

Green Synthesis of Carbon Quantum Dots from Citrus-Based Citric Acid and Ascorbic Acid Precursors: Investigation of Polyethylene Glycol's Role in Size Modulation

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Abstract—Carbon quantum dots (CQDs) have garnered increasing interest in recent years for their distinctive physicochemical properties, such as strong photoluminescence, high water solubility, and biocompatibility, which make them suitable for diverse applications including bioimaging, drug delivery, and optoelectronic devices. In this study, we propose an environmentally benign synthesis pathway for CQDs using naturally derived citric acid from citrus fruit pulp (lemon and orange), as well as synthetic citric and ascorbic acid powders. Further, we investigate the effect of polyethylene glycol (PEG-400) on the size and dispersion uniformity of the CQDs. Characterization was carried out using UV-Visible spectroscopy, photoluminescence (PL) emission analysis, dynamic light scattering (DLS), and transmission electron microscopy (TEM). Our results demonstrate that PEG addition significantly reduces CQD particle size and enhances monodispersity, likely due to steric stabilization and surface passivation. These findings suggest a facile, sustainable route for the scalable production of high-quality CQDs with tunable features suitable for green nanotechnology applications.

I. INTRODUCTION

Carbon quantum dots (CQDs) are a new class of photoluminescent carbon-based nanomaterials with significant interest due to their nontoxicity, low cost, chemical stability, and excellent optical properties. Various synthetic approaches have been developed, including hydrothermal, microwave-assisted, and pyrolysis methods. The 'green synthesis' approach using plant-based waste and biomolecules aligns with sustainable chemistry goals.

Citric acid, a tricarboxylic acid found abundantly in citrus fruits, serves as an efficient carbon precursor for CQD synthesis. Ascorbic acid, a reducing agent, can

enhance the surface passivation and emission properties of CQDs. Polyethylene glycol (PEG) is known to influence the size and surface characteristics of nanoparticles by acting as a passivating and steric hindrance agent.

In this research, we synthesize CQDs using filtered pulp from lemon and orange as natural citric acid sources and compare them with control samples made from citric acid and ascorbic acid powders. We then incorporate PEG into all batches to assess its effect on the resulting CQD size.

II. MATERIALS AND METHODS

2.1. Materials

Fresh lemons and oranges were sourced locally. Analytical grade citric acid, ascorbic acid, and polyethylene glycol (PEG-400) were used. All aqueous solutions were prepared using deionized (DI) water.

2.2. Extraction and Preparation

Lemon and orange pulp were filtered to extract juice and then centrifuged to remove solid residues. The filtrate was used directly. For control experiments, 1 g of citric acid and 0.5 g of ascorbic acid were dissolved in 20 mL of DI water.

2.3. Synthesis of CQDs

All samples underwent hydrothermal treatment in Teflon-lined autoclaves at 180°C for 6 hours.

- Sample A: Lemon pulp extract
- Sample B: Orange pulp extract
- Sample C: Citric acid + Ascorbic acid
- Sample D: Lemon pulp + PEG
- Sample E: Orange pulp + PEG
- Sample F: Citric + Ascorbic acid + PEG

PEG was added in 1 mL aliquots (5% v/v) to the reaction mixture prior to hydrothermal processing.

2.4. Characterization Techniques

UV-Vis spectroscopy was used to determine absorption features, while photoluminescence (PL) spectroscopy evaluated emission properties. Dynamic Light Scattering (DLS) was used to measure particle size distribution. Transmission Electron Microscopy (TEM) was optionally used for direct visualization of CQD morphology.

III. RESULTS AND DISCUSSION

3.1. Optical Properties

All CQD samples exhibited strong UV absorption between 270–290 nm, corresponding to $\pi-\pi^*$ transitions of C=C bonds and $n-\pi^*$ transitions from C=O bonds. PL spectra showed excitation-dependent emission with maxima observed between 420–470 nm depending on precursor composition.

3.2. Size Analysis

The following table summarizes the average particle size from DLS measurements:

Sample | Precursor | PEG Added | Average Size (nm)

Sample	Precursor	PEG Added	Average Size (nm)
A	Lemon pulp	No	~6.2
B	Orange pulp	No	~7.1
C	Citric + Ascorbic Acid	No	~5.5
D	Lemon pulp	Yes	~3.2
E	Orange pulp	Yes	~3.8
F	Citric + Ascorbic Acid	Yes	~2.9

PEG significantly reduced CQD size, supporting its role as a capping agent. The reduced size is attributed to steric hindrance during nucleation, promoting more uniform and smaller particle formation.

3.3. Morphology (Optional)

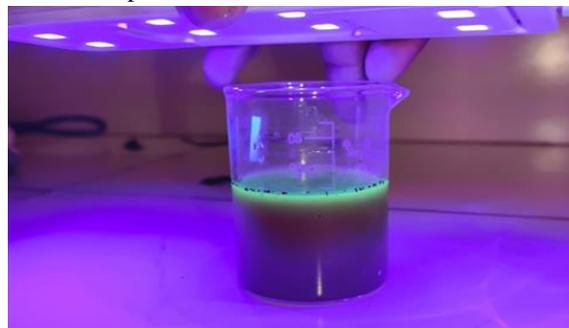
TEM images (if obtained) confirmed spherical morphology and narrower size distribution for PEG-assisted CQDs compared to the polydisperse structures in non-PEG batches.

IV. CONCLUSION

We have successfully demonstrated a green synthesis method for producing CQDs using citrus fruit-derived precursors, offering a sustainable and low-cost alternative to conventional techniques. The addition of PEG during synthesis significantly modulates particle size and improves size uniformity, making it a

valuable additive for fine-tuning CQD properties. The approach described herein offers a scalable route to producing environmentally friendly CQDs suitable for biomedical, environmental, and electronic applications.

Future studies will focus on evaluating the quantum yield, zeta potential, and application-specific behavior of the synthesized CQDs, particularly in bioimaging and sensor platforms.



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