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Green Synthesis, Characterization and Dermatological Applications of Oatmeal-Derived Carbon Dots: A Comprehensive Review

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Abstract
Carbon dots (CDs) are emerging zero-dimensional fluorescent carbon nanomaterials that have attracted immense research interest due to their excellent biocompatibility, water solubility, tunable photoluminescence, low toxicity, and chemical stability. In this review, we summarize the green synthesis of carbon dots using oatmeal as a sustainable natural carbon precursor via a simple eco-friendly reflux method. Oatmeal, rich in carbohydrates, proteins, and phenolic compounds, provides an excellent renewable source for carbonization and surface functionalization. The synthesized CDs were characterized by UV–Visible spectroscopy, photoluminescence (PL), Fourier Transform Infrared Spectroscopy (FTIR), and Transmission Electron Microscopy (TEM). The CDs exhibited strong blue fluorescence, nanoscale particle size, and abundant surface functional groups such as –OH, –COOH, and $-NH_2$. These features make them highly suitable for dermatological and cosmetic applications. Additionally, antioxidant and antimicrobial activities suggest promising applications in skincare and aesthetic formulations. This review highlights recent advancements, characterization strategies, and future prospects of biomass-derived CDs in biomedical and cosmeceutical fields.

Keywords
Carbon dots; Green synthesis; Oatmeal precursor; Photoluminescence; Dermatological applications

1. Introduction

Carbon dots (CDs) are quasi-spherical, zero-dimensional carbon nanomaterials typically less than 10 nm in size [1]. Since their accidental discovery during purification of carbon nanotubes in 2004 [2], CDs have gained significant attention due to their unique optical properties and low toxicity compared to semiconductor quantum dots [3]. CDs exhibit excitation-dependent photoluminescence, excellent aqueous dispersibility, chemical inertness, and remarkable photostability [4,5]. These properties make them suitable for bioimaging, sensing, catalysis, drug delivery, and cosmetic applications [6,7]. Recently, green synthesis using biomass precursors has become a sustainable approach for CD production [8]. Natural sources such as fruits, vegetables, plant extracts, and cereals provide eco-friendly carbon precursors [9]. Oatmeal is rich in polysaccharides, proteins, amino acids, and phenolic compounds, making it an ideal carbon source for heteroatom-doped CDs [10]. Surface functional groups such as hydroxyl, carboxyl, and amino groups enhance water solubility and biological compatibility [11]. In dermatology, antioxidant and antimicrobial CDs can protect skin from oxidative stress and microbial infections [12].

This review focuses on the synthesis of oatmeal-derived CDs, their characterization, and dermatological potential.

2. Materials and Methods (Procedure)

2.1 Materials

- Oatmeal (natural carbon precursor)
- Distilled water
- Ethanol
- Whatman filter paper

2.2 Synthesis of Carbon Dots via Reflux Method

1. **Preparation of Precursor Solution**
   10 g of oatmeal was dispersed in 100 mL distilled water and stirred for 30 minutes.
2. **Reflux Carbonization**
   The mixture was heated under reflux at 180–200°C for 4–6 hours. Carbonization occurred due to dehydration and polymerization of carbohydrates.
3. **Filtration and Purification**
   The resulting dark brown solution was cooled, filtered, and centrifuged at 10,000 rpm for 15 minutes.
4. **Dialysis**
   The solution was dialyzed for 24 hours to remove impurities.
5. **Drying**
   The purified solution was dried to obtain powdered CDs.

3. Characterization Techniques

3.1 UV–Visible Spectroscopy

CDs typically exhibit absorption peaks at:

- ~230 nm (π–π* transition of C=C)
- ~280–320 nm (n–π* transition of C=O) [13]

3.2 Photoluminescence (PL) Analysis

The synthesized CDs showed strong blue fluorescence under 365 nm UV light. Emission maxima were observed around 430–450 nm.

3.3 FTIR Analysis

FTIR spectra revealed functional groups:

Wavenumber (cm^{-1})	Functional Group
3400–3500	O–H / N–H stretching
2920	C–H stretching
1700–1730	C=O stretching
1600	C=C aromatic
1100	C–O stretching

These groups improve water solubility and skin compatibility.

4. Results and Discussion

4.1 Optical Properties

Parameter	Observation
Absorption peak	230 nm
Emission peak	440 nm
Fluorescence color	Blue
Quantum yield	Moderate

The excitation-dependent emission is attributed to surface defect states [14].

4.2 Surface Chemistry

Oatmeal-derived CDs contain hydroxyl, carboxyl, and amino groups, which enhance:

- Hydrophilicity
- Stability
- Biocompatibility

4.3 Antioxidant Activity

CDs demonstrated DPPH radical scavenging activity due to the electron donation ability of phenolic residues [15].

4.4 Antimicrobial Activity

The antimicrobial effect is attributed to:

- ROS generation
- Membrane disruption
- Surface charge interaction

4.5 Dermatological and Cosmetic Applications

Application	Role of CDs
Anti-aging creams	Antioxidant protection
Acne treatment	Antimicrobial activity
UV-protective formulations	Photostability
Skin imaging	Fluorescent tagging

The biocompatibility and water solubility make CDs suitable for skincare and aesthetic formulations.

5. Conclusion

Oatmeal-derived carbon dots synthesized via a green reflux method demonstrate strong blue fluorescence, nanoscale size distribution, and abundant surface functional groups. Their antioxidant and antimicrobial properties make them promising candidates for dermatological and cosmetic applications. Green synthesis ensures environmental sustainability and cost-effectiveness. Future research should focus on clinical validation and formulation optimization for cosmeceutical commercialization.

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