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The Effect of Microwave Heating Time on the Optical Properties of CDs from Soursop Leaves Based on UV-Vis Spectrum Analysis

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ABSTRACT

This study investigated the effect of microwave heating duration on the optical properties of Carbon Dots (CDs) synthesized through a green synthesis using soursop leaf extract (Annona muricata L.) as a natural carbon precursor. The synthesis process was carried out using microwave-assisted carbonization with heating durations of 0 minutes (Non), 10 minutes (T10), and 20 minutes (T20) to evaluate the influence of reaction time on the optical characteristics. UV–Vis spectroscopic analysis was performed at a wavelength range of 200–800 nm to determine the absorption of resulting CDs. The spectrum showed that the absorbance intensity increased significantly with longer microwave heating times, with a dominant peak observed around 280 nm, corresponding to the π–π* electronic transition of aromatic C=C bonds. Transitions from heteroatom-containing groups such as C=O or C–N can be seen at a weak shoulder around 320–350 nm, which was attributed to n–π*. The increased absorption intensity at T20 indicates a higher degree of conjugation and carbonization, showing more developed sp^2 domains within the CDs. This research demonstrates that microwave heating duration tunes the optical and electronic properties of the synthesized CDs, offering potential control of band structure and absorption for future applications in photonic and optoelectronic materials.

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1. INTRODUCTION

Carbon Dots (CDs) have gained attention in the field of nanotechnology, mainly due to their remarkable optical, chemical, and biocompatible properties, over the past decade [1]. CDs particle sizes are typically less than 10 nm, with an amorphous or semi-crystalline carbon nucleus surrounded by functional groups in nitrogen and oxygen [2]. They have strong light absorption in ultraviolet to visible range, high fluorescence ability, and outstanding photochemical stability based on structural combination [3].

Green synthesis techniques, which use natural biomass as carbon precursors, have been the focus of recent developments in CDs synthesis. Sustainable alternatives or organic sources, such as leaves, fruits, roots, agricultural waste, and plant-based compounds, have been explored as carbon precursors [4]. Soursop leaves (*Annona muricata L.*), an organic compound, have such as lignocellulose, flavonoids, and polyphenols, making it a promising biomass source from nature [5], [6]. These compounds contain carbon and heteroatoms (O and N), forming active functional groups on the surface CDs [7].

Based on various synthesis CDs, microwave heating is an efficient and versatile technique. Unlike conventional, microwave irradiation induces rapid and uniform volumetric heating, accelerating the carbonization and dehydration of organic molecules in a short time [8]. In addition, this method allows precise control of synthesis parameters such as temperature, time, and power, which influence the particle size, surface functionalization, and optical characteristics [9].

This study purpose to investigate the effect of microwave heating duration on the optical characteristics of CDs from soursop leaves using UV–Vis spectroscopy analysis. This provides a deeper the relationship between heating duration and formation of conjugated systems in CDs structure, offering a fundamental understanding for the development of biomass-derived carbon materials for optoelectronic and sensing applications.

2. METHODS

a. Materials and Equipment

Fresh soursop leaves from the local environment and distilled water as the solvent. All materials were used without further purification. The main equipment includes a microwave oven (600 W), a glass beaker, filter paper, a centrifuge, a measuring pipette, and a UV–Vis spectrophotometer (Shimadzu UV-2600) for optical characterization.

b. Preparation of Soursop Leaf Extract

The soursop leaves were washed, air-dried, and then ground into a fine powder. A total of 10 grams of the powdered soursop leaves were boiled in 100 mL of distilled water for 30 minutes to extract organic compounds, which serve as carbon precursors. The resulting solution was filtered using a fine cloth. The brownish-green filtrate was used as the starting material for the synthesis of CDs.

c. Synthesis of CDs via Microwave Heating

A total of 20 mL of the soursop leaf was placed in a glass beaker and heated in a microwave oven operated at 80% of 600 W $(600\ \text{W} \times 0.8 = 480\ \text{W is actual power output})$ was used for heating process with the following variations:

- Non: without microwave heating (as control),
- T10: heated for 10 minutes,
- T20: heated for 20 minutes.

The ‘Non’ sample represents the soursop-leaf extract without any microwave heating and serves as the untreated baseline. The sample underwent filtration and centrifugation only, without exposure to thermal carbonization.

d. Purification of CDs Product

After cooling to room temperature, the solution was centrifuged at 5,000 rpm for 10 minutes to remove coarse particles and biomass residues. The clear supernatant was filtered using a 0.22 μm membrane filter, resulting in a homogeneous suspension containing nanosized CDs.

e. Characterization Using UV-Vis Spectroscopy

Optical characterization using a UV–Vis spectrophotometer within the wavelength range of 200–800 nm.

3. RESULT AND DISCUSSION

The formation of nanoscale carbon structures was initially indicated by the color change of the soursop leaf extract. The initial color, like a brownish-green, indicated the dominance of organic compounds such as polyphenols, flavonoids, and lignin, which play key roles as carbon precursors and natural reducing agents. The solution turned dark brown after 10 minutes (T10). After 20 minutes (T20), it became darker and more intense (Figure 1). This color change indicates the increasing degree of carbonization due to the dehydration and condensation of organic compounds, leading formation of aromatic carbon cores. Similar phenomena have been reported in various biomass sources, such as tea leaves, orange peels, and agricultural waste, which show color changes as indicators during the synthesis of CDs [6], [10].

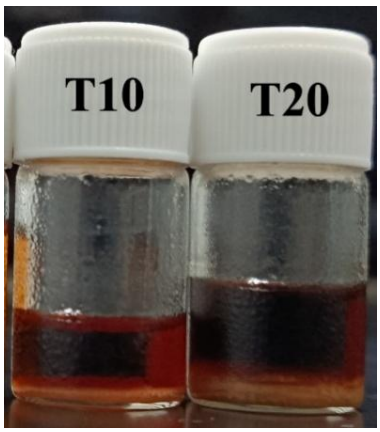

Figure 1. Result of CDs Synthesis via Microwave Heating for T10 and T20 samples.

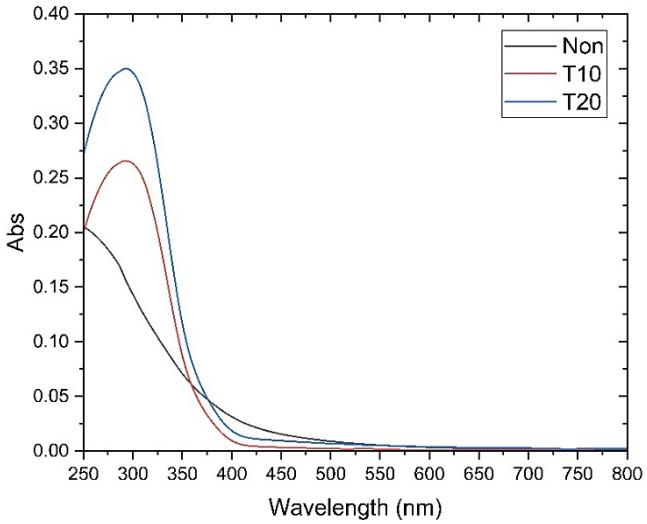

Figure 2. UV-Vis Spectrum of CDs with Microwave Heating Time Variation.

The UV–Vis spectroscopic analysis, as shown in Figure 2, provided the formation of conjugated aromatic domains. The sample without microwave treatment (Non) has no absorption peak in the wavelength range of 200 – 400 nm, indicating that the organic compounds have not yet transformed into conjugated carbon structures. The sample heated for 10 minutes (T10) showed a sharp absorption peak around 280 nm with intensity 0.26 a.u., corresponding to the π–π* electronic transition of C=C bonds within sp^2 carbon. This peak signifies the initial formation of aromatic structures resulting from the thermal polymerization of organic molecules under microwave irradiation [11]. The microwave heating process provides high activation energy, efficient dehydration, and condensation reactions of active compounds. The longer heating duration enhanced the carbonization process and expanded the π-conjugated system, as shown on the T20 sample. This indicates larger aromatic domains and a high density of π-electrons in the carbon structure. The absence of redshift implies the growth of the carbon core did not substantially type of electronic transition, but increased the number and size of conjugated [12]. In other words, heating time increases the quantity and ordering of sp^2-carbon structures, without changing their intrinsic electronic characteristics. Our findings align with previous reports on biomass-derived CDs such as tea leaves and papaya peels, which similarly exhibited a dominant π–π* transition around 270–300 nm, indicating the formation of aromatic sp^2 domains under microwave or hydrothermal treatment [13], [14].

The chemical reactions, including dehydration, decarboxylation, and aromatization, make a unique structure of CDs [15]. In the initial stage, heating induces the removal of water molecules through dehydration reactions between hydroxyl and carboxyl groups. Decarboxylation eliminates CO_2 groups from carbonyl compounds, leading to the formation of C=C double bonds and

reinforcing the aromatic framework. The accumulation of double bonds generates conjugated carbon structures acting as core of CDs. Duration heating longer facilitates wider aromatic and removal of polar groups such as –OH and –COOH, resulting in an increased intensity of the π–π* band around 280 nm [11]. This marks a simple organic systems transition to optically and thermally stable nanocrystalline. Extending the duration of heating promotes the formation of more sp^2 domains, resulting in more delocalized π-conjugated [12]. This enhances the efficiency of electron transitions from π to π* levels, resulting in stronger absorption peaks. The shoulder peaks above 320 nm indicate groups such as C=O, C–N, or N–H are few or mostly degraded [16]. T20 possesses a more homogeneous structure with aromatic carbon cores rather than polar functional groups, improved optical stability and stronger visible fluorescence emissions. Microwave processing not only accelerates synthesis but also affects the dynamics of electronic structure at the atomic level. The precursor molecules absorb electromagnetic energy, trigger a reaction of localized high energy, create microplasma conditions, and make new C=C and C=O bonds [17]. CDs are denser and smaller carbon cores with uniform electronic energy distribution. Time is a key factor in explaining the correlation between absorbance intensity and heating duration to control the degree of π-conjugation. Furthermore, an increase in UV absorbance suggests a potential enhancement in photoluminescence (PL) on CDs synthesized, broader and homogeneous aromatic structures π–π* electronic transitions [7]. This characteristic is important for optoelectronic applications such as fluorescence sensors, bioimaging, and visible-light-based photocatalysis. The T20 sample has the highest absorbance can be attributed to quantum efficiency, as the dominance of larger sp^2.

The heating duration can confirm the correlation between UV–Vis absorbance and the electronic structure by controlling microwave duration to optimize the optical performance of green CDs derived from natural biomass such as soursop leaves. This study is limited to UV–Vis spectral analysis and does not include quantum yield measurements, fluorescence characterization, or particle size analysis such as TEM or DLS. These characterizations will be incorporated in future work to comprehensively evaluate the optical behavior and morphology of plant-derived CDs.

4. CONCLUSIONS

The synthesis of CDs based on soursop leaf was successfully demonstrated using microwave time duration. The enhanced carbonization process, accompanied by the formation of conjugated aromatic domains, is indicated by the color change from brownish green to dark brown. The UV–Vis spectrum confirmed that increasing the heating time from 10 to 20 minutes increased absorption around 280 nm, which is associated with the π–π* transition of aromatic C=C bonds. A longer heating duration expands the sp^2-carbon domains and enhances π-electron delocalization, improving the ultraviolet light absorption capability.

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