A SHORT REVIEW ON N-CQDS GREEN SYNTHESIS, CHARACTERIZATION, AND PROPERTIES

Nurul Ayunni Abdul Latif[1,] Jeefferie Abd Razak[2]

Corresponding Author: ayunnilatif@gmail.com***;** jeefferie@utem.edu.my

[1]Politeknik Melaka, No. 2, Jalan PPM 10, Plaza Pandan, Malim, 75250, Melaka, Malaysia.

[2]Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100,
Durian Tunggal, Melaka, Malaysia

ABSTRACT: This review provides a concise overview of the green synthesis, characterization, and properties of nitrogen-doped carbon quantum dots (N-CQDs), a remarkable class of nanomaterials gaining significant attention due to their unique optical properties, biocompatibility, and environmental friendliness. Green synthesis approaches for N-CQDs, which utilize natural precursors like plant extracts, align with the principles of green chemistry by minimizing the use of hazardous substances and energy. Comprehensive characterization techniques such as UV-Vis spectroscopy, photoluminescence spectroscopy, TEM, XPS, and FTIR reveal the enhanced optical, electrical, and chemical attributes of N-CQDs resulting from nitrogen doping. These properties make N-CQDs suitable for a wide range of applications, including bioimaging, drug delivery, sensing, and optoelectronics. This review underscores the potential of N-CQDs synthesized via eco-friendly methods for sustainable and innovative applications in various fields.

1.0 BRIEF ON N-CQDS

The intriguing family of nanomaterials known as carbon quantum dots, or CQDs, have attracted a lot of attention recently because of their special qualities and their uses in a variety of industries. These carbon-based materials at the nanoscale, which usually have a diameter of less than 10 nanometers, have unique properties like fluorescence, high biocompatibility, and adjustable surface chemistry [1]. Due to their potent and adjustable fluorescence emission characteristics, semiconductor quantum dots have been the subject of much research for many years, opening new avenues for biosensing and bioimaging. However, due to the high toxicity of the heavy metals used in their synthesis and manufacture, semiconductor quantum dots have several drawbacks[2]. Because of their design, they may interact with light to produce photoluminescence, a useful characteristic in optoelectronics, bioimaging, and sensing applications. In addition, they are appropriate for biomedical applications like as cancer therapy and drug administration due to their high biocompatibility and low toxicity [3]. Nitrogen-doped carbon quantum dots (N-CQDs) are a type of carbon quantum dots with nitrogen atoms in their structure. Nitrogen doping is important because it improves the optical, electrical, and chemical properties of CQDs, making them more useful. Adding nitrogen atoms to the carbon structure has several benefits. First, nitrogen doping often enhances the photoluminescence of CQDs, making their fluorescence stronger and more stable. This improvement is especially important for applications like biosensors and medical imaging, which require high sensitivity and precise detection. As said by Vercelli et al., (2021), N-doping can increase the quantum yield of CQDs, enhancing their fluorescence properties [4]. Based on the research made by Šafranko et al., (2023), the doping can modify the band gap (broaden or narrow) of CQDs thus impacting their electrical conductivity and charge carrier dynamics [5]. When it comes to biological applications requiring specialized biomolecule binding or focused medication administration, this reactivity is especially helpful. The CQDs are utilized in chemical sensing for detecting heavy metals like Hg2, showcasing their low toxicity, water solubility, photostability, and chemical stability [2].

2.0 THE GREEN SYNTHESIS OF N-CQDS

Traditional synthesis methods often involve harsh chemicals and conditions, which pose environmental and health risks. Green synthesis methods aim to mitigate these issues by utilizing natural precursors, such as plant extracts, and environmentally benign procedures. This review aims to summarize recent advancements in the green synthesis, characterization, and properties of N-CQDs. Green synthesis of N-CQDs involves the use of natural, renewable resources and environmentally friendly methods. Common natural precursors include fruits, vegetables, and plant extracts, which are rich in carbon and nitrogen sources. This literature review delves deeper into the evolution of CQDs synthesis, focusing on the hydrothermal method and its impact on the development of Carbon Quantum Dots with unique characteristics and broad applications. One of the primary benefits of the hydrothermal method is its simplicity and cost-effectiveness [6]. By exploring the historical context and outlining key synthesis techniques, better understanding on how CQDs have emerged as a significant area of research in the realm of nanotechnology could be established. The CQDs synthesized using this method exhibited a narrow size distribution and high quantum yield, indicating their potential for use in sensitive biosensing applications. The following Figure 1 depicts the graphical summarization of CQDs synthesized from the urea and citric acid source as adapted from Sharma & Chowdhury, (2023) [1]. Furthermore, the surface functionalization of these CQDs can be tailored to specific biological targets, enabling precise targeting and imaging in various biomedical research fields. Moreover, recent studies have demonstrated the biocompatibility of these surface-functionalized CQDs, paving the way for their utilization in targeted drug delivery systems for enhanced therapeutic efficacy. The source of carbon from lime provides a sustainable and cost-effective approach to synthesizing CQDs, making them even more attractive for widespread adoption in biomedical and pharmaceutical applications. This fact is supported by the study conducted by many researchers as tabulated in the following Figure 2.

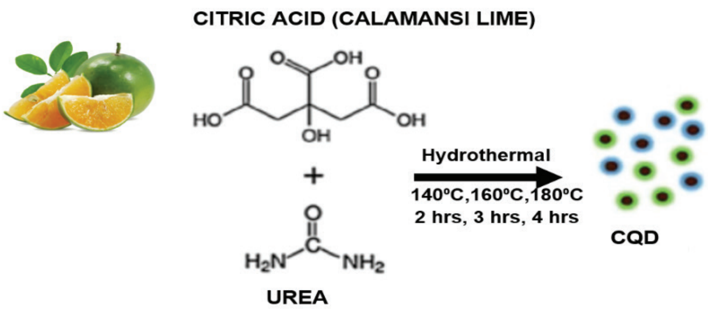

Fig 1: Schematic illustration for the synthesis of CQDs from urea and citric acid (Adapted from Sharma, 2023)

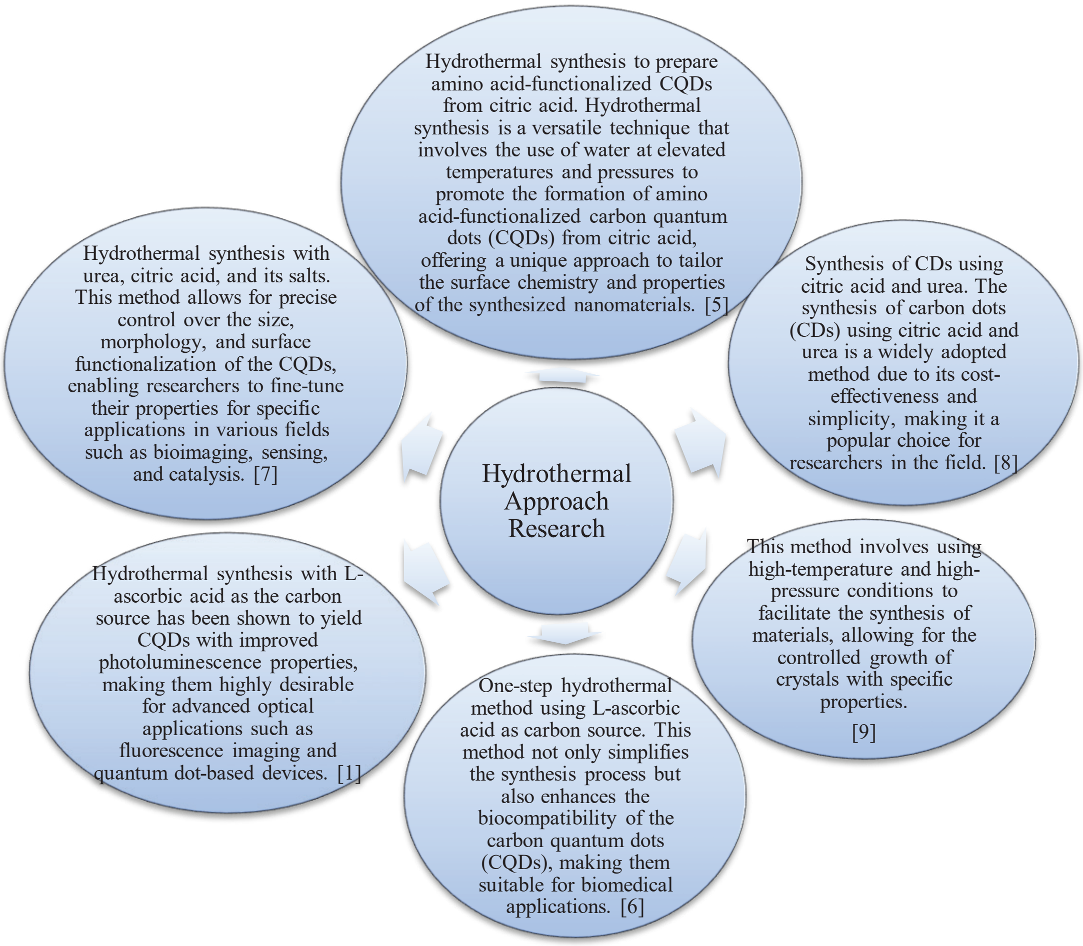

Fig. 2. The recent research using the hydrothermal approach from various sources of past literature.

3.0 CHARACTERIZATION OF N-CQDS

Over the past decade, most research in nanotechnology has emphasized the investigation of N-CQDs. The characterization of N-CQDs involves a multi-faceted approach, encompassing optical, structural, and chemical analyses. Characterizing N-CQDs involves several common techniques as depicted in Figure 3. UV-Vis Spectroscopy measures the absorption of ultraviolet and visible light by the N-CQDs, providing information about energy levels and bandgap, crucial for understanding their optical properties [1][2]. Photoluminescence Spectroscopy assesses the quantum yield, emission wavelength, and fluorescence stability of N-CQDs, revealing how nitrogen doping affects these properties and their potential use in optical applications [9][10]. Transmission Electron Microscopy (TEM) provides high-resolution images, allowing examination of size, shape, and morphology, which confirms the nanoscale structure and identifies structural defects [11][12]. X-ray Photoelectron Spectroscopy (XPS) analyzes the elemental composition and chemical states within N-CQDs, confirming the presence of nitrogen and other elements, thus offering insights into the bonding environment and surface chemistry [9]. Fourier-transform Infrared Spectroscopy (FTIR) identifies functional groups on the N-CQDs' surface, such as hydroxyl, carboxyl, or amine groups, which is valuable for understanding surface chemistry and interactions with other molecules [13]. Recent studies utilizing these techniques have demonstrated that nitrogen doping enhances photoluminescence, providing opportunities for improved fluorescence-based applications, and that analysis of surface functional groups facilitates tailored chemical modifications for applications in drug delivery and sensing [14][15].

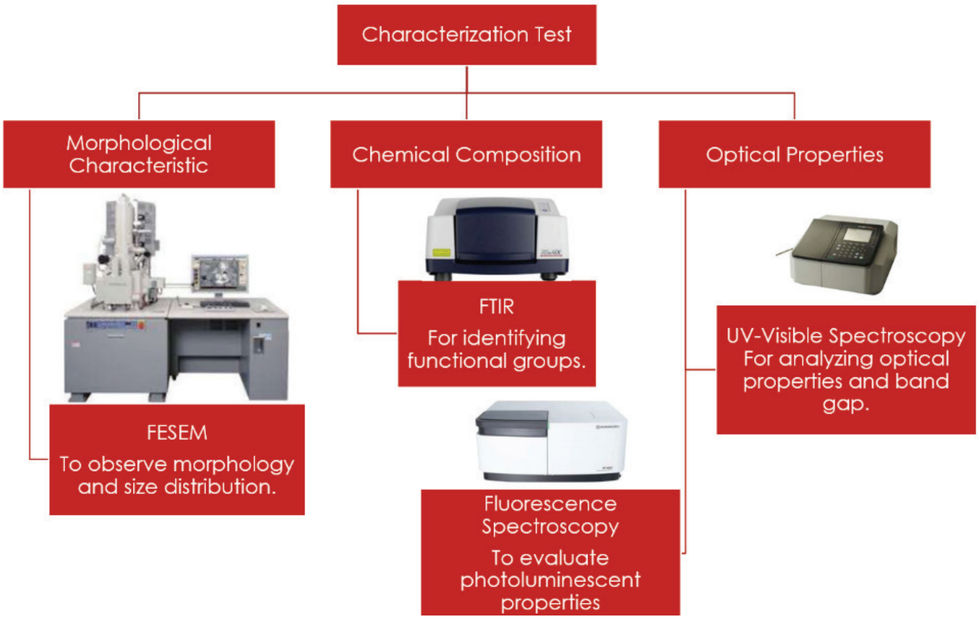

Fig. 3. The characterization techniques of N-CQDs and its function

4.0 PROPERTIES OF N-CQDS

Recent studies on N-CQDs have demonstrated significant progress in both synthesis and application, particularly with the use of the hydrothermal method. Notable benefits include enhanced photoluminescence, where nitrogen doping significantly increases the brightness and stability of fluorescence, crucial for bioimaging and sensor applications [16]. Improved electrical conductivity has also been reported, opening new avenues for the use of N-CQDs in optoelectronic devices and energy storage systems [1]. Additionally, versatile surface functionalization has been achieved by exploring different nitrogen sources and precursors, allowing N-CQDs to be tailored for specific applications such as drug delivery and sensors [4]. Low toxicity and high biocompatibility have been confirmed, reinforcing the suitability of N-CQDs for biomedical applications [9]. Finally, the hydrothermal method's scalability and cost-effectiveness enable larger-scale production, which is crucial for commercial applications and broader adoption in various industries [1]. The following Table 1 provide the summary of the previous literature which explored similar interest for this study. Several studies have explored the synthesis and characterization of CQDs using various organic precursors and methods. These studies provide a basis for the current study and highlight the potential improvements in eco-friendly synthesis methods.

Table 1: The Variable of precursor effect the results.

Study	Precursor(s)	Synthesis Method	Results	Limitations
[17]	Citric acid	Hydrothermal treatment	Good photoluminescence properties	High temperatures, significant byproducts
[18]	Glucose	Microwave-assisted method	Narrow size distribution, good luminescence	Complex procedures, non-renewable materials
[1]	Urea and citric acid	Hydrothermal	Strong luminescence, biocompatibility	Requires optimization for higher purity
[19]	Soybean milk	Hydrothermal carbonization	Biocompatible, good luminescence	Energy-intensive process
[20]	Citric acid, ethylenediamine	Hydrothermal treatment	High photoluminescence efficiency	Use of non-renewable solvents

5.0 APPLICATIONS OF N-CQDS

The unique characteristics of N-CQDs, largely due to nitrogen doping, open multiple avenues for their application. In bioimaging, N-CQDs' strong photoluminescence and high biocompatibility make them ideal for visualizing biological structures, tracking cellular processes, and monitoring drug distribution within biological systems, with reduced toxicity compared to traditional semiconductor quantum dots [1]. In drug delivery, the surface functional groups introduced by nitrogen doping enable N-CQDs to bind with various biomolecules, providing a platform for efficient and targeted drug delivery to specific cells or tissues [5]. N-CQDs also excel as sensors due to their strong fluorescence and chemical reactivity, making them capable of detecting specific molecules or environmental changes, such as pH variations, metal ions, or biomolecules, for applications in environmental monitoring, medical diagnostics, and food safety [16]. In optoelectronic devices, N-CQDs' enhanced electrical conductivity and tunable photoluminescence are valuable for creating more efficient and cost-effective light-emitting devices and photovoltaic cells [9]. A considerable amount of literature has been published regarding benefits and its potential application of the tailored N-CQDs as summarized in the following Table 2, while the following Figure 4 illustrate the variable potential application of NCQDs.

Table 2: The potential application of the tailored N-CQDs CQDs from various literature

Ref	Benefits	Potential Application
[17][21]	Enhanced Photoluminescence	bioimaging and sensor applications
[10]	Improved Electrical Conductivity	optoelectronic devices and energy storage systems.
[8]	Versatile Surface Functionalization	drug delivery and sensors.
[1][6]	Low Toxicity and Biocompatibility	drug delivery systems and bioimaging
[2]	Scalability and Cost-Effectiveness	commercial applications and broader adoption in various industries

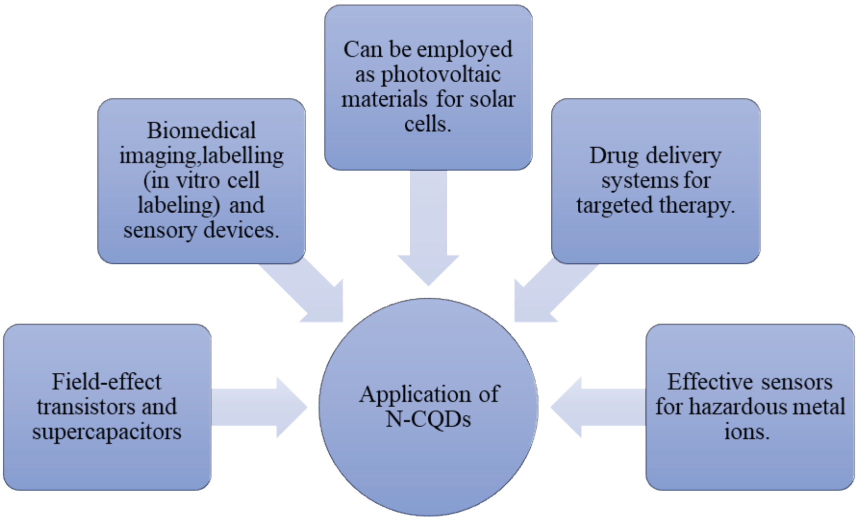

Fig 4: The variable application of the tailored N-CQDs

6.0 CONCLUSIONS

Green synthesis of N-CQDs presents an environmentally friendly and sustainable approach to produce these versatile nanomaterials. The use of natural precursors and benign methods aligns with the principles of green chemistry, making N-CQDs attractive for various applications. Characterization techniques provide detailed insights into their properties, which can be tailored for specific applications. The unique optical, electronic, and chemical properties of N-CQDs open up new possibilities in bioimaging, sensors, optoelectronics, and catalysis. Future research should focus on optimizing synthesis methods and exploring new applications to fully harness the potential of N-CQDs.

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