

Synthesis of Green Carbon Dots from *Nephelium Lappaceum L.* Seeds

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Abstract: This study used rambutan (*Nephelium Lappaceum L.*) seeds to fabricate green carbon dots (gCDs) using hydrothermal processes. The synthesized CDs were evaluated using Fourier transform infrared (FT-IR) and X-ray photoelectron spectroscopy (XPS) for the structural properties and UV-Vis and fluorescence spectrophotometry for the optical properties. The results showed the solubility of gCDs in water and their excellent optical properties. UV-Vis examination revealed that the produced gCDs had an absorption peak at 265 nm and a shoulder peak at 330 nm, which referred to C=C ($\pi - \pi^*$) and C=O ($n - \pi^*$), respectively. In addition, the photoluminescence of gCDs showed excitation dependent on emission spectra. FTIR and XPS spectra results confirmed the presence of functional groups and chemical compositions such as C=C, C=O, -COOH, and -OH on the surface of gCDs. This study contributes to developing sustainable nanomaterial synthesis and highlights the potential of gCDs derived from *Nephelium lappaceum L.* seeds, in a range of applications.

Keywords: Green Carbon Dots; Hydrothermal; Rambutan Seeds.

Introduction

Recently, there has been a lot of interest in the production of carbon dots (CDs) due to their many potential uses in fields like optoelectronics [1], biomedicine [2], and environmental remediation [3]. As a class of carbon-based nanomaterials, CDs are highly promising for several technological enhancements due to their outstanding optical characteristics, biocompatibility, and low toxicity [4,5]. However, using hazardous materials and energy-intensive processes in conventional synthesis methods highlights concerns regarding the sustainability and safety of the environment.

Developing environmentally conscious synthesis strategies for CDs that use natural resources and eco-friendly techniques has gained traction as an alternative to these problems. Among these, using biomass-derived precursors and agricultural waste allows an intriguing approach that offers affordable and sustainable substitutes for conventional synthesis methods [6,7].

Nephelium lappaceum L., commonly known as the rambutan fruit, is abundant in tropical regions and has been explored for its diverse applications in traditional medicine, food, and cosmetics. The tropical fruit rambutan (*Nephelium lappaceum L.*), extensively grown in Indonesia, is renowned due to its tempting pulp. The seeds of *Nephelium lappaceum L.* are particularly intriguing due to their carbon-rich composition, making them a promising precursor for synthesizing carbon dots. Fats (33.5%), proteins (14%), carbs (46%), anthocyanins (3%), catechins (3%), and complex polyphenols are found in rambutan seeds [8]. Moreover, utilizing *Nephelium lappaceum L.* seeds for carbon dot synthesis aligns with the principles of

green chemistry, offering a sustainable and environmentally friendly approach.

This study introduces a distinctive green synthesis method for gCDs, employing rambutan seed as a precursor by hydrothermal method. Hydrothermal synthesis enables the controlled formation of carbon dots by subjecting precursor mates and utilizing aqueous solutions. Utilizing non-toxic materials and environmentally friendly processes offer a practical path toward producing gCDs with enhanced optical properties and biocompatibility. Using rambutan seed promotes the creation of valuable goods and provides a sustainable approach to waste management. Overall, the green synthesis of gCDs from rambutan seed represents a sustainable and eco-friendly approach towards developing advanced nanomaterials with wide-ranging applications.

Research Methods

Material

The seeds were collected from rambutan harvested in the West Nusa Tenggara Province of Indonesia. It was first rinsed in tap water and then dried in the sunlight for some time. The dried rambutan seeds were ground into a fine powder, and the larger particles were removed by passing them through a 60-mesh screen.

Synthesis of gCDs

The present study used hydrothermal to synthesize the gCDs, with rambutan seeds treated as the precursor. Typically, 1.5 g of rambutan seeds were dissolved in 25 mL

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of DI water and mixed for a few minutes throughout the synthesis process. The solution was added to 50 ml of autoclave and heated for two hours at 180°C in an oven. The mixture was then run through a 0.22 µm micron filter, and dialysis was performed for 24 hours using a 3500 Da dialysis membrane. To obtain the solid, the filtrate was oven-dried at 60 °C. Subsequent analyses were conducted using the sample.

Characterization of gCDs

The functional group on the gCDs surface was verified using a Fourier Transform Infrared (FTIR) spectrometer provided by Perkin Elmer (USA). Using a PHI Hybrid Quanterra, X-ray photoelectron spectroscopy (XPS) was employed to explore the elemental composition of gCDs. A spectrofluorometer (Jasco, Japan) was used to observe the PL spectra. A spectrophotometer ultraviolet-visible UV-vis (Perkin Elmer, USA) was used to acquire absorption spectra.

Results and Discussion

FTIR Characterization

The FTIR spectra that revealed the surface functions of the gCDs are presented in Figure 1. There is evidence of C-O functional groups in the bands between 1040 and 1300 cm⁻¹ [9,10]. Characteristic stretching vibrations for C=C at 1457 cm⁻¹ confirm the presence of aromatic hydrocarbons in the generated gCDs [10]. The carboxylic acid peak, represented by C=O, was seen at 1745 cm⁻¹ [11]. C-H stretching vibration was evident at peaks 2923 and 2854 cm⁻¹ [12,13]. In the meantime, the broad O-H absorption is responsible for the peaks at 3331 cm⁻¹ [14]. As a result, the FTIR study demonstrates that the surface of gCDs contains significant functional groups, including C=O, C=C, C-O, and O-H. According to the main components of rambutan seeds reported by Sirait (2023) [8], it's possible that these primary components' molecular characteristics were passed down to the synthesized gCDs.

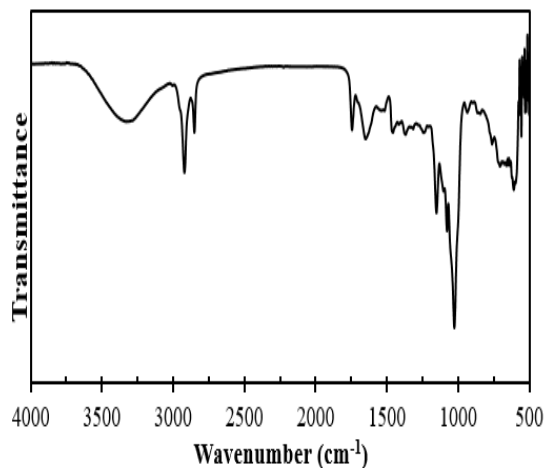


Figure 1. FTIR spectrum of gCDs

XPS Characterization

The two peaks of the XPS spectra, designated as C1s and O1s, indicate that C and O made up an atomic

percentage ratio of C: O= 75,7: 24,3 in the gCDs synthesis (Figure 2). The high-resolution XPS spectra in Figure 3 showed that C-C/C=C was responsible for the C1s spectrum at 284.5. The receding peaks at 287.8 eV and 285.8 eV were assigned to C=O (carboxyl) and C-OH (hydroxyl). This outcome is in line with earlier researchers [15-18]. Concurrently, the C=O/COOH group was assigned to the single peak at 531.4 in the O1s spectrum, as seen in Figure 4. The results of the FTIR spectra, the XPS spectra thus demonstrate that the gCDs' surface was composed of -COOH, -C=O, -OH, and a π conjugated structure.

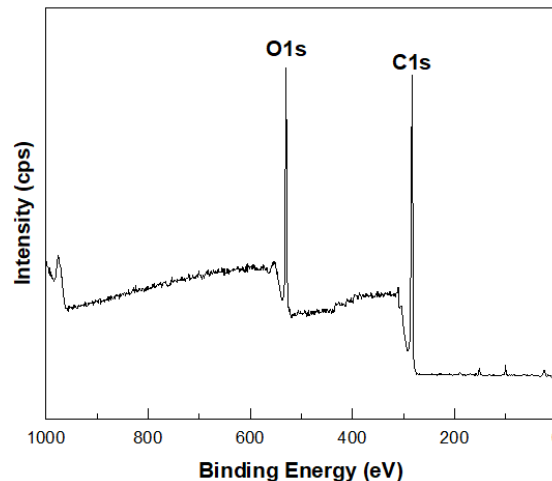


Figure 2. The gCDs' X-ray Photoelectron Spectrum (XPS)

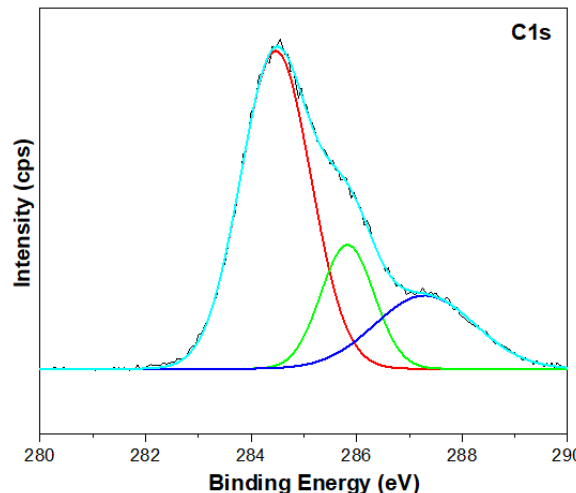


Figure 3. High-Resolution Spectrum of C1s

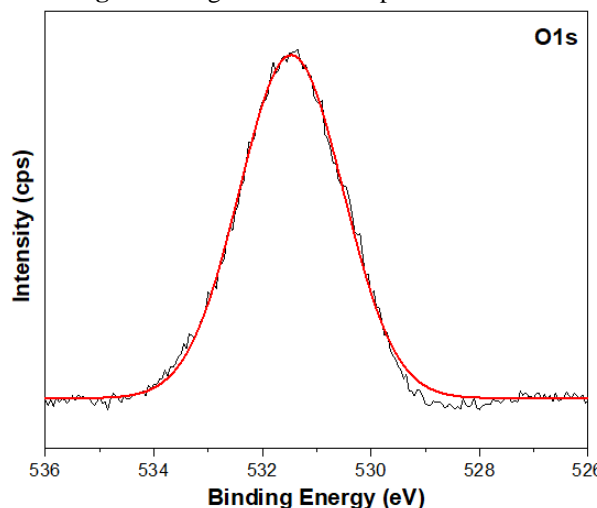


Figure 4. High-Resolution Spectra of O1s

Optical Properties

The UV-Vis result of gCDs is displayed in Figure 5. The center of the absorption peak is 265 nm, whereas the shoulder peak is 330 nm. These peaks, $\pi - \pi^*$ and $n - \pi^*$, respectively, are most likely connected to the transitions of C=C bonds and C=O [19-21]. These transformations were also demonstrated for carbon dots derived from different natural sources [22]. For comparison, the $\pi - \pi^*$ transition was absorbed in approximately 240 and 270 nm for carbon dots made from citrus lemon juice [10], and neem (*Azadirachta indica*) leaves [23]. About the $n - \pi^*$ transition, reports have shown that the absorption peak at 350 nm is the same for the carbon dot generated citrus lemon juice and neem (*Azadirachta indica*) leaves. These findings show that, in comparison to carbon dots generated from lemon juice, gCDs from rambutan seeds have a bigger $\pi - \pi^*$ and a smaller $n - \pi^*$ energy gap. Compared to carbon dots generated from neem leaves, gCDs have a broader energy gap in either $\pi - \pi^*$ or $n - \pi^*$. The differences in the electrical structures of carbon dots can be attributed to different synthesis techniques or precursor chemical components [24,25].

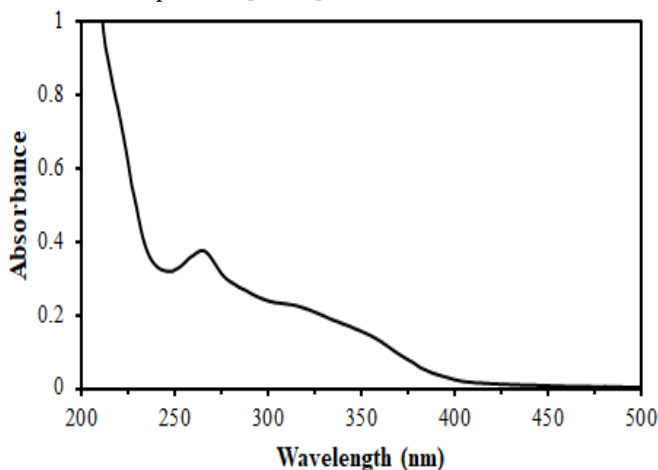


Figure 5. UV-Vis Absorption Spectra of gCDs

Excitation and emission spectra were obtained using a spectrofluorometer to provide insight into the photoluminescence of gCDs. Figure 6 shows that the maximum emission intensity was measured at 406 nm while the maximum excitation intensity was measured at 330 nm. - different emission spectra at varying excitation wavelengths were observed to determine if the synthesized gCDs showed excitation-dependent photoluminescence.

Figure 6 depicts the photoluminescence emission spectra of the CQDs at excitation wavelengths within 300 and 480 nm. Depending on the photoluminescence excitation, two distinct regions of photoluminescence appeared. This result is consistent with studies reported by previous researchers [26-28]. The photoluminescence emission showed a red shift from 405 to 420 nm when the photoluminescence excited about 300 to 370 nm. When the photoluminescence excitation was between 350 and 480 nm, the photoluminescence emission revealed a red shift from 435 to 515 nm. Additionally, at photoluminescence excited wavelength greater than 480 nm, no photoluminescence is emitted. The emission wavelength alterations at different excitation wavelengths were linked

to the surface functional groups and the varying diameters of the gCDs particles [13,29,30].

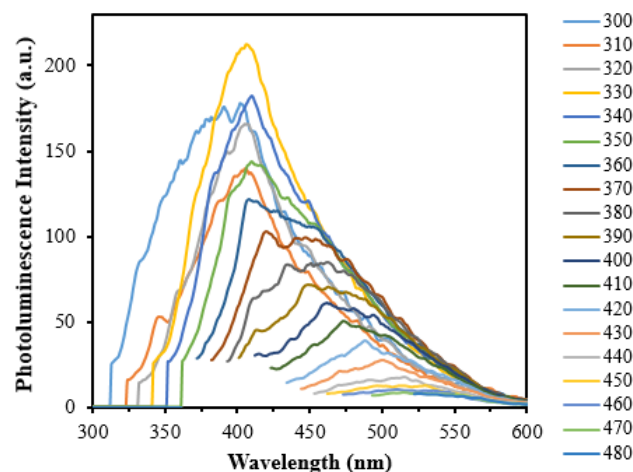


Figure 6. Photoluminescence Intensity at Various Excitation Wavelengths of gCDs

Conclusion

In summary, water-soluble gCDs have been produced using rambutan seeds as a precursor and a simple hydrothermal method. It has been shown that gCDs possess characteristics comparable to those resulting from synthesized carbon dots from previous studies. Finally, because gCDs from rambutan seeds have exceptional optical properties and good solubility in water, we believe they have considerable potential for further development in various applications.

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