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Review: Characterization of Optical and Structural Properties of Carbon Nanodots (CNDs) from Biomass Waste by Microwave Method

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ABSTRACT

This review focuses on examining the synthesis and characterization of Carbon Nanodots (CNDs) from the utilization of Tandan Kosong Kelapa Sawit (TKKS) using the microwave method as an environmentally friendly approach. The resulting CNDs were characterized for their optical and structural properties to evaluate their potential application in the field of biosensors. The synthesis process involves carbonizing TKKS at 500°C for 3 hours, followed by activation using a microwave at 450 Watts for 15 minutes. UV-Vis characterization shows an absorption peak at 280 nm, which indicates $n-\pi^*\,(C=O)$ *and* $\pi-\pi^*\,(C=C)$*. Meanwhile, FTIR characterization aims to determine the presence of the carbonyl* $C=O$ *functional group at 1990,98* cm^{-1} *and the aromatic* $C=C$ *bond at 1416,2* cm^{-1}*. The CNDs from TKKS exhibit photoluminescent properties and surface functional groupss that enhance adsorption performance and chemical reactivity. This research offers an efficient and sustainable method for synthesizing CNDs, while also being a breakthrough in utilizing biomass wate, particularly TKKS. The findings have the potential for developing carbon materials in environmental and energi applications.*

1. INTRODUCTION

Carbon Nanodots are research focused on supporting a science and technology development. Carbon Nanodots (CNDs) are the newest group of nanomaterials, with a size of less than 10 nm and zero dimensions (Abinaya et al., 2021). CNDs exhibit functional properties based on variations in their size, crystal structure, and quantum confinement (Chen et al., 2019). The advantages of CNDs include good optical properties, high chemical stability, photostability, water solubility (Novita, 2023), good biocompatibility, and low toxicity (Guo et al., 2023). The structural variations of CNDs include amorphous carbon structures with graphite, graphite oxide structures, and crystals. The chemical and physical properties of CNDs play an important role in improving high photoluminescence properties. The photoluminescence emission produced by CNDs has varying wavelengths due to the wavelength changes caused by excitation (Ng et al., 2021). If using CNDs, it can be used in a variety of aspects, such as biological imagingety, photocatalysis, biosensors, chemical detection, nanomedicine, electrocatalysis and more (Dua et al., 2023). Based on research conducted by Jenitha in 2023, CNDs have been successfully explored for the detection of metal ions. As the effect on nanoscalar is reduced, the semiconductor properties such as fluorescence acting as an isolator are reduced. The reduction effect occurs due to radiative recombination of electron-hole pairs (Fairlin Jenitha & Sudhaparimala, 2023).

CNDs can be synthesized from all materials containing carbon bonds, such as biomass, making them environmentally friendly (Gultom, 2024). Biomass is a sustainable, inexpensive, and environmentally friendly raw ingredient as a carbon source (Rajkishore et al., 2023). TKKS are a biomass waste that can be utilized as a primary raw material due to their high adsorption properties toward various organic and inorganic substances (Oktaviani et al., n.d.). TKKS as lignocellulosic waste contain active carbon bonds and thus may be biostested (Suryani et al., 2024). Generally, the synthesis of CNDs can be done through top-down and bottom-up methods. The techniques such as mortar and grinding. On the other hand, the bottom-up method involves polymerizing and carbonizing small materials (Elugoke et al., 2024).

One way to utilize biomass waste as a raw material for CNDs is to converted into high-value nanomaterials using microwave techniques. The method using microwaves is considered more efficient, energy-saving, and environmentally friendly (Fairlin Jenitha & Sudhaparimala, 2023). Based on research conducted by Prasasti in 2022, it was stated that the microwave method can be carried out through a heating process utilizing microwave waves, resulting in a simpler and faster synthesis process (Prasasti et al., 2022). This review aims to examine the optical and structural properties of CNDs synthesized from biomass as a carbon source using the microwave technique. Optical characterization was performed using UV-Vis Spectroscopy. Meanwhile, to determine the structure, characterization was conducted using FTIR (Fourier Transform Infrared Spectroscopy). This review represents a more sustainable alternative to CND integration, and is expected to act as an original step for efficient use of agricultural and industrial waste.

2. METHODOLOGY

The method used in compiling this review journal is divided into several system stages. The first step is to conduct a literature study and gather references from various sources including relevant journal articles or scientific paper on CNDs from biomass. The search and collection of references are conducted using reliable databases and accredited publication quality, such as ScienceDirect, ResearchGate, and Google Scholar. The second stage is the analysis and understanding of objectives, relevance of methods, result, and conclusions of each journal. The third stage involves comparing and synthesizing the findings from the selected journals to identify trends and the scientific contributions generated. The synthesis results are systematically presented in the form of a journal review, including an introduction, methodology, discussion, and conclusion.

3. RESULTS AND DISCUSSION

Carbon Nanodots (CNDs) can be synthesized from a variety of materials, including biomass. Based on research conducted by Rajkishore in 2023, it was explained that biomass can be utilized as a raw material for CNDs. CNDs are synthesized using the hydrothermal methods as they are more economical and environmentally friendly (Rajkishore et al., 2023). One type of biomass waste that can be utilized as a carbon source is TKKS (Tandan Kosong Kelapa Sawit). Based on research conducted by Suryani in 2024, it was stated that TKKS has a chemical composition consisting of lignin, cellulose, and hemicellulose, which are precursors in the production of CNDs (Suryani et al., 2024).

3.1. Synthesis Methods CNDs

The synthesis methods for CNDs are divided into two types: Top-Down and Bottom-Up synthesis.

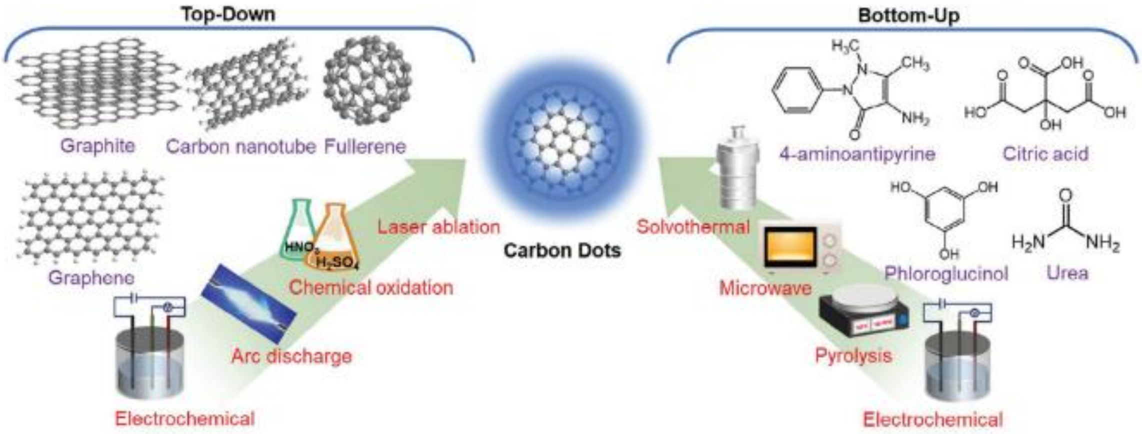

Figure 1. Synthesis methods for Carbon Nanodots (CNDs) (Ren et al., 2024)

The top-down method involves grinding or crushing large-sized materials into smaller sizes. In contrast, the bottom-up method involves changing particle size from small to larger using various techniques such as homogenization and grinding (Maslahat et al., 2022). The synthesis method used microwave heating because it is simpler. Microwave methods include heating using microwave radiation. Based on previous study, it was found that synthesis processes using microwave methods can simplify and accelerate the synthesis process (Prasasti et al., 2022). Carbon produced by microwave method has good absorption capabilities for various organic and inorganic compounds (Oktaviani et al., n.d.). TKKS samples were carbonized using an oven at 500°C for 3 hours until they became powder (Novita, 2023). The carbon product was then ground using a sieve until a particle size of 100 mesh was obtained. The sample was washed with distilled water 4 times and dried using a hotplate at 120°C to reduce the moisture content of the sample. The sample was then microwaved at 450 Watts for 15 minutes. The sample were then centrifuged to separate the CNDs from deleted carbon source. Sample was centrifuged at 800 rpm for 10 minutes (Oktaviani et al., n.d.). Based on research conducted by Prasasti in 2022, it is stated that the addition of doping is highly necessary to help improve the sensitivity of CNDs as a biosensor. The Fe^{3+} metal ions added to the CNDs sample will form carbon chains, causing a shift in their absorbance peak. The observed shift indicates a reaction between CNDs and Fe^{3+} (Prasasti et al., 2022). Sample characterization was performed using UV-Vis Spectroscopy and FTIR *(Fourier Transform Infrared Spectroscopy).*

3.2. Characterization

Using Ultraviolet and visible (Vis) light, UV-Vis characterization was performed to measure the absorption or transmission of light absorbed. Research conducted by Abinaya in 2021 found that the TKKS sample showed absorptionat a wavelength of 280 nm (Figure 2). Figure 2 shows that the light scattering produced when the sample illuminated with ultraviolet light differs from the light scatering produced when the sample is not illuminated with ultraviolet light. This indicates the presence of an $n - \pi^*$ transition from the $C = O$ band and $n - \pi^*$ transition from the $C = C$ (Abinaya et al., 2021)

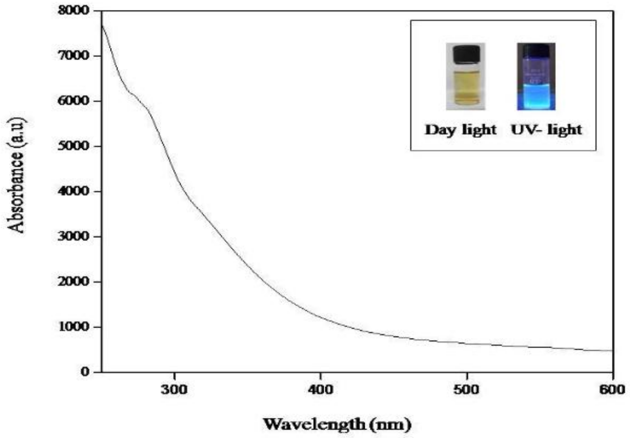

Figure 2. The UV-Vis spectrum of CNDs shows an absorption peak at 280 nm (Abinaya et al., 2021)

The solution samples not exposed to ultraviolet light showed a pale yellow color, while the environment of the samples exposed to ultraviolet light showed blue-colored light emission scattering, as shown in Figure 2. This result aligns with Nguyen's 2022 study, which found that hydrothermally synthesized banana peel hydrogel materials have an absorption peak at 280 nm, directly related to the $n - \pi^*$ transition (Nguyen et al., 2022). According to Novita's research in 2023, UV-Vis test characterization shows that the sample will be excited due to the absorption of ultraviolet wavelength energy. The sample's excitation energy causes wavelengths to form, leading to UV-Vis characterization absorption. According to Novita (2023), electron excitation occurs when electrons move from the Highest Occupied Molecular Orbital (HOMO) to the Lowest Unoccupied Molecular Orbital (LUMO) (Novita, 2023).

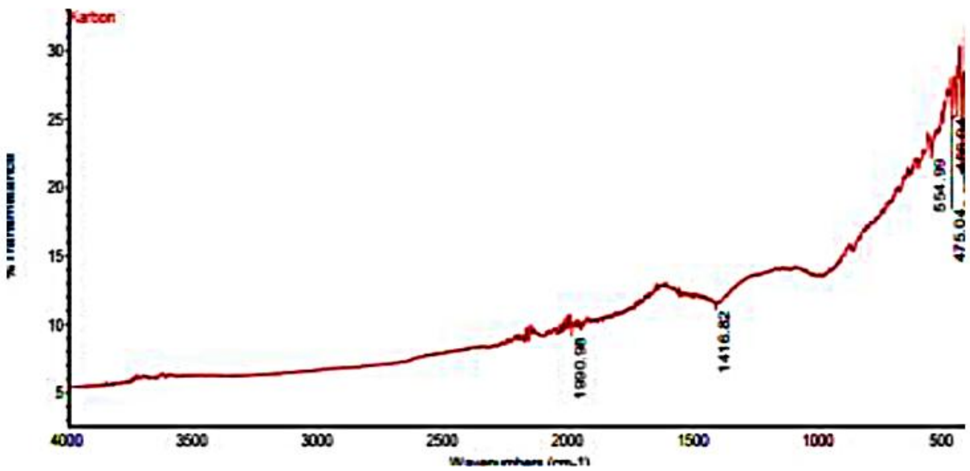

Figure 3. FTIR functional group spectrum of CNDs microparticles (Maslahat et al., 2022)

The samples were analyzed using FTIR (Fourier Transform Infrared Spectroscopy) to identify the functional groups present in micro-sized CNDs. The FTIR test not only demonstrates the adsorption properties of carbon materials with unlimited pore size but also reveals the presence of functional groups in the samples. According to research conducted by Maslahat in 2022, during FTIR testing, vibrations were observed for each functional group. The resulting functional groups (as shown in Figure 3) show a wavelength at1990,90 cm^{-1}. The results identify the presence of a C=O group. FTIR testing also yielded pyrolysis values that form C=C bonds at a wavelength of 1416,2 cm^{-1}. The increase in temperature during the characterization process causes a shift in the absorption peaks and the formation of unstable radical compounds (Maslahat et al., 2022)

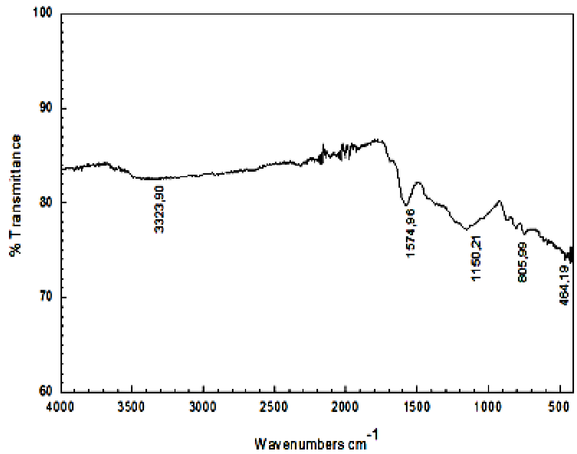

Figure 4. FTIR functional group spectrum of coconut shell activated carbon content (Studi et al., 2019).

According to research conducted by Putri in 2019 (Figure 4), FTIR testing on activated carbon from coconut shells successfully showed the functional groups present in the sample. The resulting spectrum shows absorption at wavelengths corresponding to the $\mathbf{C = C}$ hydroxyl functional group of activated carbon. Based on Figure 4, the wavelength spectrum is at 3323,90 $\mathbf{cm^{-1}}$. The $\mathbf{C = C}$ stretching vibration is found at a wavelength of 1574,94 $\mathbf{cm^{-1}}$, while the $\mathbf{C = O}$ group is observed at an absorption peak of 1150,21 $\mathbf{cm^{-1}}$. The $\mathbf{C - C}$ stretching vibration appears at a wavelength of 464,18 $\mathbf{cm^{-1}}$ (Studi et al., 2019).

CNDs from coconut shells exhibit photoluminescent properties and surface functional groups that enhance adsorption performance and chemical reactivity. This review offers an efficient and sustainable method for synthesizing CND and is an innovation in utilizing biomass waste, particularly coconut shells. This finding has the potential to develop carbon materials for environmental and energy applications

4. CONCLUSION

The CNDs from TKKS exhibit promising photoluminescent properties with blue light emission upon UV excitation. These properties, coupled with the abundant surface functional groups, make CNDs a material with good adsorption performance and chemical reactivity. This research has successfully proven that TKKS biomass waste can be converted into high-value nanomaterials. Additionally, this research provides an innovative solution for utilizing sustainable biomass waste. The existing findings present an opportunity for the application of nanomaterials in the fields of biosensors, photocatalysis, and biomedicine. The relatively simple and environmentally friendly synthesis process further strengthens the potential for large-scale implementation. Thus, this review not only contributes to material development but also serves as a new sustainable approach to utilizing renewable resources.

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