbon sources such as palm empty fruit bunches, M. liliiflora flowers, algae, grass, red lentils, as well as various fruit extracts. The utilization of hydrothermal methods in CQD synthesis offers flexibility in controlling reaction time and temperature to influence the physicochemical properties of the resulting CQDs. Synthesis outcomes from different carbon sources also manifest in the photoluminescence characteristics of CQDs, such as quantum yield (QY) efficiency and excitation (λex) and emission (λem) wavelengths, indicating significant variations depending on the intrinsic properties of the raw materials used.

Table 1. Carbon sources, conditions, quantum yield, and photoluminescence of hydrothermally synthesized CQDs

Hydrothermal Methods						
Carbon source	**Time (Jam)**	**Tempe rature (°C)**	**QY (%)**	**λ_{ex} (nm)**	**λ_{em} (nm)**	**Ref.**
Empty palm oil bunches	3	200	24.6	360	440	(6)
M. liliiflora flower	12	240	11	340	405	(7)
Algae	3	200	8	340	415	(8)
Grass	2	180	-	490	640	(9)
Red lentils	5	200	13.2	360	448	(10)
Lemon, Turmeric, and grapefruit extract	6	180	20	350	460	(11)
Pear juice	36	180	18	380	470	(12)
Chocolate	8	200	-	280	354	(13)

This study highlights the pivotal role of hydrothermal methods in CQD synthesis from biomass wastes, emphasizing the potential utilization of abundant organic materials as sustainable carbon sources. Through meticulous characterization of quantum yield and photoluminescence of synthesized CQDs, this research demonstrates that factors such as time, temperature, and types of carbon sources can significantly influence the optical and physicochemical properties of the final products. A profound understanding of these synthesis parameters is crucial in optimizing the CQD synthesis process from biomass wastes for broader applications, including in the fields of optoelectronics, catalysis, and biomedicine.

Conclusions

Overall, this review illustrates the importance of developing biomass hydrothermal techniques in carbon quantum dot (CQD) synthesis. Recent studies indicate that biomass waste can be a potential source for producing CQDs with desired properties. Hydrothermal methods offer an efficient and sustainable approach to utilizing biomass as a precursor for CQDs, with adjustable reaction time and temperature settings that can be tailored to produce products with desired characteristics. With a deep understanding of the factors influencing CQD synthesis and characterization, this research provides valuable insights for optimizing biomass hydrothermal techniques in producing CQDs with wider and potential applications across various fields, from optoelectronics to biomedicine.

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