

Synthesis of Fluorescent Carbon Dots from Raw Materials: An Overview of Textile Applications

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Abstract

Since their discovery in 2004, fluorescent carbon dots (C-dots) have been in increasing development with a wide range of applications. Since 2012, the use of carbon sources made from raw materials such as seeds, flowers, and others has increased, and the green synthesis of fluorescent carbon dots has increased. These C-dots have potential in several bioapplications due to their biocompatibility, stability, relatively low cost, biodegradability, nontoxicity, and environmental friendliness. This work discussed C-dot synthesis using different raw materials with different carbon sources and the main synthesis methods. The photophysical parameters of the fluorescence quantum yield (η) and fluorescent lifetime (τ) are presented for green synthesized nitrogen-doped and undoped C-dots as important nanomaterial for environmental control. These carbon dot-based materials can be used to minimize waste in the textile industry and enhance their waste properties as possible antifungal and bactericidal agents for bioapplications. An overview of the different C-dots used for textile engineering applications and degrading dyes typically used in textile fabrics is presented.

Keywords: Carbon dots; Raw materials; Fluorescence quantum efficiency; Fluorescence lifetime; Textile application

Introduction

Fluorescent carbon nanoparticles or carbon dots (C-dots) were discovered in 2004 during the process of carbon nanotube fragment purification [1-3]. These nanomaterials are widely reported to have average sizes typically smaller than 10nm, are spherical or semispherical in shape, are water soluble, and have fluorescent properties, enabling a wide range of bio applications [4-6]. Carbon dot synthesis has recently attracted increasing attention and interest due to its sustainable synthesis, low toxicity, low cost, and easy implementation [4-7]. These carbon-based nanoparticles have been widely explored, but green syntheses stand out because the raw materials used as carbon sources are components of plants and fruits (such as roots, seeds, leaves, flours, fruit peels, and extracts) and other foods [2,4,8-10]. The first reported green synthesis using coffee grounds as a carbon source occurred in 2012, with C-dots of approximately 5 ± 2 nm in size [8]. Several novel C-dots have been proposed using different carbon sources [8,11-22], and this work presents an overview of these carbon dots, the values of their average sizes, fluorescence quantum yield (η), fluorescence lifetime (τ) values, and high potential for reported textile applications [23-27].

Discussion

Figure 1 presents the timeline of the main raw carbon sources and methods used in green synthesis from 2012-2024 [8,11-22]. The synthesis C-dots involves hydrothermal, pyrolysis, and microwave methods [11,16,17]. Several carbon sources, such as coffee grounds, sweet pepper, corn flour, Jinhua Bergamot, Lotus roots, Acacia Concinna seeds, Papaya waste, cherry tomatoes, microalgae Spirulina, grapefruit juice, Naregamia alata leaves and Pumpkin seeds, used for C-dot green synthesis are presented in Figure 1. The fluorescence quantum efficiency

(η) and fluorescence lifetime (τ) are given for some C-dots reported in Table 1. A hydrothermal method was used for all the synthesized

C-dots, as shown in Table 1. These photophysical characteristics are crucial for fluorescence applications of C-dots.

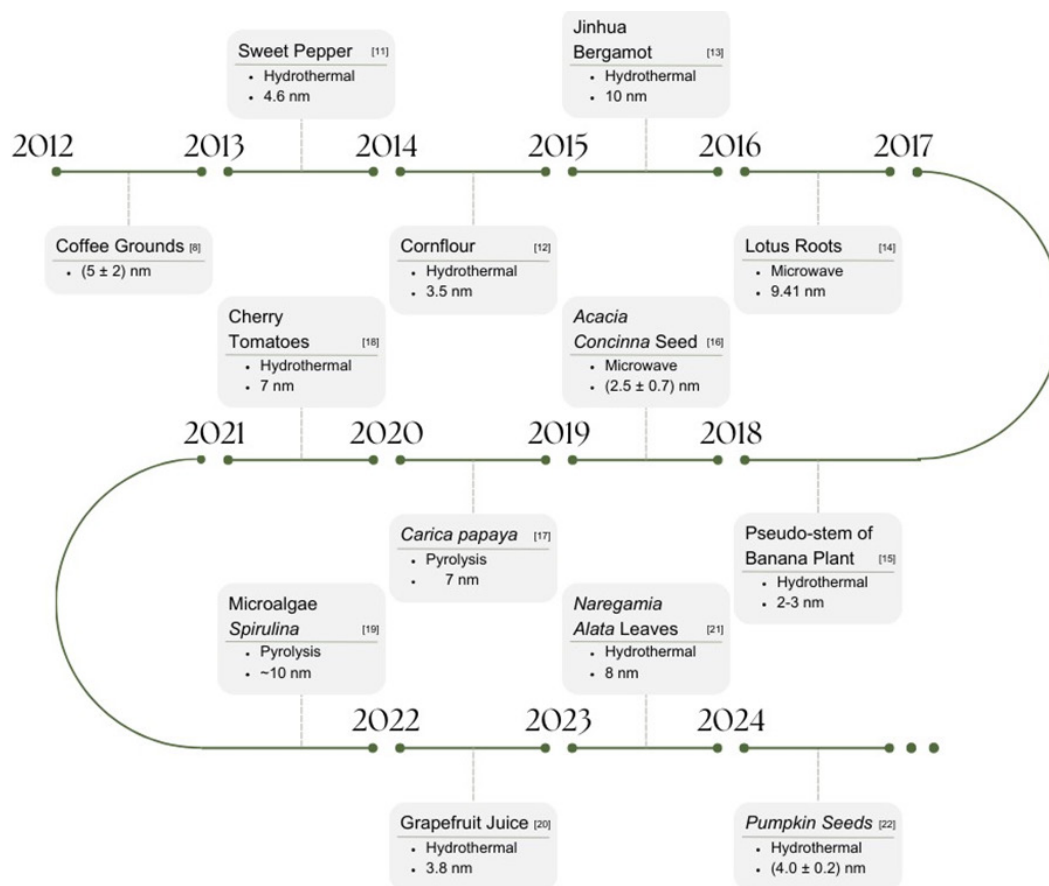


Figure 1: Some raw carbon sources and methods used in C-dot green synthesis from 2012-2024 [8,11-22].

Table 1: Several carbon sources have been presented for C-dot green hydrothermal synthesis and textile applications. The average sizes of the C-dots and the η and τ parameters are presented.

^aAverage lifetime.

| Carbon Source | Average Size (nm) | η (%) | τ (ns) | Applications |
|--|-------------------|------------|------------------|--|
| Rice straw | (71-101) | 24.03 | 7.55 | Cotton textile mask as a possible fluorescent sensor for detecting acetone vapor in the breath of diabetic patients [23] |
| Indigo | (3.5±0.5) | 3.8 | 3 ^a | |
| <i>Curcuma longa</i> | (2.6±0.5) | 0.8 | 3.9 ^a | Textile printing for anti-counterfeiting [24] |
| <i>Sophora japonica</i> L. | (5.2±0.7) | 1 | 1.0 ^a | |
| Date fruit (charcoal) | (5±6) | 14.5 | -- | Functional textiles with better UV protection, antibacterial activity, and potential for heavy metal detection [25] |
| <i>Syzygium cumini</i> L. seed extract | 6.3 | 15.9 [26] | 5.2 [26] | Biomedical textiles with antimicrobial properties [27] |
| Green tea (Tetley) and chitosan | 6 | -- | -- | Functional textiles with antioxidant and antimicrobial properties for possible smart textiles [28] |

Table 1 presents different C-dots synthesized by the green method and used in textile engineering applications [23-28]. Rice straw was used as a carbon source in nitrogen-doped C-dot synthesis and applied as a fluorescent sensor for acetone detection in cotton in textile masks [23]. The natural dyes extracted from *Curcuma longa* and *Sophora japonica* L. were used in C-dot synthesis and tested as possible textiles for anti-counterfeiting [24]. Other

textile applications using C-dots are presented in Table 1. The values obtained for η and τ for rice straw as raw materials highlight the fluorescent sensor textile applications of C-dots.

Table 2 presents different green processes for C-dot synthesis [29-38], such as hydrothermal, pyrolyzed, and calcination processes. These nanodots are potential candidates for detecting

and degrading dyes typically used in textile fabrics [29,31,32,35-38]. C-dots and N-doped C-dots were synthesized using carbon sources such as peels, seeds, fruits, and leaves. Table 2 presents the average C-dot sizes and fluorescence quantum yield parameters η . For doped C-dots, L-aspartic acid or aqueous ammonia was used

for nitrogen doping [36,37], and green synthesis was achieved via hydrothermal processes. N-doped C-dots have been reported to have potential in wastewater analysis for Congo Red dye detection and Safranin-O dye degradation [36,37]. Table 2 presents other C-dot applications for the detection and degradation of dyes.

Table 2: The different carbon sources used in green synthesis and the average of the C-dots used in dye removal applications in textiles are presented.

^aCarica papaya juice was used as a carbon source [30].

^bC-dots were doped with nitrogen (pyrolysis for 3h) [32].

^cA hydrothermal method was used, and C-dots with a size of 1nm were obtained [33].

^dThe excitation wavelength was 380nm [34].

| Carbon Source | Synthesis Method | Average Size (nm) | η (%) | Doping Material | Application |
|----------------------------------|-------------------------|------------------------|-----------------------|----------------------------|--|
| Canon ball fruit | Hydrothermal | 11.2 | 7.24 | -- | Sensor for metal ion detection and catalytic reduction of textile dyes [29] |
| Papaya peel | Hydrothermal | 4.5 | 7.0 ^a [30] | -- | Nanocomposites were tested for photodegradation of textile dye methylene blue [31] |
| Onion (<i>Allium cepa</i>) | Pyrolysis | 4.48 ^b [32] | 6.2 ^c [33] | Ammonia (NH ₃) | Decontamination of methylene blue and rhodamine B dyes [32] |
| Olive pomace | Pyrolysis and oxidation | (2.8±0.6) | 19 ^d [34] | -- | Photodegradation of methylene blue dye pollutants [35] |
| <i>Ziziphus mauritiana</i> fruit | Hydrothermal | (7±2) | -- | Aqueous ammonia | Degradation of Safranin-O dye pollutant [36] |
| Rambutan seed | Hydrothermal | 3.07 | 16.87 | L-aspartic acid | Detection of Congo Red Dye [37] |
| <i>Azadirachta indica</i> leaves | Calcination | 3.0-8.0 | 42.3 | -- | Sensing and degradation of Malachite green [38] |

Furthermore, other carbon dots or nanoparticles have been reported in textile applications [39,40]. The carbon quantum dots synthesized by the hydrothermal method can be highlighted by using banana leaves as a carbon source. These nanomaterials are applied for superhydrophobic coating on fabrics for oil and water separation [39]. On the other hand, graphene films integrated with Prussian blue and quantum dots have been reported for textile devices [40]. These proposed advanced films show potential for wearable biosensors and photoelectronic devices, such as glucose and H₂O₂ monitoring sensors [40]. Red-emissive carbon dots (R-Cdots) are used to construct smart fabrics. The hydrothermal synthesis of these R-Cdots uses o-phenylenediamine and catechol in ethanol as carbon sources. R-Cdots exhibit fluorescent patterns on cotton fabrics, are pH sensitive, and can be used for MnO₄ detection in aqueous solutions [41]. Finally, fabric scraps can also be reused as a carbon source for new carbon dot synthesis, ranging from leather scraps to hospital masks [42-44].

Conclusion

Since the first green synthesis of carbon dots (C-dots), different carbon sources obtained from seeds, leaves, peels, and other parts of plants have been used in novel synthesis processes. The fluorescence properties, water solubility, and low toxicity are characteristics of carbon dots that stand out for their wide range of applications. In textile applications, C-dots have been used in different applications, such as in printing on textiles to combat counterfeiting and in textiles, highlighting their antioxidant and

antimicrobial properties. Another important carbon nanoparticle approach is evaluated for the detection and degradation of dyes commonly used in textile fabrics. Over the years, important new applications of carbon dots have emerged in different research areas of investigation, increasing opportunities for the development of relevant applications in textile engineering.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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