JCNaR
Journal of Chemical Natural Resources
Journal homepage: https://jcnar.usu.ac.id

Exploring the Effect of Ethylenediamine Concentration on the Optical Properties of Carbon Dots Synthesized from Candlenut Shell Biomass

Tjut Siti Safhura[1], Marpongahtun[2*], Amir Hamzah Siregar[2]

[1]*Postgraduate School of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan, 20155, Indonesia*

[2]*Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan, 20155, Indonesia*

[*]Corresponding Author: marpongahtun@usu.ac.id

ARTICLE INFO

Article history:
Received 26 April 2025
Revised 14 May 2025
Accepted 23 May 2025
Available online 31 May 2025

E-ISSN: 2656-1492

How to cite:
Tjut Siti Safhura, Marpongahtun, Amir Hamzah Siregar. Exploring the Effect of Ethylenediamine Concentration on the Optical Properties of Carbon Dots Synthesized from Candlenut Shell Biomass. Journal of Chemical Natural Resources. 2025, 7(1):20-29.

https://doi.org/10.32734/jcnar.v7i1.20639

ABSTRACT

Carbon dots are fluorescent nanomaterials with a size below 10 nm, known for their good optical properties, including fluorescence emission and biocompatibility which are very suitable for various applications, such as bioimaging, sensors and optoelectronics. This research aims to synthesize CDs and NCDs from candlenut shells as a biomass source using the hydrothermal method at 230°C for 6 hours with the addition of ethylenediamine (EDA) as a nitrogen dopant at concentrations of 4%, 8% and 12% (v/v). The study also evaluates the effect of varying EDA concentrations on the optical properties of CDs and NCDs. Based on the results, under 365 nm UV irradiation, all samples showed bluish green fluorescence. The results of UV-Vis analysis showed an absorption peak at a wavelength of 271 nm for CDs and additional absorption peaks at 274 nm and 324 nm for NCDs, corresponding to the π–π* and n–π* transitions, respectively. Increasing EDA concentration is associated with a gradual decrease in the absorption intensity of CDs and NCDs. The photoluminescence results showed the CDs emission peak at 494 nm with a quantum yield (QY) of 18% and the strongest fluorescence at 498 nm for NCDs 8% with the highest QY of 27%. The results of FTIR analysis showed -OH, C=O and C=N functional groups in all samples and additional -NH functional groups in the NCDs, indicating successful nitrogen incorporation.

Keyword: Carbon Dots, Candlenut Shells, Hydrothermal Method, Dopant, Ethylenediamine

ABSTRAK

Carbon dots merupakan nanomaterial berfluoresensi yang memiliki ukuran di bawah 10 nm dan dikenal dengan sifat optiknya yang cukup baik, termasuk emisi fluoresensi dan biokompatibilitasnya yang unggul sehingga cocok untuk berbagai aplikasi seperti *bioimaging*, sensor dan optoelektronik. Penelitian ini bertujuan untuk mensintesis CDs dan NCDs dari cangkang kemiri sebagai sumber biomassa menggunakan metode hidrotermal pada suhu 230°C selama 6 jam dengan penambahan etilendiamina (EDA) sebagai dopan nitrogen pada konsentrasi 4%, 8% dan 12% (v/v). Penelitian ini juga mengevaluasi pengaruh dari variasi konsentrasi EDA terhadap sifat optik CDs dan NCDs. Berdasarkan hasil penyinaran di bawah sinar UV 365 nm, semua sampel menunjukkan fluoresensi berwarna hijau kebiruan. Hasil analisis UV-Vis menunjukkan puncak serapan pada panjang gelombang 271 nm untuk CDs dan puncak serapan tambahan pada 274 nm dan 324 nm pada NCDs dengan masing-masing puncak tersebut merujuk pada transisi π–π* dan n-π*. Meningkatnya konsentrasi EDA berhubungan dengan penurunan bertahap intensitas serapan dari CDs dan NCDs. Hasil fotoluminesensi menunjukkan puncak emisi CDs pada 494 nm dengan *quantum yield* (QY) sebesar 18% dan fluoresensi terkuat pada 498 nm untuk NCDs 8% dengan QY tertinggi sebesar 27%. Hasil analisis FTIR menunjukkan gugus fungsi -OH, C=O dan C=N pada semua sampel dan tambahan gugus fungsi -NH pada NCDs yang mengkonfirmasi keberhasilan doping nitrogen.

Kata Kunci: *Carbon Dots*, Cangkang Kemiri, Metode Hidrotermal, Dopan, Etilendiamina

1. Introduction

Carbon dots (CDs) are zero-dimensional, carbon-based fluorescent nanoparticles with a quasi-spherical shape measuring less than 10 nm, which are composed of sp^2/sp^3 hybridized carbon and contain functional groups such as nitrogen, oxygen and other groups after undergoing a synthesis process [1]. CDs are known as a new generation of environmentally friendly nanomaterials, with several advantages over traditional semiconductor quantum dots, such as tunable fluorescence, good thermal and photostability, water solubility, biocompatibility and low toxicity [2,3]. Quantum yield (QY) is an important parameter used to evaluate how efficiently material converts absorbed excitation energy into emitted photons, as well as QY is an important characteristic for various light-based applications. Due to their good optical and chemical properties, CDs have shown promising application in photoluminescence, electrochemical sensors [4], biosensors [5], drug delivery [6], antibacterial agents [7], and bioimaging [8].

In recent years, waste biomass, with its abundant availability, renewable nature, low cost, and environmental benefits, has attracted attention as a potential precursor for the synthesis of CDs. The components of biomass sources, such as proteins, cellulose, lignin and hemicellulose, contribute to the formation of CDs with superior optical properties through the carbonization process. Thus, supporting the principles of environmentally friendly carbon dots synthesis [9]. Several previous studies have also reported the use of biomass waste as a source for the synthesis of CDs, including empty oil palm fruit bunches [10], palm kernel shells [11], and banana stems [12]. However, although interest in biomass-based CDs continues to grow, the use of candlenut shells as a biomass source for CDs synthesis remains underexplored. In comparison, candlenut shells have a high carbon content (75.79%), exceeding the carbon content in empty oil palm fruit bunches (40.93% to 68.3%) [13]. In addition, candlenut shells also contain holocellulose (49.22%) and lignin (54.46%) [14], both of which play a role in forming a better carbon framework, which ultimately improves the optical quality of the resulting CDs. Candlenut shells are often an agricultural by-product that are thrown away or burned [15], encouraging their use in this research to support circular economy principles with the development of value-added carbon-based nanomaterials. Therefore, this research aims to synthesize and evaluate the feasibility of using candlenut shells as a biomass source for the synthesis of CDs that have better fluorescence properties and are environmentally friendly.

Synthesis methods and doping strategies play an important role in determining the optical properties of CDs, in addition to precursor selection. There are two approaches to CDs synthesis, top-down and bottom-up. However, the bottom-up method is more popular and widely used because it is simple, low cost, and environmentally friendly. Among several types of the bottom-up methods, the hydrothermal method is considered an effective technique for synthesizing CDs from biomass waste with several advantages, including narrow particle size distribution, stable fluorescence emission and high product purity [16]. It is more efficient than other bottom-up methods such as microwave-assisted synthesis and pyrolysis, which often produce CDs with a wider particle size distribution and incomplete carbonization. Several previous studies have also reported that the hydrothermal method is a suitable method for producing CDs with superior biocompatibility [17], high quantum yield [18], and stable fluorescence emissions [19] from biomass sources such as *Prosopis juliflora*, cassava pulp, and *Enthemorpha prolifera*, respectively. Thus, although the hydrothermal method offers several notable advantages for biomass carbonization, further studies of the optical properties of CDs often require surface functionalization or heteroatom doping.

Nitrogen doping has been widely used due to its ability to improve charge distribution, form surface trap states and increase quantum yield (QY) to produce superior optical properties of CDs [20]. Nitrogen is an effective dopant because it has an atomic radius compatible with the carbon lattice, its lone pair of electrons facilitates strong electronic interactions, and has high electronegativity. This characteristic allows the formation of energy levels between electron-rich nitrogen atoms and electron-deficient carbon sites, thereby enhancing radiative recombination and shifting the emission wavelengths toward longer values [21]. Among the various nitrogen sources, ethylenediamine (EDA), which has a bifunctional amine group and high reactivity toward biomass precursors and nitrogen sources, is often used because it can affect the QY value. Previous studies reported that NCDs synthesized from quinoa saponin with EDA doping using the hydrothermal method produced high QY values of 22.2% [22]. In comparison, CDs from jackfruit peel biomass sources and nitrogen-doped tamarind peels using dichloromethane as a nitrogen source showed lower QY values of 13.04% and 6.13%, respectively [23]. Furthermore, another study using a nitrogen source from ammonia (NH_3) with a glucose precursor which is a biomass-derived compound, showed a QY value of 9.6%. Based on the results of this study, nitrogen doping with EDA produced significantly better results than other nitrogen sources.

However, although several studies have explored the study of precursor materials and dopant types, the influence on EDA concentration has not been further investigated. Thus, this research focuses on synthesizing and evaluating the effect of varying EDA concentration on the optical properties of CDs with precursors from candlenut shells biomass waste.

Many studies have explored the effectiveness of EDA as a nitrogen source, but further studies focusing on the effect of varying EDA concentrations on improving the optical properties of CDs are still limited, especially when combined with biomass that has high carbon and lignocellulosic content such as candlenut shells. It is expected that varying the concentration of EDA can influence the level of nitrogen incorporation into CDs which in turn can affect the surface state and defect density, thereby enhancing the fluorescence properties and QY value of the CDs. Thus, this study systematically investigates the effect of various concentrations of EDA to understand its role in determining the optical properties of CDs synthesized from candlenut shell biomass waste, thereby contributing to the development of environmentally friendly carbon-based nanomaterials to be applied in various applications.

2. Material and Methods

2.1 Materials

This study utilized the following materials: candlenut shells, deionized water (Merck), distilled water, and ethylenediamine ($C_2H_4(NH_2)_2$, 98 wt%). The instruments used included: standard laboratory glassware (Pyrex), analytical balance (Toledo), autoclave (Biobase BKM P-18(A)), centrifuge (MPW MED Instruments), furnace (Bio-One), UV lamp (Panasonic), drying oven (Bio-One), ultrasonic bath (Elmasonic S 300 H), UV-Vis spectrophotometer (Shimadzu), photoluminescence (PL) spectrometer (Horiba FL-1000), and Fourier-transform infrared (FTIR) spectrometer (Shimadzu IR Prestige 21).

2.2 Characterization

UV Lamp

A UV lamp 365 nm was used to investigate the physical properties of the CDs and NCDs samples. The synthesized CDs and NCDs samples were placed in test tubes and then irradiated with a UV lamp to observe the color of their fluorescence emission.

UV-Vis Characterization

Each 5 mL sample of CDs and NCDs was characterized with the aid of a UV-Vis spectrophotometer (Shimadzu) within the wavelength range of 200-700 nm to analyze the electronic transitions, including π-π* transitions within the core and n-π* transitions related to the surface states.

Fourier Transform Infrared (FTIR) Characterization

Each 5 mL sample of CDs and NCDs was analyzed through FTIR spectroscopy within the wavenumber range of 4000 cm^{-1} to 400 cm^{-1} to determine the chemical bonds and surface functional groups of the CDs and NCDs samples.

Photoluminescence (PL) Characterization

Each 5 mL sample of CDs and NCDs sample was characterized using Photoluminescence (PL) spectrometer (Horiba FL 1000) to identify the emission wavelength and assess the optical characteristics, including fluorescence emission intensity and quantum yield performance. Quinine sulfate was employed as the fluorescence reference (QR = 0.54, η = 1.33). I refer to the integrated area of fluorescence intensity measured at an excitation wavelength of 370 nm. The following formula was applied to determine the Quantum Yield (QY) as presented in Eq.1:

$$\boldsymbol{QY = QR} \times \left(\frac{I}{IR}\right)\left(\frac{AR}{A}\right)\left(\frac{\eta}{\eta R}\right)^2 \qquad \text{Eq.1}$$

Description:

QY = Quantum yield value
QR = Quantum yield reference (0.54)
I = The integrated area under the fluorescence peak of the CDs
IR = The integrated area under the fluorescence peak of the reference
AR = UV absorbance of reference
A = UV absorbance of CDs
η = Refractive index of CDs

ηR = Refractive index of reference

2.3 Preparation Sample

The candlenut shells were cleaned from the impurities, followed the washing using distilled water, and air-dried for two days. The dried candlenut shells are carbonized ~~in~~ utilising a furnace at 350°C for 4 hours to produce candlenut shells carbon.

2.4 Synthesis of Carbon Dots

Synthesis of carbon dots (CDs) using the hydrothermal method, was carried out by dispersing 8 g of candlenut shells carbon matrix with 50 mL of deionized water which was stirred for 30 minutes until the solution was homogeneous. The homogeneous solution was transferred into a Teflon-lined stainless-steel autoclave and heated at 230°C for 6 hours. After that, the autoclave was cooled naturally to room temperature and the resulting solution was ultrasonicated for 30 minutes and centrifuged at 5500 rpm for 30 minutes. Then, the supernatant was filtered using Whatman filter paper No.32. Furthermore, filtration was carried out using a 0.22 µm nylon syringe filter to obtain more purified CDs solution for further characterization. The same procedure was carried out for the synthesis of NCDs with the addition of ethylenediamine (EDA) at concentrations of 4%, 8%, and 12% (v/v), corresponding to 2.0 mL, 4.0 mL and 6.0 mL, respectively.

3. Result and Discussion

3.1 Preparation Sample

Candlenut shells were carbonized using at 350 °C for 4 hours resulted in a carbon matrix, which was subsequently used as the precursor for CDs synthesis. The resulting carbon exhibited a fine powder texture, indicating efficient thermal decomposition of organic components and the formation of a carbon-rich structure suitable for hydrothermal processing.

3.2 Synthesis of Carbon Dots

Synthesis of CDs and NCDs with varying concentrations of ethylenediamine (EDA) at 4%, 8% and 12% (v/v) was successfully carried out, characterized and analyzed. The visual observation showed that the CDs and NCDs solutions that have been synthesized using the hydrothermal method appeared as brown solutions under visible light. Under a 365 nm UV lamp, bluish-green fluorescence was visible in all samples and is attributed to electronic transitions facilitated by the surface chemical states of the organic precursor [24]. Based on these visual observations, it was found that varying the concentration of EDA does not significantly change the color of the solution under 365 nm UV light, although all NCDs samples exhibited stronger fluorescence intensity compared to CDs. This enhancement is attributed to the addition of new functional groups containing nitrogen by EDA, which increases surface energy and facilitates radiative recombination. The similar research has also been reported, showing that the presence of surface passivation with nitrogen doping can lead to increased luminescence due to the formation of additional emission sites and surface functional groups on CDs [25]. Additionally, no precipitation or degradation was observed in any of the samples. These results indicated that the CDs and NCDs solutions have good colloidal stability. The sample synthesis and visualization scheme can be seen in Figure 1.

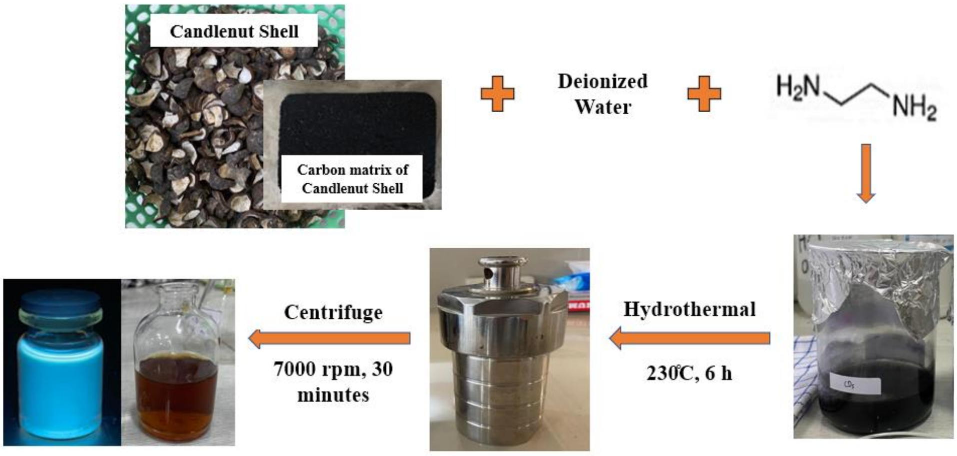

Figure 1. Schematic illustration of the synthesis Carbon Dots

3.3 Characterization of Carbon Dots

UV-Vis

The optical properties of CDs and NCDs with varying concentrations of ethylenediamine (4%, 8%, and 12% (v/v)), were characterized and analyzed using UV-Vis absorption spectroscopy. The UV-Visible absorption peaks in relation to the wavelength of each sample are demonstrated in Figure 2. The CDs exhibited a distinct absorption peak at 271 nm, which is attributed to the a π-π^* electronic transition. This transition corresponds to the excitation of electrons from bonding π orbitals to antibonding π^* orbitals within sp^2-hybridized carbon domains, and is typically associated with delocalized electronic structures such as conjugated graphitic or aromatic regions. The presence of this transition indicates an electronic configuration originating from the carbon core, which indicates the existence of a certain degree of conjugation associated with efficient absorption in the UV region [26]. Thus, CDs have a relatively ordered carbon framework with wide π-conjugation, contributing to their UV absorption characteristics.

The absorption peak exhibited a slight red-shift to 274 nm after doping, which indicates disruption in the electronic system of the CDs due to the addition of a new functional group containing nitrogen. This shows that nitrogen doping can change the energy levels in the carbon framework and the local electronic distribution, likely due to changes in electron density in the π electron cloud or the presence of local trap states affecting the π–π^* transition energy. Such electronic reconfiguration can slightly reduce the transition energy required, hence shifting the absorption to longer wavelengths. In addition to this shift, NCDs exhibit a secondary absorption peak at 324 nm, which is attributed to the n-π^* transition. This transition arises from the excitation of non-bonding electrons (n) present in surface-bound nitrogen or oxygen functional groups (such as amine or carbonyl groups) into π^* orbitals [27]. The appearance of this absorption peak indicates that there is an interaction between the functional groups on the carbon core and the surface, which affects the energy transitions and absorption spectrum. The presence of this new absorption band further confirms the successful nitrogen doping through the introduction of nitrogen-containing functional groups that improve surface chemistry and contribute to new optical pathways.

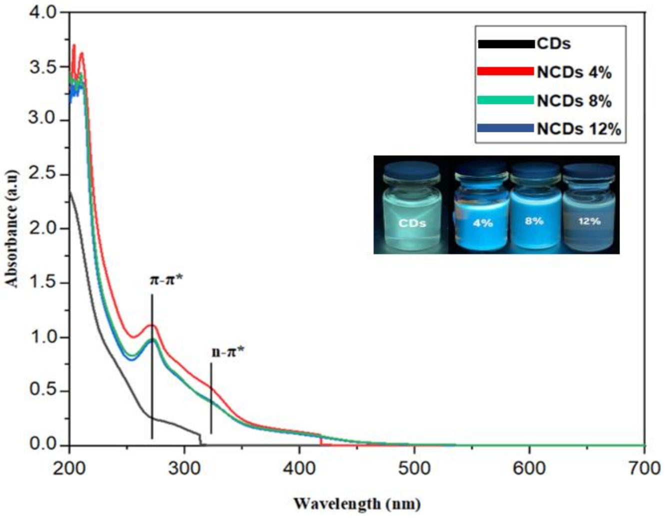

Figure 2. UV-Visible Spectra of CDs and NCDs

The analysis of the NCDs revealed a gradual decrease in the absorbance intensity in line with the increase in ethylenediamine (EDA) concentration. This phenomenon is related to the addition of functional groups containing nitrogen resulting in the replacement of epoxy groups on the surface of CDs with functional groups containing nitrogen such as amides and aliphatic amines. However, excessive nitrogen content increases the density of electron donors and results in a denser electron cloud, thereby inhibiting light absorption [28]. Conversely, when nitrogen content is too low, the number of active amine sites is insufficient to effectively alter the surface states, also leading to reduced absorbance efficiency. These observations indicate that light absorption is sensitive to the degree of doping, and that both under and over doping can compromise optical performance.

Photoluminescence (PL)

The fluorescence and optical characteristics of CDs and NCDs were evaluated by photoluminescence (PL) analysis using a Horiba FL-1000 spectrophotometer. A total of 5 mL of CDs and NCDs solutions with varying EDA concentration was excited at a wavelength of 370 nm, while the emission spectrum was scanned in the wavelength range 400-700 nm. The PL spectrum of CDs and NCDs can be seen in Figure 3.

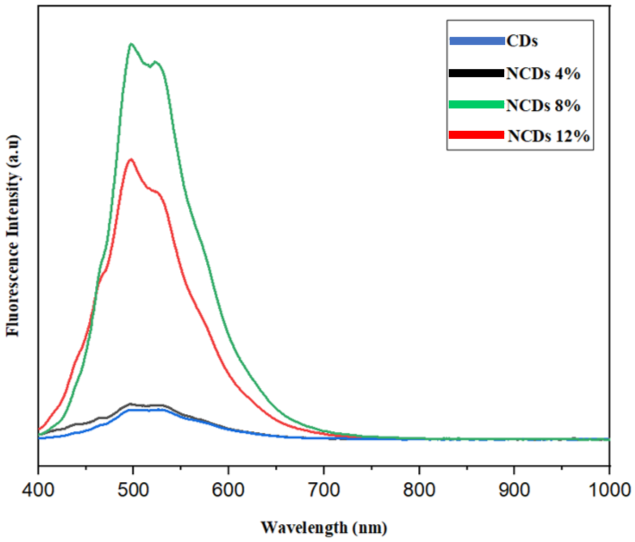

Figure 3. Fluorescence Spectra of CDs and NCDs

The CDs showed an emission peak at 494 nm, which corresponds to the bluish-green fluorescence typically seen in biomass-based CDs. The resulting emission intensity is relatively stable, indicating low surface defect density and good fluorescence stability [18]. After nitrogen doping with EDA, a slight red-shift occurred in the emission, at 494 nm for NCDs 4%, 498 nm for NCDs 8%, and 497 nm for NCDs 12%. The NCDs 8% showed the greatest red-shift, indicating a higher degree of electronic structure change and energy level modulation. This red shift is mainly caused by the modification of the electronic structure of the CDs induced by the nitrogen atom. During the doping process, nitrogen introduces new localized energy levels within the bandgap that act as emissive trap states and are located between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO), thereby effectively narrowing the bandgap. As a result, the electronic transition occurs in a smaller energy gap, resulting in emission at a longer wavelength (red-shift) when illuminated with the same photon energy. The existence of trap states due to nitrogen doping also plays an important role in stabilizing the excited electrons, thereby increasing the possibility of radiative recombination and suppressing non-radiative decay processes. Additionally, nitrogen atoms help protect surface defects, which are generally the main cause of non-radiative relaxation. Therefore, the presence of nitrogen not only increases the emission intensity but also increases the quantum yield (QY) by promoting radiative pathways and reducing energy loss through non-radiative mechanisms [18,29].

Table 1. Quantum Yield of CDs and NCDs samples

No	Materials	λexcitation	λemission	QY (%)
1	CDs	370 nm	494 nm	18%
2	NCDs 4%	370 nm	494 nm	23%
3	NCDs 8%	370 nm	498 nm	27%
4	NCDs 12%	370 nm	497 nm	25%

One of the important parameters for evaluating the fluorescence efficiency of nanomaterials is the quantum yield (QY). A high quantum yield value indicates that the sample has a stronger fluorescence intensity due to energy conversion from excitation energy to emitted light. In this study, the quantum yield value for CDs at 18% and was classified as producing quite good emission efficiency. Then, the quantum yield value increased from 23% for NCDs 4%, 27% for NCDs 8%, and 25% for NCDs 12%. This indicates that nitrogen doping increases the QY value (Table 1). NCDs 8% exhibited the highest QY and emission intensity among all concentrations tested, indicating that this doping level provides the best response under the conditions tested, as well as showing strong potential for fluorescence-based applications. This is related to the rearrangement of electron-hole pairs and modification of the surface state which is integrated with the introduction of nitrogen.

In this case, nitrogen exhibits a new energy level on the surface of the CDs, so that it can narrow the band gap, causing the emission spectrum to a red-shift. This modification of the surface state of CDs associated with nitrogen, also promotes radiative recombination which effectively suppresses non-radiative decay. Meanwhile, the presence of nitrogen-containing functional groups, which act as electron donors, increases the degree of π-conjugation in the carbon network. This allows an electronic transition to occur from the ground state to the excited singlet state, ultimately contributing to an increase in the quantum yield (QY) value. Overall, these processes support enhanced fluorescence performance [18,30].

Table 2. Comparison of Quantum Yield (QY) Values of Biomass-Derived Nitrogen-Doped Carbon Dots (NCDs)

No.	Biomass Precursor	Doping Element	Synthesis Method	QY (%)	References
1	Castor seed	Nitrogen	Hydrothermal	9.6%	[31]
2	*E. plorifera*	Nitrogen	Hydrothermal	10.1%, 12.3%	[18]
3	Drumstick leaves	Nitrogen	Hydrothermal	12.5%	[32]
4	Pitaya peel	Nitrogen	Hydrothermal	5.6%	[33]
5	Candlenut Shells	Nitrogen	Hydrothermal	27%	This work

A comparison of studies with the synthesis of similar NCDs from various biomass precursors was analyzed to provide results in the context of this study (Table 2). NCDs synthesized from biomass precursors of castor seed, *E. prolifera*, drumstick leaves and pitaya peel produced QY values ranging from 5.6% to 12.5%. Compared to previous research, NCDs synthesized from candlenut shells biomass precursors in this study successfully achieved a QY value of 27%. This is related to the high carbon content in candlenut shells (75.79%) and the lignocellulosic composition which facilitates the formation of abundant graphitic domains and oxygenated groups in the hydrothermal carbonization process [13]. Combined with effective nitrogen doping of EDA, the result is densely packed emission sites, reduced non-radiative decay, and stronger fluorescence. These findings confirm, that even though the same hydrothermal and nitrogen doping methods are applied, the type and structure of the biomass precursor play an important role in determining the optical performance and QY values of the resulting CDs.

Fourier Transform Infrared (FTIR)

The FTIR spectra of CDs and NCDs synthesized with varying concentrations of ethylenediamine (4%, 8%, and 12% v/v) were analyzed to identify the dominant surface functional groups, as shown in Figure 4. In the CDs spectrum, three major absorption bands were observed at approximately 3250 cm^{-1}, 2109 cm^{-1}, and 1640 cm^{-1}. The broad band around 3250 cm^{-1} corresponds to -OH stretching vibrations, indicating the presence of hydroxyl groups that contribute to the hydrophilicity and aqueous dispersibility of the CDs. The peak at 2109 cm^{-1} is attributed to C=N stretching vibrations, likely originating from imine groups formed during the dehydration and condensation reactions in the synthesis process. The band near 1640 cm^{-1} corresponds to the stretching vibration of carbonyl groups (C=O), contributing to the polarity and reactivity of the CDs surface. In the FTIR spectra of NCDs, similar functional groups were observed with slight variations in peak position and intensity across the doping levels. Interestingly, the peaks in the range 3250-3272 cm^{-1} become sharper and more intense, especially in the 8% and 12% NCDs samples, indicating increased N-H stretching vibrations associated with the primary or secondary amine groups introduced through EDA doping. The appearance of peaks around 2109-2124 cm^{-1} in all NCDs samples, confirms the addition of imine groups (C=N). The carbonyl peak at around 1640 cm^{-1} is also visible in all samples, confirming the presence of oxygen-containing groups that remain present during the nitrogen doping process [34]. These results indicate the successful doping of nitrogen-containing functional groups with the presence of -NH and C=N groups on the surface of NCDs. The presence of surface modification with nitrogen doping is concluded to improve the electronic structure and surface chemistry of nanomaterials which improves the fluorescence properties of CDs and their potential in light-based applications.

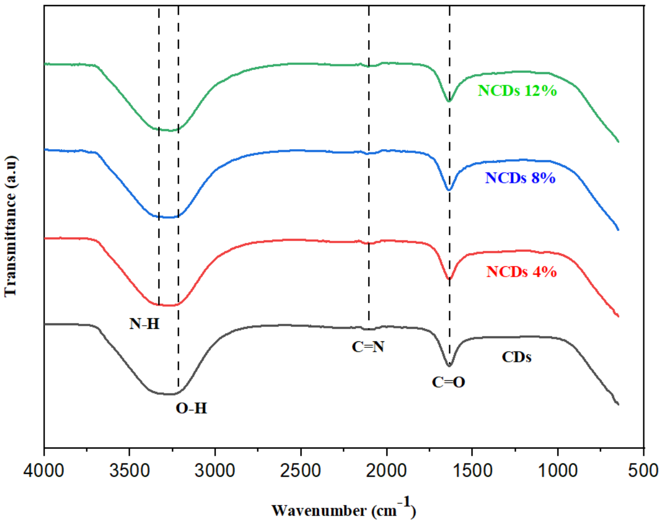

Figure 4. FTIR Spectra of CDs and NCDs

4. Conclusion

CDs and NCDs with varying concentrations of ethylenediamine (EDA) at concentrations of 4%, 8% and 12% (v/v) using the hydrothermal method were successfully synthesized, characterized and analyzed for their optical properties. Bluish-green fluorescence emission was observed in all samples under 365 nm UV light irradiation. The results from UV-Vis showed an absorption peak at 271 nm for the CDs sample and additional absorption peaks at 274 nm and 324 nm for NCDs, which correspond to the π–π^* and n–π^* transitions, respectively. The absorbance intensity is influenced by the EDA concentration, although the peak position is relatively constant. Functional groups such as -OH, -NH, -C=N and C=O were confirmed by FTIR analysis which showed the success of nitrogen doping on the surface of NCDs. Meanwhile, photoluminescence analysis showed fluorescence emission at 484 nm for CDs with a QY of 18%. For NCDs 4% and 12% showed emission wavelengths at 494 nm and 497 nm with QY of 23% and 25%, respectively. Nitrogen doping had the best effect on NCDs 8% which showed the highest fluorescence intensity of all samples at a wavelength of 498 nm and a QY of 27%. Based on these results, it can be confirmed that the addition of EDA as a nitrogen source in the synthesis of CDs succeeded in improving the optical properties of CDs by modifying their surface structure and fluorescence properties.

5. Acknowledgements

The authors sincerely thank the Ministry of Higher Education for the research funding granted through the DRTPM Master Thesis Research Contract Project No: 110/UN5.4.10.S/PPM/KP-DRTPM/2024.

6. Conflict of Interest

Authors declare no conflicts of interest.

References

[1] C. Ren, C. Tian, M. Zhang, F. Li, Y. Li, F. Zhang, J. Zhang, G. Chen, J. Tang, The fluorescence properties of nitrogen-doped carbon dots by microwave green approaches, J. Mol. Struct. 1319 (2025) 139364. https://doi.org/10.1016/j.molstruc.2024.139364.

[2] V. Kansay, V.D. Sharma, G. Chandan, I. Sharma, A. Bhatia, S. Chakrabarti, M.K. Bera, Sustainable synthesis and characterization of fluorescent nanoprobe based on unintentional heteroatom doped-carbon quantum dots for bioimaging of human neuroblastoma cancer cells and living organisms, J. Photochem. Photobiol. A Chem. 443 (2023) 114879. https://doi.org/10.1016/j.jphotochem.2023.114879.

[3] A. Imran, F. Ahmed, Y.A. Ali, M.S. Naseer, K. Sharma, Y.S. Bisht, A.H. Alawadi, U. Shehzadi, F. Islam, M.A. Shah, A comprehensive review on carbon dot synthesis and food applications, J. Agric. Food Res. 21 (2025) 101847. https://doi.org/10.1016/j.jafr.2025.101847.

[4] L. Wang, C. Gu, L. Wu, W. Tan, Z. Shang, Y. Tian, J. Ma, Recent advances in carbon dots for electrochemical sensing and biosensing: A systematic review, Microchem. J. 207 (2024) 111687. https://doi.org/10.1016/j.microc.2024.111687.

[5] B. Wang, H. Cai, G.I.N. Waterhouse, X. Qu, B. Yang, S. Lu, Carbon Dots in Bioimaging, Biosensing and Therapeutics: A Comprehensive Review, Small Sci. 2 (2022). https://doi.org/10.1002/smsc.202200012.

[6] N.A. Abdullah, H.E. Mahmoud, N.A. El-Nikhely, A.A. Hussein, L.K. El-Khordagui, Carbon dots labeled

Lactiplantibacillus plantarum: a fluorescent multifunctional biocarrier for anticancer drug delivery, Front. Bioeng. Biotechnol. 11 (2023) 1–17. https://doi.org/10.3389/fbioe.2023.1166094.

[7] G. Gedda, S.A. Sankaranarayanan, C.L. Putta, K.K. Gudimella, A.K. Rengan, W.M. Girma, Green synthesis of multi-functional carbon dots from medicinal plant leaves for antimicrobial, antioxidant, and bioimaging applications, Sci. Rep. 13 (2023) 1–9. https://doi.org/10.1038/s41598-023-33652-8.

[8] H. Zhang, G. Wang, Z. Zhang, J.H. Lei, T.M. Liu, G. Xing, C.X. Deng, Z. Tang, S. Qu, One step synthesis of efficient red emissive carbon dots and their bovine serum albumin composites with enhanced multi-photon fluorescence for in vivo bioimaging, Light Sci. Appl. 11 (2022). https://doi.org/10.1038/s41377-022-00798-5.

[9] R. Atchudan, S. Chandra Kishore, P. Gangadaran, T.N. Jebakumar Immanuel Edison, S. Perumal, R.L. Rajendran, M. Alagan, S. Al-Rashed, B.C. Ahn, Y.R. Lee, Tunable fluorescent carbon dots from biowaste as fluorescence ink and imaging human normal and cancer cells, Environ. Res. 204 (2022) 112365. https://doi.org/10.1016/j.envres.2021.112365.

[10] M. Marpongahtun, R. Pramudita, S. Gea, A. Daulay, Synthesis of Carbon Dots From Empty Fruit Bunch Biochar an Acid-Free Hydrothermal Method, Elkawnie 9 (2023) 61. https://doi.org/10.22373/ekw.v9i1.14524.

[11] M. Kumar, S. Chinnathambi, N. Bakhori, N. Abu, F. Etezadi, V. Thangavel, D. Packwood, E. Sivaniah, G.N. Pandian, Biomass-derived carbon dots as fluorescent quantum probes to visualize and modulate inflammation, Sci. Rep. 14 (2024) 1–12. https://doi.org/10.1038/s41598-024-62901-7.

[12] J. Goswami, H. Barman, P. Hazarika, P. Manna, A. Devi, L. Saikia, Biomass-derived phosphorous-doped carbon quantum dots (P-CQD): An excellent biocompatible material for in-vitro cell imaging, Inorg. Chem. Commun. 162 (2024) 112276. https://doi.org/10.1016/j.inoche.2024.112276.

[13] D. Nurdiati, Astuti, Sintesis Komposit PAni / Karbon dari Tempurung Kemiri (Aleurites moluccana) Sebagai Elektroda Kapasitor, J. Fis. Unand 4 (2015) 51–57.

[14] R.K. Dewi, M.I. Hudha, A. Rauda, S. Tsulusia, Chemical and Physical Process Combinations: Microwave in Lignin Degradation of Pecan Shells as Alternative Fuel Raw Materials, 1 (2020) 63–67. https://doi.org/10.2991/snk-19.2019.16.

[15] M. Desa, D. Selatan, K. Gorontalo, Insan Cita, 7 (2025) 761–773.

[16] M. El-Azazy, A.I. Osman, M. Nasr, Y. Ibrahim, N. Al-Hashimi, K. Al-Saad, M.A. Al-Ghouti, M.F. Shibl, A.H. Al-Muhtaseb, D.W. Rooney, A.S. El-Shafie, The interface of machine learning and carbon quantum dots: From coordinated innovative synthesis to practical application in water control and electrochemistry, Coord. Chem. Rev. 517 (2024) 215976. https://doi.org/10.1016/j.ccr.2024.215976.

[17] N. Prathap, P. Balla, M.S. Shivakumar, G. Periyasami, P. Karuppiah, K. Ramasamy, S. Venkatesan, Prosopis juliflora hydrothermal synthesis of high fluorescent carbon dots and its antibacterial and bioimaging applications, Sci. Rep. 13 (2023) 1–11. https://doi.org/10.1038/s41598-023-36033-3.

[18] Y. Xu, D. Li, M. Liu, F. Niu, J. Liu, E. Wang, Enhanced-quantum yield sulfur/nitrogen co-doped fluorescent carbon nanodots produced from biomass Enteromorpha prolifera: Synthesis, posttreatment, applications and mechanism study, Sci. Rep. 7 (2017) 1–12. https://doi.org/10.1038/s41598-017-04754-x.

[19] T. Watcharamongkol, P. Khaopueak, C. Seesuea, K. Wechakorn, Green hydrothermal synthesis of multifunctional carbon dots from cassava pulps for metal sensing, antioxidant, and mercury detoxification in plants, Carbon Resour. Convers. 7 (2024) 100206. https://doi.org/10.1016/j.crcon.2023.100206.

[20] R. Zhou, C. Chen, J. Hu, X. Liao, H. Hu, Z. Tong, J. Liang, F. Huang, The self-nitrogen-doped carbon quantum dots derived from Morus alba L. leaves for the rapid determination of tetracycline, Ind. Crops Prod. 188 (2022) 115705. https://doi.org/10.1016/j.indcrop.2022.115705.

[21] M. Vega, R.M. Gomila, J. Pons, A. Frontera, C. Rotger, A. Costa, Synthesis and fluorescence of N-squaraine dianions derived from electron-deficient primary anilines, Dye. Pigment. 207 (2022) 110746. https://doi.org/10.1016/j.dyepig.2022.110746.

[22] C. Zhou, S. Wu, S. Qi, W. Song, C. Sun, Facile and High-yield Synthesis of N-doped Carbon Quantum Dots from Biomass Quinoa Saponin for the Detection of Co2+, J. Anal. Methods Chem. 2021 (2021). https://doi.org/10.1155/2021/9732364.

[23] A. Paul, M. Kurian, Facile synthesis of nitrogen doped carbon dots from waste biomass: Potential optical and biomedical applications, Clean. Eng. Technol. 3 (2021) 100103. https://doi.org/10.1016/j.clet.2021.100103.

[24] H. Shabbir, E. Csapó, M. Wojnicki, Carbon Quantum Dots: The Role of Surface Functional Groups and Proposed Mechanisms for Metal Ion Sensing, Inorganics 11 (2023). https://doi.org/10.3390/inorganics11060262.

[25] H. Ding, X.H. Li, X.B. Chen, J.S. Wei, X.B. Li, H.M. Xiong, Surface states of carbon dots and their influences on luminescence, J. Appl. Phys. 127 (2020). https://doi.org/10.1063/1.5143819.
[26] B. Zhang, W. Liu, X. Wu, J. Zhu, W. Hu, A. El Jaouhari, X. Liu, Facile Preparation of Fluorescent Carbon Dots from Glutathione and l -Tryptophan for Sensitive and Selective Off/On Detection of Fe3+Ions in Serum and Their Bioimaging Application, ACS Omega 7 (2022) 7853–7864. https://doi.org/10.1021/acsomega.1c06757.
[27] N.K. Khairol Anuar, H.L. Tan, Y.P. Lim, M.S. So'aib, N.F. Abu Bakar, A Review on Multifunctional Carbon-Dots Synthesized From Biomass Waste: Design/ Fabrication, Characterization and Applications, Front. Energy Res. 9 (2021) 1–22. https://doi.org/10.3389/fenrg.2021.626549.
[28] R. Riska, M. Marpongahtun, S. Gea, Synthesis and characterization nitrogen-doped carbon dots from candlenut shells using hydrothermal and solvothermal methods, J. Pendidik. Kim. 16 (2024) 15–22. https://doi.org/10.24114/jpkim.v16i1.56957.
[29] F. Yan, Z. Sun, H. Zhang, X. Sun, Y. Jiang, Z. Bai, The fluorescence mechanism of carbon dots, and methods for tuning their emission color: a review, Microchim. Acta 186 (2019). https://doi.org/10.1007/s00604-019-3688-y.
[30] M. Ali, A.S. Anjum, R. Riaz, A. Bibi, K.C. Sun, S.H. Jeong, Unraveling the surface states related Stokes shift dependent electrocatalytic activity of N-doped carbon quantum dots for photovoltaic applications, Carbon N. Y. 181 (2021) 155–168. https://doi.org/10.1016/j.carbon.2021.04.075.
[31] S. Elkun, Green synthesis of fluorescent N-doped carbon quantum dots from castor seeds and their applications in cell imaging and pH sensing, (2024) 1–24.
[32] K.S. Raju, G.S. Das, K.M. Tripathi, Nitrogen-doped carbon quantum dots from biomass as a FRET-based sensing platform for the selective detection of H2O2 and aspartic acid, RSC Sustain. 2 (2023) 223–232. https://doi.org/10.1039/d3su00343d.
[33] Y. Jia, Z. Cheng, G. Wang, S. Shuang, Y. Zhou, C. Dong, F. Du, Nitrogen doped biomass derived carbon dots as a fluorescence dual-mode sensing platform for detection of tetracyclines in biological and food samples, Food Chem. 402 (2023) 134245. https://doi.org/10.1016/j.foodchem.2022.134245.
[34] A. Dager, T. Uchida, T. Maekawa, M. Tachibana, Synthesis and characterization of Mono-disperse Carbon Quantum Dots from Fennel Seeds: Photoluminescence analysis using Machine Learning, Sci. Rep. 9 (2019) 1–10. https://doi.org/10.1038/s41598-019-50397-5.