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Synthesis of carbon dots from tea powder waste

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Abstract

Tea waste is inexpensive, easily available and sustainable carbonaceous source. The carbon derived from tea powder waste can be used for variety of applications. Carbon dots (CDs) are derived from this carbon. CDs are zero-dimensional carbon-based materials in the size range of a few tens of nano meters and can be doped with N, S, P, and B heteroatoms. They are chemically modifiable to enhance and render some additional functional properties. In this work carbon dots are synthesized from tea powder waste by carbonization method. The CDs are identified by exposing the liquid obtained from carbonization method to ultraviolet light. Carbon dots have shown quality result of photo luminescence under UV radiation.

Keywords: Carbonaceous; Heteroatoms; Carbonization; Photo luminescence

1. Introduction

The synthesis of carbon dots from kitchen-derived tea powder waste is an innovative approach that addresses both waste management and the production of valuable nanomaterials. Carbon dots, which are small fluorescent carbon nanoparticles, have garnered significant attention in recent years due to their unique properties and potential applications in various fields. Tea, one of the most widely consumed beverages worldwide, generates a significant amount of waste in the form of used tea bags or leftover tea leaves [1-3]. Instead of disposing of this waste, researchers have explored its potential as a precursor for synthesizing carbon dots. This approach not only provides an eco-friendly solution for waste utilization but also offers a sustainable route for the production of carbon-based nanomaterials. The synthesis process typically involves extracting organic compounds from tea powder waste and subsequently subjecting them to controlled thermal decomposition or carbonization. The resulting carbon dots exhibit exceptional properties such as strong fluorescence, good water solubility, low toxicity, and excellent stability [2]. The utilization of tea powder waste as a carbon dots precursor offers several advantages. Firstly, it is a readily available and cost-effective source material that can be easily obtained from kitchen waste. Secondly, tea powder waste contains various organic compounds, including polyphenols and tannins, which serve as carbon sources during the synthesis process. These organic compounds play a crucial role in the formation of carbon dots and contribute to their unique properties [2-3]. Lastly, the resulting carbon dots can find applications in diverse fields such as bioimaging, sensing, energy storage, and catalysis. By converting tea powder waste into valuable carbon dots, this synthesis method promotes sustainable practices and reduces the environmental impact of waste disposal[4]. Furthermore, the versatility and tunability of carbon dots make them promising candidates for numerous applications, fostering research and innovation in nanotechnology [5].

2. Literature review

Li et al.'s article from 2019 titled "Green Synthesis of Fluorescent Carbon Dots from Tea Waste for Sensing and Bioimaging Applications"

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The goal of this study was to develop a straightforward hydrothermal technique for producing carbon dots from tea trash. The carbon dots were used as a sensor platform for the detection of metal ions since they showed high fluorescence. The authors illustrated the potential of carbon dots in bioimaging applications and emphasised the environmentally beneficial quality of tea trash as a precursor.

Ma et al. (2018) published "Facile Synthesis of Luminescent Carbon Dots from Tea Waste and Their Applications".

In this study, carbon dots were created using a one-step hydrothermal process from tea residue. The generated carbon dots had exceptional photoluminescence characteristics and were utilised as fluorescent probes to detect.

Wang et al. (2020), "Green Synthesis of Carbon Dots from Tea Waste for Highly Selective and Sensitive Detection of Hg2+"

The scientists described a resource-efficient and environmentally friendly method for creating carbon dots out of leftover tea. The artificial carbon dots were used as a fluorescent sensor for the detection of mercury ions (Hg2+) since they produced a strong fluorescence emission. The significance of using tea trash as a renewable resource for the synthesis of carbon-based nanomaterials was emphasised by the study.

Zhou et al. (2021), "Carbon Dots Derived from Tea Waste for Selective and Sensitive Detection of Nitroaromatic Explosives"

The one-pot hydrothermal approach was utilised in this study to create carbon dots from tea residue. The resulting carbon dots displayed excellent stability, good water solubility, and photoluminescence.

3. Methodology

3.1. Materials required

Table 1 Materials Required

Sr. No	Materials	Quantity
1	Tea powder	20 g
2	Distilled water	100 ml

3.1.1. Tea waste

Tea powder waste is collected from the local tea stalls has traces of milk and sugar washed and dried under sunlight, until water content is totally removed from the tea powder waste. The dried tea powder is made into fine powder. Tea powder is the carbon source for the synthesis of carbon dots.

3.1.2. Distilled water

Distilled water is water that has been boiled into vapor and condensed back into liquid in a separate container. Impurities in the original water that do not boil below or near the boiling point of water remain in the original container. Thus, distilled water is a type of purified water.

3.1.3. Apparatus required

- Muffle furnace
- Magnetic stirrer
- Centrifuge machine
- UV Light source

3.2. Method

3.2.1. Carbonization method

In this study carbonization method is utilized for the synthesis of carbon dots. This carbonization method comes under top-down approach where larger particles are break down in smaller particles. Carbonization is a process where organic materials like wood, tree leaves are converted into carbon through destructive distillation. Destructive distillation is a chemical process in which decomposition of unprocessed material is achieved by heating it to a high temperature; the term generally applies to processing of organic material in the absence of air or in the presence of limited amounts of oxygen or other reagents, catalysts, or solvents, such as steam or phenols. It is an application of pyrolysis. The process breaks up or 'cracks' large molecules. Coke, coal gas, gaseous carbon, coal tar, ammonia liquor, and coal oil are examples of commercial products historically produced by the destructive distillation of coal.

3.2.2. Steps involved in synthesis of carbon dots

The following are the steps involve in the synthesis of carbon dots by using tea powder as carbon source:

- Freshly prepared tea waste is taken and dried under sunlight until all the water content is removed from it and the dried tea waste is made into fine powder.
- Powdered tea waste is taken into a crucible and kept in a muffle furnace where it is heated at 200°C for 5 hours. Heating is done to obtain pure carbon source and removing the impurities and this helps in formation of carbon dots.
- After the heating process the crucible is taken out which consists of residue of the tea powder, which is a pure carbon source. This process is called as calcination process where heating is done in the absence of oxygen so that pure carbon is obtained. This obtained carbon is the source to produce carbon dots.
- The tea powder residue is taken in to a plate, from the tea residue 20g of the tea powder residue is taken into a beaker and 100ml of distilled water is added to it (Distilled water is used because it doesn't contain any impurities).
- The tea residue present in the solution will not mix with the distilled water it has to be stirred for proper mixing of tea residue and distilled water. This is achieved by magnetic stirrer. The beaker is kept on the plate of magnetic stirrer (The plate of magnetic stirrer helps in heating the beaker it has heating coils under it and the temperature is set to 70°C) the stirring operation is done at 400rpm for 8 hours. A lid kept on the beaker in order to stop the vapours of water from escaping.
- After stirring operation, the solution is filtered with the help of filter paper so that visible and heavy particles are removed and a clean solution is obtained.
- Obtained clean solution is sent for centrifugation where large particles which can't be seen by the human eye are separated. Centrifugation is done at 12000rpm and due to this heavy particles will be settled at the bottom.
- After the centrifugation process the desired solution is filtered with the help of filter paper and the filtered solution is taken into a glass container.

Finally, a clean solution is obtained which contains carbon dots

4. Results and discussion

The clear sight of carbon dots is given by the Photoluminescence test. The results of these tests are discussed below.

4.1. Photoluminesence

Photoluminescence is a contactless non-destructive method of proving the electronic structure of material. When light is directed onto a sample where it is absorbed and impart excess energy into the material in a process called photo excitations, one way this excess energy can be dissipated by the sample is through the emission of light or luminance, and in case of photo excitation this luminescence is called photo luminescence. The two main PL mechanisms that have been suggested for C-dots are defect state emission (surface energy traps) and intrinsic state emission (electron–hole recombination, quantum size effect/zigzag sites). To study this carbon dots solution is used which is shown in figure.

Figure 1 Carbon dot solution

When UV light of wave length of 395nm is directed onto the sample a bluish colour fluorescence is observed. This fluorescence is observed because, the electrons in the solution when struck by a UV light, jumps into a higher energy orbital. The electron is only stable there for a short time where it returns to the lower energy level emitting a photon of light. It is important to recognize that the light in fluorescence is temporary in other word when no light is applied no fluorescence that is shown in figure 4.3.2.

Figure 2 Fluorescence before and after UV light

The blue emission (shorter wavelength) is formed due to the intrinsic state emission i.e., when the electron lost some of its energy it recombines with the hole during this recombination process photons are emitted so this is the recombination of holes and electrons. And also, it ascribes π-π* transition of C=C bond and n-π* transition of C=O bond. Various colours of CDs can be obtained by changing the wavelength which is tabulated below.

Table 2 Standard colours, wave lengths and sizes of different carbon dots

Color	**Wave length interval**	**Size**
Blue	318 nm-460 nm	2 nm
Dark Green	520 nm-560 nm	2.5 nm
YELLOW	560 nm-590 nm	3 nm
ORANGE	590 nm-635 nm	5 nm
RED	635 nm-700 nm	6 nm

The size of the carbon dots is approximately 2 nm according to the table above, because we got blue fluorescence when using UV light with a wave length of 395nm.

5. Conclusion

The porous carbon is obtained by the calcination of tea powder waste at 200 °c for 5hrs. By using this carbon, CD s are successfully synthesized by adopting a simple carbonization method from tea powder waste which is low cost and abundantly available. More importantly, the one-step synthesis process is simple but effective, requiring neither a strong acidic solvent nor surface modification reagent, which makes it very suitable for large-scale production of photoluminescent carbon nanomaterials and also this method become eco-friendly, greener one over the other methods The synthesized light yellow CDs solution emitted strong blue fluorescence under the irradiation of ultraviolet light with a wavelength of 395 nm which indicates the size of the CD is approximately 2nm.This is the preliminary work done on the carbon dots. Based on their high quantum yield, optical and photoluminescence properties these are employed in bio- imaging, bio-sensors, electrocatalysts, LEDs, supercapacitors, rechargeable batteries, metal–air batteries, fuel cells and in 3D printing.

Future scope of work

- The following scope of work can be done in the future to learn more about the characteristics, properties, and applications of carbon dots:
- Determination of crystallographic structure, orientation and strain using X-Ray Diffraction (XRD) analysis.
- Determination of quality, shape, size and density of carbon dots by Transmission Electron Microscopy (TEM) analysis.
- Determination of optical and photoluminescence properties of carbon dots by Photoluminescence Spectroscopy (PLS).
- Carbon dots impregnated 3D printed scaffold for bioimaging of cells.
- The carbon dots can be used in printing ink, suitable for stereo lithography 3D printing.
- Carbon dots impregnated fluorescent nanofibrous scaffold for skin tissue generation

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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[5] Radhika et al.(2020) "Synthesis of Carbon from Tea Powder Waste for Development of Polymer Nanocomposites