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Synthesis of Carbon Dots and their Functional Impact on Natural and Synthetic Fabrics

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In Loving Memory of Late Professor Doctor ""Mohamed Refaat Hussein Mahran""

Abstract
A family of carbon-based nanomaterials known as carbon dots (or CDs) that are spherical in shape with a diameter of less than 20 nm has attracted a lot of attention recently because of their special qualities and wide range of uses. A comprehensive review of the synthesis processes and new uses and applications for carbon dots in the textile field are discussed in this work. A variety of techniques, including hydrothermal and microwave, are used in the synthesis of CDs, which produce nanoscale carbon structures with remarkable quantum entanglement effects and adjustable surface characteristics. Carbon-rich biological precursors or synthetic precursors are capable of being utilized to create these kinds of carbon-based nanoparticles. Furthermore, CDs' sustainable origins—they are produced using ecologically favorable synthesis techniques and carbon-rich precursors—align with the textile industry's expanding focus on ecologically friendly practices. CDs have demonstrated their potential to be used as UV, flame-retardant, as well as antibacterial materials that may be added to textiles to provide them the protective properties required for the safety of the wearer. They perform excellently in the aforementioned textile applications because of their biocompatibility, non-toxic behavior, photoluminescence, low cost, and the presence of functional groups like carboxyl and hydroxyl.
Keywords: Carbon Dots, natural and synthetic fabrics.

1. Introduction

The manufacture of fibers, yarns, textiles, apparel, and textile items for home and décor, in addition to technical and industrial applications, is the economic activity that defines the textile sector. One of the most established and sophisticated industries as part of manufacturing is textiles, which has several subsectors that work together to produce raw materials, intermediate goods, and finished goods. Activities in the textile sector are divided into several categories, each with unique characteristics [1-10].

One of the subsectors of the textile industry is the field of textile finishing which is divided into two other types, chemical finishing and mechanical finishing. And it's a crucial stage before the fabrics can be used [11]. Mechanical finishing is basically how the aesthetic and the hand feel of the fabric change using a of machines leading into changing the surface of the fabric. Conversely, chemical variety finishing is a process that is used to enhance the comfort and other performance characteristics of textiles while also including additional functionalities to safeguard the person wearing the fabric material. For example, textiles with antibacterial properties, self-cleaning properties, hydrophobic properties, flame-retardant properties, and UV protection capabilities are created by the application of chemical finishing, mostly using nanomaterials.

The use of nanomaterials in chemical finishing applications has several benefits since, in contrast to particles or bulk materials, they exhibit unique mechanical properties. Because nanomaterials are easily manipulated and have a large surface area, their mechanical characteristics are enhanced [12]. But despite the advantages of using nano-materials, the metals used as a source for them are not exactly the best materials whether environmentally or money-wise on an industrial scale. To address the problem of metal consumption in the chemical finishing industry, a novel material generated from carbon was discovered given that carbon is one of the elements that is most prevalent on Earth and that it can make a vast variety of bonds with other materials as well as involving itself [13]. These carbon-derived

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nanostructures can take on several shapes, such as two-dimensional graphene, one-dimensional carbon nanotubes (CNTs), and nanowires. Additionally, they can be limited to zero-dimensional nanostructures known as "Carbon Dots" (CDs) [14].

Sp2 - hybridized carbon atoms make up the majority of the extremely fluorescent new carbon nanomaterials known as carbon dots, which have a diameter of 1 to 10 nm. Due to their basic advantages, which include low toxicity, compact size, notable biocompatibility, several functional groups, such as carboxyl, hydroxyl, and amino, and a large number of affordable sources, these fluorescent CDs have been widely used in a variety of applications. Additionally, Graphene quantum dots (GQDs), carbon quantum dots (CQDs), and carbonized polymer dots (CPDs) are the three primary categories into which CDs are divided based on their distinct micro- and nanostructures, production mechanisms, and characteristics [15, 16]. Furthermore, there are several ways to make CDs, including microfluidic, magnetic hyperthermia, hydrothermal/ solvothermal, and microwave-assisted, along with additional techniques [17].

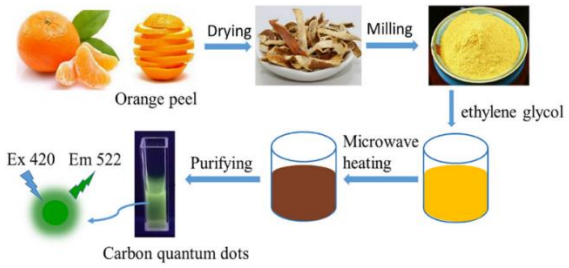

Figure 1: Diagrammatic representation for CQD preparation [18]

There are several uses for CDs in the textile finishing industry, on both synthetic and natural textiles like polyester and cotton. The carbon nanomaterial can impart hydrophobic, UV protection, flame retardant, and antibacterial properties to the aforementioned types of fabrics as well as being excellent sensors for metal ions. Also, one further advantageous feature of CD nano-materials is their facile preparation due to their ability to be manufactured from both natural and synthetic precursors. For example, as seen in (**Figure 1**), Hu, X., et al. were able to produce CQDs from orange peel using a microwave-assisted technique [18]. Another instance of naturally synthesized CDs is when Lin, R., et al. used a one-step hydrothermal process to create CDs out of red onions, garlic, and ginger [19]. Regarding the synthetically generated CDs, Zhang, H., et al. used an amino acid precursor to create CDs using a hydrothermal process [20], whereas Vallan, L. made CDs using citric acid as a precursor [21].

This paper aims to discuss not only the many precursors and production processes used to create Carbon Dots (CDs) but also the uses of the carbon nano-material in the textile industry.

2. Synthesis of CDs

Both synthetic and green precursors, including biomass, can be used to make CDs, which yield highly effective carbon nanomaterial that has a wide range of textile industry applications.

2.1. Environmentally friendly carbon dots' synthesis

2.1.1. N-CDs synthesized from fresh tea leaves

According to Ge, G., et al., fresh tea leaves may be used as a precursor in a one-pot hydrothermal process to create nitrogen-doped carbon dots, or N-CDs. The fresh tea leaves were initially dried in an electrically powered oven before being crushed into tiny bits. Subsequently, they added 5 g of tea pieces after dissolving 5 g of urea in 100 mL of ultrapure distilled water. The mixture was then placed inside a Teflon-lined, 150 mL stainless steel autoclave. Dark brownish solutions were produced after heating at 200˚ C for 10 hours and letting cool gradually to ambient temperature. The outcome was then centrifuged at **10,000** rpm for 20 minutes, and then processed into a supernatant using a dialysis membrane for two days with ultrapure water (cut off = 500 Da). Ultimately, the vacuum-dried dark brown powders were gathered and kept at 4˚ C for further use *[22]*.

Upon analysis, the resulting N-CDs showed clear evidence of excitation wave-dependent fluorescence, brilliant blue fluorescence once exposed to UV light, and high stability over an extended period of preservation. Additionally, N-CDs' morphology was described using a Transmission Electron Microscope (TEM), which means it was discovered that they are almost spherical, monodispersed, and completely free of apparent agglomeration in an aqueous solution. Their sizes vary from 2.0 to 2.5 nm, with an average diameter of 2.32 nm. The abundance of oxygen and nitrogen functional groups in the resulting carbon nanomaterial was another discovery made by scientists [22].

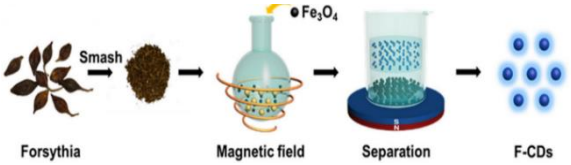

Figure 2: Diagram showing how the magnetic hyperthermia technique of F-CD synthesis is carried out schematically *[23]*

2.1.2. CDs synthesized from a Chinese herb forsythia

Through the process of initially purchasing the forsythia fruits, cleaning them properly using pure water, drying them in an oven at 50 C, followed by crushing them into powder using a ball mill, Chen, X., et al. were able to manufacture CDs from the Chinese herb known as forsythia introducing (F-CDs). Subsequently, 50 grams of forsythia powder as well as 5 grams of Fe_3O_4 nanoparticles were added to a 100- 100-milliliter round-bottom flask to be thoroughly mixed. After that, the round-bottom flask was positioned under 100 kHz as well as 13 kW in the inductive coil of a magnetothermal reactor, and the temperature was kept track of using an infrared thermometer throughout the entire process. In particular, the reaction system's temperature quickly rose to about 230 °C in about five seconds by using the Fe_3O_4 nanoparticles as a thermal supply to heat the precursors in an induction electromagnetic field. The end components were delicately collected and allowed to cool down after 90 seconds. The specimens were then divided up and subjected to an hour-long ultrasonication in a beaker filled with purified water. For ten minutes, the beaker's bottom was magnetized to extract the Fe3O4 nanoparticles. Subsequently, its suspension underwent filtration using a filtering membrane with a pore dimension of 0.22 µm. It was then processed for two days using a dialysis bag with a molecular weight cut-off of 1000 Da, with a 1000 mL dialysate change two times a day. Ultimately, F-CDs were dried out and gathered as F-CD powders for additional analysis and use. Finally, the synthesis process is depicted in (**Figure 2**) [23].

The scientists examined the final powder and the shape of the particles after creating the F-CDs nanomaterial. The F-CDs' TEM picture revealed that they are evenly distributed nanoparticles, with an average size of 1.64 nm as well as a majority of particle sizes ranging from 1.05 to 2.25 nm. Additionally, when exposed to 365 nm UV light, the F-CDs solution's dark brown dispersion fluoresced blue. Furthermore, the F-CDs' fluorescence remained constant during the storage time, demonstrating the stability of those nanoparticles [23].

2.1.3. CQDs synthesized from red cabbage

Red cabbage was successfully used as a feedstock for the synthesis process by Sharma, N. et al. to successfully synthesize CQDs. Initially, the red leaves of cabbage were divided, repeatedly cleaned in purified water, and then cut into little pieces. To extract the liquid, the pieces were crushed in a blender. Following three rounds of mesh filtration, the resulting juice underwent a hydrothermal procedure to synthesize CQDs. The obtained juice was processed for 36 hours at 220 °C in a 100 mL Teflon-lined stainless-steel autoclave. Following autoclaving, a syringe filter (0.22 µm) was used to purify the resulting material. The resulting dark-brown mixture was kept at ambient temperature for storage. Subsequent analysis of the produced carbon nanoparticle by the scientists revealed that the synthesized rcCQDs had excellent QY of 8.3%, great fluorescence stability, and emission behavior that was dependent on stimulation. Additionally, the produced rcCQDs had a 3 nm average size and released blue fluorescence [24].

2.1.4. CDs synthesized from rice bran

About 50 g of rice bran powder as well as 250 mL of double distilled water were used by Jothi, V.K., et al., in addition, the mixture was completely mixed before being stirred for five hours in a magnetic stirrer. A bright yellow-colored solution was formed after five hours and was put to use as a supply of carbon for the production of CDs. Two milliliters of sodium hydroxide (1 M) were incorporated into the solution described above. After filling the 100 mL Teflon-coated stainless-steel autoclave, the resulting mixture was heated to 200 °C for three hours. After the reaction process was finished, the autoclave was opened slowly and allowed to cool to ambient temperature. The resulting dark brown solution demonstrates how RB-CDs are formed. After that, the mixture was centrifuged for 45 minutes at 3500 rpm. For future research, a clear brown solution incorporating RB-CDs has been obtained and kept in a refrigerator at 4 °C [25].

The scientists' investigation subsequently showed that, within the small range of 1 to 6 nm, the average diameter of RB-CDs was 2.96 nm. Additionally, when exposed to 365 nm ultraviolet (UV) light, the artificially created water-dispersed RB-CDs exhibit green luminescence. Furthermore, it was discovered that the self-surface passivated RB-CDs had a 7.4% quantum yield. Furthermore, the existence of carboxyl and hydroxyl groups in the water-soluble RB-CDs was also determined [25].

2.2. Synthetic manufacture of CDs

2.2.1. CDs synthesized from plastic

Plastic waste materials, including bags, cups, and bottles, have been effectively used by S. Chaudhary, M. Kumari, P. Chauhan, and others to create CDs, as seen in (**Figure 3**). Using a separate cylinder to purge nitrogen gas, the researchers first placed the previously mentioned substances in a ceramic cup. Thermal calculations were then carried out in a muffle oven for two hours at an approximate temperature of 400 ˚C in an inert environment. After cooling to room temperature, the resulting black granules were physically ground to create a powdery substance. To create a carbonized C-dot solution, 1

gram of the produced powder was then added to 200 milliliters of distilled water while being stirred. To get rid of the larger-sized leftovers, the produced C-dot dispersion was centrifuged for 15 minutes at 7000 rpm. The supernatant solution was filtered through a 0.22 mm filter membrane to purify the C-dots. To turn the distributed C-dots into solid extracts of P-CDs, C-CDs, and B-CDs (the C-dots were taken from used poly bags, cups, and bottles, correspondingly), ultracentrifugation was performed at 17,000 rpm [26].

After reviewing and analyzing the fluorescent CD powder that had been produced, the researchers were capable of determining that the P-, C-, and B-CDs had crystalline diameters of 22, nm, 30.4 nm, and 9.1 nm, accordingly. Additionally, it was discovered that, at 310 nm stimulation, the quantum yield measurements for P-CDs, C-CDs, and B-CDs varied between 62, 65, and 64%. Furthermore, the artificial C-dots contain various functional groups, such as ACOOH and AOH, over their external surface and exhibit excellent water solubility [26].

2.2.2. Nitrogen doped-CDs synthesized from 2-aminoterphathalic acid

Nitrogen carbon dots (N-CDs) were created by Y. Tu and colleagues using a one-pot hydrothermal carbonization process. 0.4 g of 2-aminoterphathalic acid (ATA) and 0.2 g of NaOH were submerged in 50 mL of water at 60 ˚C while mixing in a standard synthetic technique. The solution afterward went into a 100 mL stainless-steel autoclave with a Teflon lining, and thereafter it was kept in an oven at 160 °C for 12 hours. The resultant light-yellow mixture was then dialyzed within a dialysis bag (1000 Da) for five days to eliminate NaOH and unaffected ATA shortly after the autoclave automatically chilled down. This was done by frequently restoring the bag's outside water. Ultimately, the dialysis bag containing the acquired N-CD solution was retrieved for additional experimentation. Additionally, (**Figure 4**) can show how the N-CDs are synthesized [27].

By using Field Emission Transmission Electron Microscopy (FETEM) to analyze the blue fluorescence result N-CDs, the scientists were able to assess the shape of the particles, which ranged in diameter from 5 to 10 nm. It was also found that the resulting N-CDs included a large amount of carboxylic acid and other functional groups that contained oxygen [27].

2.2.3. CDs synthesized from citric acid

Using a solvothermal technique, Z. Lin et al. produced carbon dots from citric acid (CA-CDs) with efficiency. They started by dissolving 0.3 g of citric acid in water, and then they pyrolyzed the mixture for 12 hours at 200 °C. To create CA-CDs for later usage, the initial product was refined by dialysis and then dehydrated in a high vacuum. The resulting luminous carbon nanoparticles' shape could then be examined by the researchers by utilizing TEM. The CA-CDs showed an average particle size of 1.65 nm and a homogeneous dispersion. Additionally, it was discovered that the percentages of the two components C and O in CA-CDs were 58.98% and 41.02%, correspondingly [28].

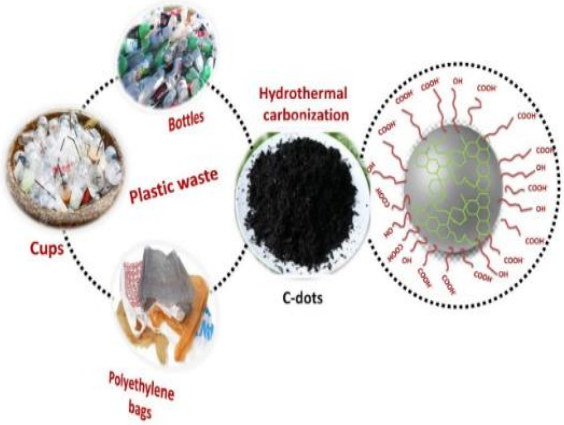

Figure 3: Diagrammatic representation demonstrating the creation of C-dots from various plastic trash kinds *[26]*

Figure 4: The technique of synthesizing N-CDs by the hydrothermal carbonization reaction of 2-amino terephthalic acid is illustrated schematically *[27]*

2.2.4. CDs synthesized from oleic acid

Rimal, V., et al. used the bottom-up manufacturing approach to create CDs using oleic acid. Researchers began by dissolving 2 g of NaOH in 20 mL of water and stirring it until a clear solution appeared. After that, 10 mL of oleic acid was heated for a few minutes at 260 C., NaOH and oleic acid were combined and filtered. Then for 15 minutes, the aqueous solution of oleic acid CDs was sonicated, after evaluating the CDs, the scientists found that the nanoparticles were nano-dimensional quasi-spherical particles with an ultimate luminescence intensity of 400 nm at an excitation wavelength of 400 nm. It was also established that the aforementioned CDs had no spherical aggregates with a diameter of less than 10 nm for the particle size [29].

3. Applications of CDs in the textile industry

3.1. Applications of CDs as flame retardants

Flame retardant processing represents one of the essential characteristics imparted to textiles that are crucial for various fire-safe applications, which are outlined briefly as follows:

a. For clothes: such as firefighter apparel, uniforms for soldiers, different specialized job apparel, nightwear for children, as well as athletic activities clothing [30].
b. Seating, rugs, and other types of furnishings for automobiles, trains, aviation, and marine boats are examples of transportation textiles [30].
c. Interior fabric upholstery, beds, blinds, and drapes [30].

CDs can provide this type of finishing treatment to fabrics while also being a green substitute for frequently employed substances such as chemicals that include halogens (brominated and chlorinated compounds), phosphorus, and nitrogen since, despite their development, those normally utilized substances serve a significant risk to both the environment and human health and produce smoke throughout combustion, endangering human life. [31].

3.1.1. CDs derived from polypropylene carbonate

C. Liu, H. Li, R. Cheng, and colleagues created a form of CD that is synthesized from polypropylene carbonate (PPC) via solvothermal treatment alongside ethylenediamine. When they synthesized CDs, they discovered that applying a small amount of citric acid increases the quantum yield of luminous carbon nanoparticles from 30% to 86%. The examination of the manufactured CDs revealed that they had an abundance of functional groups on their surface and were flame retardant.

The scientists inserted CDs inside polystyrene microspheres to benefit from the flame retardancy properties of the CD substance. They then demonstrated superior polyurethane and other polymer fiber combustion resistance. Furthermore, unlike previous halogenated or composite additives that emit harmful gasses during combustion, CD ignition mostly emits benign and inflammable carbon dioxide (CO2). Furthermore, there is no evident structural disruption throughout the combustion process when CDs are utilized since more than 92% of the carbon atoms are in the form of char after burning, showing that CDs are non-combustion. Furthermore, the inclusion of around 20% wt CDs reduces the maximum heat release rate of polyurethane and other polymeric fibers by 75%. Considering all of the facts reported, it is possible to conclude that CDs have good flame retardant qualities [31].

3.1.2. Boron and nitrogen co-doped carbon dots (BN-CDs)

Pan, Y., et al. discovered that CDs had an abundance of carbonyl groups on their surface, which imparted excellent water solubility. This characteristic makes CDs appropriate for the fabrication of layer-by-layer (LbL) self-assembled coatings capable of modifying the surfaces of textiles. Furthermore, after incorporating boron as well as nitrogen into the CDs by utilizing one-pot-hydrothermal carbonization, as demonstrated in (**Figure 5**), the CDs with B, N co-doping showed significant blue fluorescence with a high quantum yield. Also, after the morphology of the B, N co-doped CDs was investigated, it was discovered that the carbon nanoparticles were spherical and below 10 nm in diameter [32].

The researchers next coated the cotton material with the B, N co-doped CDs. To create a 0.5 wt% solution, the PEI solution was added to deionized water and stirred for 2 hours. To get the CD/alginate combined solution, 0.6 g alginate was dissolved in 200 mL of freshly prepared CD-containing liquid. The pretreated cotton fabric was subsequently alternatively immersed for 2 minutes in PEI solution and CD+alginate solution. Every single time before soaking in the solutions, the fabric was rinsed with water for 2 minutes to eliminate any residual compounds from the prior step. One PEI layer and one CD+alginate layer were combined to form one bilayer (BL) coating. When the two layers reached the necessary values, the treated cotton fabric was dried in a 70 °C conventional oven for 3 hours. Lastly, the dry cotton was submerged in perfluoro polymer lotion for 5 minutes before being dried at 110 °C for 1 hour [32].

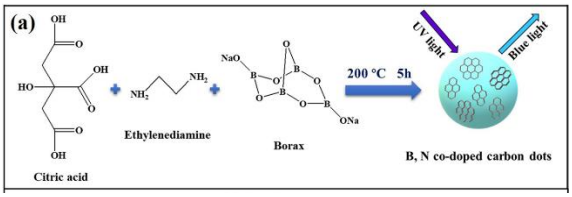

Figure 5: Preparing of B, N co-doped CDs [32].

Following the synthesis of the coated cotton textiles, the researchers used combustibility experiments to evaluate the flame-resistant properties of the chemically modified cotton fabric with the unprocessed cotton fabric. It was also discovered that when untreated and treated cotton garments were fired horizontally, they both burnt. Yet, following the burning test, the unprocessed cotton cloth leaves no char deposit. The treated cotton cloth, on the other hand, has heavier char remains. Furthermore, the burning rates of processed cotton textiles are lesser than those of unprocessed

cotton fabrics. The CD-based coating on the cotton exterior, which limits the flow of heat and combustible gasses among the fabric as well as the flame, might be related to the decrease in burning rate and higher level of char residue found in CD coating-treated cotton fabric. Finally, while the flame retardancy of cotton fabric is somewhat reduced, the results obtained show the potential of B, N co-doped CDs as a flame retardant for cotton fibers [32].

3.2. Applications of CDs as antimicrobials

Bacterial and viral infections have become a more severe hazard to the public's well-being, and combating these risks on a wide scale has grown difficult. It is also generally known that textiles can operate as an environment for the development of microorganisms that include harmful or odor-producing bacteria and fungi. Because of their large surface area and ability to retain oxygen, humidity, and water, as well as spills and bodily exudate nutrients, these materials create an ideal environment for microbial development when in touch with the body of a person. As a result, it is critical to employ antibacterial fabrics which may inhibit the growth of germs or even destroy them [33, 34].

3.2.1. Syzygium cumini L.-derived CDs

Syzygium cumini L. (SCL) is a natural seed from the tropical and subtropical Myrtaceae family, sometimes known as Indian blackberry or Jamun. Because of their inexpensive cost, environmentally friendly qualities, and curative potential, these kinds of seeds that have elevated phenolic acid and flavonoid levels are often employed in applications in biology [35]. Furthermore, CDs possess antibacterial activity against four WHO high-priority pathogens: Escherichia coli (EC), Klebsiella pneumoniae (KP), Staphylococcus epidermidis (SE), and Staphylococcus aureus (SA). As a consequence, the scientists, Pricilla, R.B., et al., were able to effectively make CDs from the seeds of the aforementioned plants using a hydrothermal technique, allowing to take advantage from all of the antimicrobial capabilities [36].

Following the researchers' investigation, CDs had a spherical form with an average diameter of 6.3 nm. They subsequently coated the 100% cotton material with synthetic CDs by immersing the cotton cloth in 20 mL of CDs and sonicating it. The instrument used for the ultrasonication stage lasted 1 hour and had a 30% amplitude. The resultant cloth was dried in a 70 °C oven. The modified cotton cloth was subsequently subjected to antimicrobial testing by the researchers [36].

When the treated cotton fabric was compared to the untreated cotton fabric, it was clear that the cotton material that had not been loaded with CDs c had typical cell enlargements for EC, SA, SE, and KP, as predicted. On the other hand, EC, SA, and SE did not show any cell development on the coated cloth. For KP, growth inhibition was only noticed at 40%, suggesting that the greater the number of CDs loaded into the cotton cloth, the more efficient the cloth will be towards bacteria. This is because the carbon nanoparticles generate reactive oxygen compounds, such as singlet oxygen (O_2), H_2O_2, hydroxyl radical (− OH), and superoxide (O_2 −), which stick and then pass through the microbial wall to induce oxidative damage and DNA/RNA disintegration, which in turn leads to misinformation or suppression of gene activity. Additionally, lipid peroxidation, intracellular protein inactivation, as well as mitochondrial malfunction are brought on by the reactive species, ultimately leading to the demise of cells. All of the aforementioned findings established the CDs' antibacterial properties when applied to cotton-based textiles [36].

3.2.2. Nano-silver-doped carbon quantum dots

Because of its shown benefits in terms of biocompatibility and nontoxicity, carbon quantum dots (CQDs) have emerged as a distinct family of optically active nanostructures that might serve as a suitable substitute for metallic quantum dots. Moreover, CQDs have excellent properties such as strong resistance to photobleaching, affordability, ease of synthesis, and biological conjugation [37, 38]. And considering both nanomaterials are well-known for their ability to delay bacteria, S.O. Alzahrani et al. integrated Ag nanoparticles with enough CQDs to put the finished component onto cotton fibers to generate antimicrobial textiles [38].

The scientists clustered sodium alginate to create both AgNPs and CQDs. After adding Ag+ and AgNPs, accordingly, to alkali hydrolyzed alginate, they created Ag-CQDs and AgNPs-CQDs and exposed them to hydrothermal circumstances. They then used a dip coating technique to transfer CQDs, Ag-CQDs, as well as AgNPs-CQDs upon the cotton textiles. Cotton fabric individual pieces (0.5 g) were impregnated individually in 50 mL of the previously produced colloids and stirred continuously for 20 minutes. The cloth pieces were then let dry out at 70 °C [38].

The findings presented in (**Table 1)** demonstrated that AgNPs-CQDs coated cotton exhibited the best antibacterial efficiency among the investigated bacteria and fungi. This indicates that the superior antimicrobial activity of AgNPs doped-CQDs was primarily associated with the successive doping of AgNPs along with its highly manageable size and shape, which allowed for easier penetration through the investigated microbial strains' cell walls and ultimately resulted in cell mortality. While contrasted with other specimens, such as untreated

samples, those infused with simply CQDs, and samples treated with Ag-CQDs, the researchers' investigation revealed that AgNPs-CQDs Cotton displayed superior antibacterial activity [38].

Table 1: antimicrobial outcomes (zone of resistance) for cotton materials that have been modified [38].

Samples	G +ve bacteria	G -ve bacteria	Fungi
	S. aureus	*E. coli*	*C. albicans*
Cotton	0	0	0
CQDs@Cotton	0	0	0
Ag-CQDs@Cotton	13.5 ± 1.0	15.5 ± 1.5	14 ± 1.5
AgNPs-CQDs@Cotton	14 ± 1.5	18 ± 1.5	16 ± 1.5

3.3. Applications of CDs as UV blockers/ absorbents

Every day, the sun's optical spectrum releases infrared (IR), apparent, and ultraviolet (UV) radiation with wavelengths ranging from 200 nm to 1 mm. On the other hand, UV radiation may be regarded as the sun spectrum's most harmful element. Furthermore, based on the wavelength and intensity, UV radiation has a variety of detrimental physiological effects on humans and other living things that can range from immediate to long-term [39]. For instance, prolonged repeated exposure to ultraviolet radiation (UVR) damages the immune system, skin, and eyes. This results in a variety of cutaneous issues, such as sunburn, wrinkles, along with skin cancer [40]. It is therefore necessary to develop personal protective equipment (PPE) to shield wearers from a variety of threats. PPE should not, however, sacrifice wearers' comfort to do this [41]. And there comes the role of integrating textiles with CDs to block all the harmful UV rays, introducing protective fabrics and comfortable ones.

3.3.1. Sulfur and nitrogen-doped carbon dots

Fiber goods made of polyethylene terephthalate (PET), a semi-crystalline thermoplastic polymer substance, are referred to as terylene. Due to its outstanding features such as superior chemical reactivity, minimal water absorption, outstanding strength, high modulus, adaptability, and superior durability against wear, terylene is extensively utilized in the textile industry for clothes and drapes [42]. However, a significant quantity of pollution is produced due to the polyester's sluggish rate of breakdown. Because PET trash is fundamentally a polymer with a high carbon atomic content as well as an important amount of benzene rings, Wu, Y., et al. found potential in employing PET waste as a precursor for generating a useful carbon material termed CDs utilizing the solvothermal process. They also introduced sulfur, nitrogen CDs utilizing phenylenediamine as the nitrogen source, sulfuric acid as the sulfur source, and, of course, PET oligomers as the carbon source, adding further significance to the content of the CDs [43].

The researchers next produced light-blocking membranes (LBFs) using fluorescent SN-CDs, which have a median particle diameter of 4.3 nm. Using 5% polylactic acid (PLA) in various ratios (0%, 1%, 2%, 3%, 4%, 5%, 6%, and 7%), the freeze-dried solid SN-CDs were combined with it. Using an ultrasonication procedure, the trichloromethane solution was homogeneously blended to create combinations with varying amounts of SN-CDs. Next, a dry petri dish of 15 cm in diameter was filled with 20 g of each combination, which had been weighed. Following a full 24-hour evaporation of the trichloromethane at room temperature, LBFs of consistent thicknesses were created [43].

Subsequent examination by the researchers revealed that LBFs had a tunable capability for light absorption in addition to blocking UV and blue light. Additionally, it was discovered that pure PLA films had a transmittance of roughly 90% in the ultraviolet to blue light regions, whereas this transmittance gradually declined as the PLA film's SN-CD content rose. These findings suggested that LBFs had powerful UV to blue light absorption in addition to an adaptable capacity for light absorption as the blocking ability was boosted with the film's SN-CD amount. all demonstrating how effective CDs are as UV blockers [43].

3.3.2. Nitrogen-doped CQDs/ TiO_2

Because of its strong absorption in the UVA and UVB bands, CQDs have been used in textile materials research. Its effectiveness, strength, and biological compatibility have also been assessed when doped with heteroatoms like nitrogen or boron. High quantum yield, exceptional UV absorption capacity, charge separation capabilities, and the distinctive qualities of graphene and quantum dots are all provided by this doping of GQDs. In addition, TiO_2 is frequently utilized in textiles as a UV protectant because of its great effectiveness, chemical stability, and light resistance. However, in the visible spectrum, these NPs have less of a scattering impact. Felipe, B.H.S., et al. could thereby apply TiO_2, nitrogen-doped GQDs (N-GQD), and N-GQD/TiO_2 NPs to fabric to assess each treated cloth's ability to filter UV light [44].

The cotton fabric was put in glass beakers containing solutions of NPs at different levels by the researchers. After adding the combination, it was placed in a sonicator and run for two hours at a frequency of 50 KHz in an ultrasonic bath. After which, it was stirred for thirty minutes at 150 rpm on an agitating table. All solutions were afterwards sent to a hydrothermal device with a bath ratio of 1:75 along with 2 g of cotton textiles. After 150 minutes at 135 ˚C, 10% polyvinyl alcohol (PVA) was added

to the bath volume to continue the nanocoating process. Thus, the procedure went on for 150 minutes at 135 ˚C. Following the nanocoating process, the materials were dried in a hot air drier for two hours at 100 ˚C [44].

Next, a comparison between the treated and untreated cotton textiles was analyzed. The treated cloth containing N-GQDs and TiO2 had the best UPF rating of 50+, according to the data. Uncoated textiles, however, exhibited little protection. Additionally, materials coated with nanocoating produced strong UPF values even after laundering, suggesting that the material has an N-GQD and N-GQD/TiO2 nanocoating on cotton fabric that is resistant to regular home washing cycles in addition to its anti-UV properties. All concluded that GQDs could enhance UV-blocking properties [44].

4. Conclusion

The term "carbon dots" (or CDs) refers to a class of spherical, less than 20 nm-diameter carbon-based nanomaterials that have garnered a lot of interest recently due to their unique properties and potential applications. This paper includes a thorough analysis of the synthesis procedures as well as novel applications and uses for carbon dots in the textile industry. Hydrothermal and microwave synthesis are two of the many methods used to create CDs, which result in nanoscale carbon structures with amazing quantum entanglement effects and modifiable surface properties. These forms of carbon-based nanoparticles can be made using synthetic or biological precursors that are rich in carbon. Moreover, the sustainable origins of CDs—they are made with carbon-rich precursors and environmentally benign synthesis techniques—align with the textile industry's growing emphasis on environmentally good methods. From UV to flame-retardant to antibacterial, CDs have shown promise as materials that may be incorporated into textiles to provide them the protective qualities needed for consumer protection. Additionally, owing to their cheap cost, photoluminescence, non-toxic behavior, biocompatibility, and the existence of functional groups like hydroxyl and carboxyl, they perform exceptionally well in the aforementioned textile applications.

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6. Conflict of interest

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