REVIEW

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Medicinal Plants Derived Green Carbon Dots: Synthesis, Characterization and Their Potential Applications in Cancer Therapy

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Abstract

Objective: This review aims to explore the synthesis, characterization, and potential applications of carbon dots (CDs) derived from medicinal plants for cancer prevention, highlighting their role as a promising alternative in nanotechnological approaches. **Methods:** A comprehensive literature search was conducted to gather information on the synthesis methods, complex matrices, characterization techniques, and potential applications of CDs derived from medicinal plants in cancer therapy. **Result:** Carbon dots (CDs) have emerged as a subject of significant interest due to their favorable chemical and biological properties. Various precursors, including graphite, carbon black, and organic molecules, are utilized in the synthesis of CDs through chemical or physical methods. Notably, CDs derived from medicinal plants offer environmentally friendly alternatives, leveraging complex matrices such as aqueous, alcoholic, and hydroalcoholic extracts. This review emphasizes the green synthesis approaches, characterization techniques, and diverse applications of CDs, including drug transport, bioimaging, biosensing, and anti-cancer therapies. Furthermore, it highlights the advantages and disadvantages of different synthesis methods, aiding researchers in selecting appropriate techniques for continuous production. **Conclusion:** Carbon dots (CDs) represent a transformative advancement in nanotheranostics, offering a versatile platform for precise cancer diagnosis and therapy. With inherent anticancer properties, CDs hold promise in photodynamic therapy (PDT) and photothermal therapy (PTT), enabling precise tumor targeting while minimizing systemic toxicity. To address the limitations of standalone PDT and PTT, researchers are exploring multimodal treatment approaches integrating CDs. By leveraging the unique properties of CDs derived from medicinal plants, a new era of precision cancer therapy may be realized, emphasizing enhanced therapeutic outcomes and reduced adverse effects.

Keywords: Carbon Dots- complex matrices- medicinal plant- nanotechnology- green synthesis- cancer therapy

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Introduction

Carbon Dots (CDs) known as ultrafine zero-dimensional nanomaterials named after the main compositional element that exhibits fluorescence behaviours, were first discovered accidentally during separation and purification of single-walled carbon nanotubes (CN) [1]. CDs are the latest nanoparticles with a distinctive diameter of 1 to 10 nanometers that are made from carbon atoms [2]. Recently, CDs have attracted great interest and studied extensively in recent years owing to their unique properties and potential in many fields. This fluorescent nanoscale or Carbon quantum dots (CQDs) [3] exploration has been pursued for their uses in luminescence imaging in vivo and in vitro, yielding results that not solely serve as the pioneer demonstration of extensively prognosticated potential but also discovered for further expansion. Graphene oxide sheets, carbon nanotubes and graphene QCDs are examples that have been identified as a compelling platform for medical applications. Each of these materials has remarkable challenges from conjugation to implementation [4]. CDs have lately been used as a safe alternative candidate as they possess excellent efficiency in both light absorption and emission [5]. CDs as a new allotrope for carbon particles also exhibit exceptional benefits including environmentally friendly biocompatibility, low cytotoxic activities, impermeability towards chemicals [6-8] and optical properties such as excellent photoinduced electron transmission facilitated in targeted drug delivery, bio-imaging and bio-sensing for biomedical applications [9-11]. Two-photon imaging, excitation-wavelength-dependent photoluminescence (PL) emissions, size-dependent photoluminescence emission, and photobleaching resilience are just a few of the exceptional optical features of CDs.

Natural precursors like medicinal plants for the

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production of CDs get much attention as sustainable carbon dots (SCDs) compared with other biomass sources (Figure 1). Anciently, plants are consumed as traditional methods of remedy to treat various illnesses without leaving any impurities [12]. As human civilization evolves, the dominance of synthetic chemistry from heavy metal-based CDs over plant-based CDs in commercial medications misleads to consequences in comparison to plant extracts as some SCDs show better efficacy [8]. Fabricating CDs from medicinal plants expands research towards their therapeutic potential because SCDs are comprised of secondary metabolites and heteroatoms like Sulphur and Nitrogen without additional requirements from additional sources [13]. Given to the abundance of other biomolecules found in parts of plants example stem, bark, leaf, fruit, seed, root, or rhizome provides basic aspects for surface functionality compared to chemical stimulants of CDs as it does not acquire different reactants for doping, and surface passivation [14].

Due to the valuable traits of SCDs or green synthesis of CDs, it has emerged in sustainable development in biomolecules [15]. Additionally, the synthesis of SCDs is easy to obtain and affordable which expresses economic scale-up manufacturing, and flexible incorporation with other nanoparticles with ease of modification [16]. Even SCDs provide profound tuneable photocatalytic activity, similar to conventional fluorescent semiconductor nanomaterials [17,18]. This review enhances the understanding of sustainability in the synthesis and characterization of SDCs from medicinal plants that highlight their wide array of applications including for cancer therapy. Henceforth, it also going to discuss medicinal plants including the complex matrices, extraction as well as extraction methods for better results.

Synthesis of carbon dots from medicinal plants

Various chemical, electrochemical and physical methods can be used to modify and functionalize CDs, generally, two methods recognized principally for the synthesis of CDs are "top-down" and "bottom-up" (Figure 2). The "bottom-up" approach involves the fragmentation of carbon dots from small molecules or precursors while the "top-down" approach involves breaking down larger carbon structures such as graphene and carbon nanotubes into smaller pieces, which are further processed to produce CDs [9, 19]. The bottom-up approach generally allows for better control over the size, morphology and surface chemistry while the top-down approach produces CDs with higher purity and crystallinity [20]. These approaches can be reached by a few methods, namely surface functionalization which refers to the modification of the CD surface by attaching various functional groups [21]. Nanohybrids involve the incorporation of other materials like metal and graphene oxide into CDs and enhance their abilities in various applications. Doping of CDs has been very well known with association with heteroatoms that alter the electronic properties of CDs and post-treatment by annealing or acid treatment to improve the stability and optical properties of CDs [22, 23]. Different synthesis procedures of CDs give chances to adjust the individual components subsequently to their properties. Both approaches have their advantages and disadvantages as the choice of method depends on the specific application of SCDs. However, these approaches methods provide a versatile and facile route for the production of SCDs with tunable optical and electronic properties making them suitable for a wide range of applications. CDs synthesized from medicinal plants are often sustainable and reduce the environmental impact of the synthesis process, making them non-toxic as can be incorporated and tailored to target specific cell types or tissues with therapeutic properties by providing a diverse range of starting materials over those synthesized from other resources [24]. Therefore, this area of research

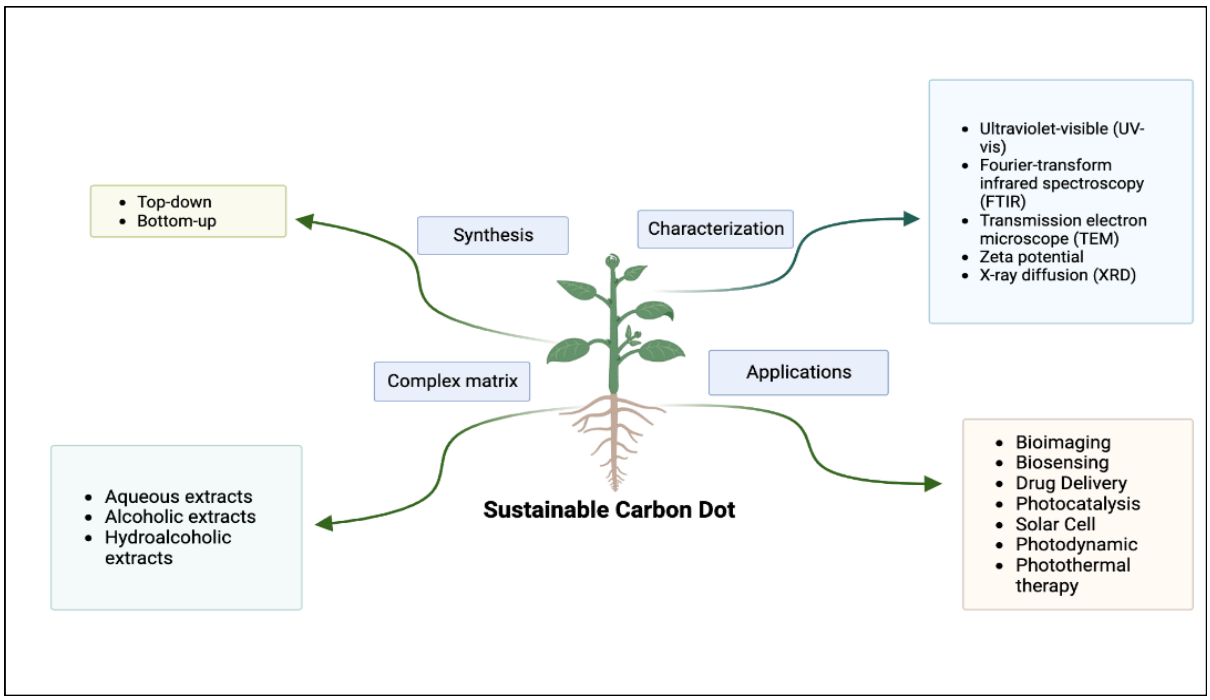

Figure 1. Schematic Diagram of Sustainable Carbon Dots

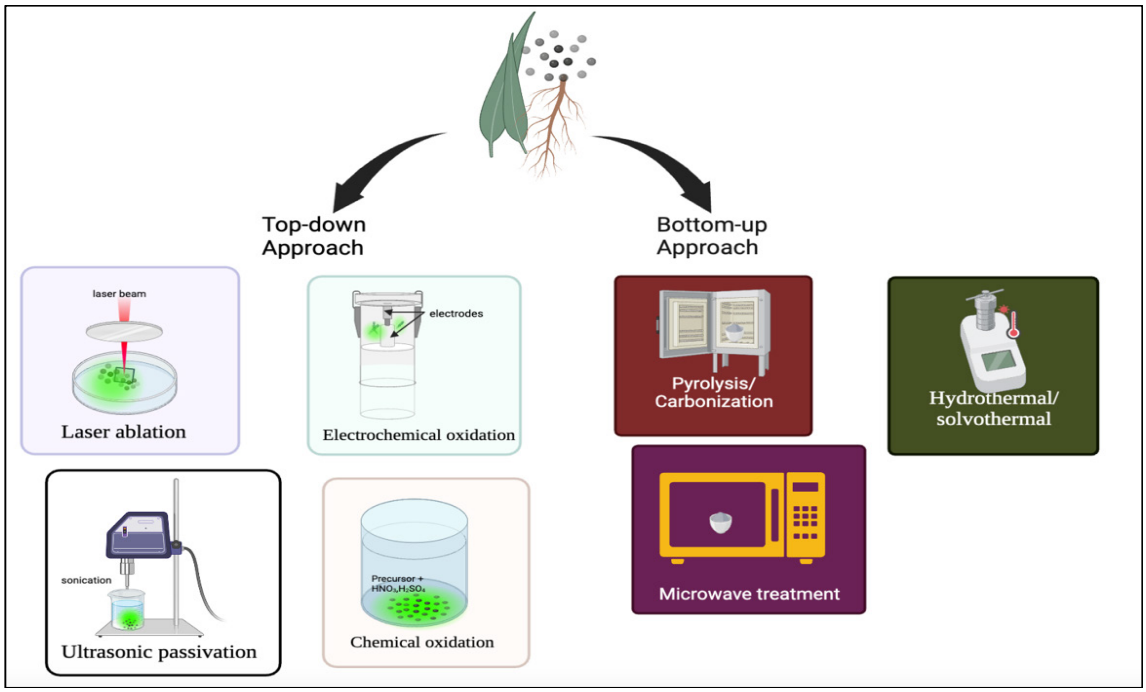

Figure 2. Top-Down and Bottom-Up Approaches for CD Synthesis.

should earn more focus in any further studies.

Tables CDs through "top-down" approaches

The "top-down" method is an effective solid layering approach developed for the synthesis of carbon dots [25]. There are several techniques like arc discharge, chemical oxidation, laser ablation, ultrasonic passivation and electrochemical synthesizing of CDs [9]. Arc discharge was used first to produce CDs in 2004 resulting in a smaller surface area that potentially occurs during the electrocatalytic process at anode in gas plasma [1, 26]. This approach includes laborious, expensive and meticulous preparation stages where purification of components is challenging. SCDs are prepared by chemical reactions that involve the conversion of precursors into CDs. Chemical oxidation is a common approach for functionalizing CDs with strong oxidizing agents [27]. Nitric acids are used in the case of synthesizing CDs utilizing the exfoliation of the graphite anodes [28]. Hydrogen peroxide or potassium permanganate introduces oxygen-containing functional groups such as hydroxyl and carboxyl groups onto the surface of CDs typically enhancing hydrophilic and stability in aqueous solutions. For example, blue florescence CDs from Cucumis melo [29], Camellia sinensis [15], tomato [30] and pineapples [31] were synthesized using acid oxidation by dissolving in H3PO2. Graphite is characterized in a solution of H2SO4 and HNO3 by the application of ultrasonication by the application of heating at 120°C for 24 h would be effective in the case of enhancing the synthetic applications of the carbon dots [32]. Therefore, additional procedures needed to eliminate impurities despite the usage of strong acid to prepare CDs is ethically a non-environmentally friendly process that led to the creation of poisonous gas and significant build-up of contaminants [22]. Meanwhile, electrochemical exfoliation for CD preparation is rarely used as it uses special equipment as a separator for graphite anode and cathode to enable a smooth electrolysis process [33]. Nevertheless, CDs can be synthesized on a big scale but involve extreme circumstances and sophisticated machinery [34, 35]. The laser ablation technique employs an intense laser beam to swiftly irradiate the targeted surface into an electrically charged state to form nanoparticles upon exposure to high temperatures [36, 37]. The energy consumption for this method is high and rather expensive producing different sizes of CDs without control alongside low quantum yield (QY) [38].

Ultrasonic passivation is used to enhance the stability and performance of CDs by treating them with ultrasonic waves. CDs from Polyalthia longifolia leaves were subjected to an ultrasonication process for an hour and showed a narrow range of 1.5 to 6.5 nm diameter [13]. Surface passivation during this technique allows the modification of surface chemistry to reduce detects on CDs [39]. The study by Reddy Prassad and Naidoo [40] investigated enhancing the photocatalytic properties of CDs by comprising Copper tungstate (CuWO4) for efficient degradation of wastewater pollution [40]. Column chromatography is used in the case of ionic separation of carbon dots with an approximate diameter of 22 nm. The wild lemon variant plant (Citrus pennivesiculata) is also used for the synthesis of CDs from medicinal plants [41]. Hence the sound waves that create mechanical agitation and microstreaming within the liquid medium promote diffusion and penetration of passivating agents into CDs structure for better coverage. Not only that but ultrasonic treatment can facilitate the attachment of functional groups for sensing applications by controlling and adjusting parameters such as frequency, duration and frequency to achieve precise size control and uniform distribution of CDs. The chemical oxidation method, ultrasonic treatment or electrochemical methods are beneficial in the case of

cutting and macro-scale materialistic screening.

"Bottom-up" approaches

The "bottom-up" method of CD synthesis refers to the formation of smaller molecular or nanoscale precursors through various processes that include solution-based methods. This approach is used for the transformations of the natural products towards the collection of the non-toxic components of CD. The Principles of Green Chemistry that emphasize designing secured chemicals and reducing the risk of hazardous chemical synthesis can be correlated with the fabrication of SCDs [42]. Hydrothermal technique is a procedure where a combination of precursors is heated between 150°C to 250°C and high pressure to produce QCDs. Xue and co-workers used Aloe vera to obtain the fluorescence of CDs at 180°C as the ideal hydrothermal temperature [43]. Different parts from nourishing medicinal plants for instance Pinellia ternata stem were dried and grinded to coarse powder before being heated at 180°C for 9 hours and transferred to a lined autoclave. The powder was well mixed using alcoholic extracts that included 10 mL of ethanol and 1 mL of ethylenediamine (EDA) evenly. High QY of 21.3% and good excitation at emission wavelength at 444 nm remarkable optical properties were obtained with the help of EDA. The emission peak spectrum for photoluminescence properties is correlated to the hydrothermal temperature during the synthesis of CDs [44]. For instance, the CDs derived from neem leaves at 150°C will depict longer shifts compared to other temperatures resulting in a high QY of up to 27% [16] approximately compared to mustard [45] at 4.6% only. Ideally, with a hydrothermal approach, carbon precursors are sealed in a reactor followed by a heating, extraction and concentration process. This method of production is effective for creating CDs due to the straightforward synthesis procedure and heteroatom doping but has some limitations including agglomeration during heating that prospects in size and solubility for the one-pot solvothermal method [46]. White pepper powder dissolved with anhydrous ethanol was heated at 150°C for 4 hours in a round bottom flask before proceeding for filtration and freeze-drying to obtain CDs [46]. Banana juice extracts are heated at 150°C for 4 hours with 20 mL of ethanol [47]. 20 mL of water and the brown soluble component is obtained through the actualization of further filtrate aspects. The retardation factors of the polar and non-polar solvents are used extensively for the synthesis of the optically active molecular infrastructures of carbon dots [48]. Moreover, highly fluorescent properties are further checked by the measurement done by UV-Vis spectroscopy. Table 1 summarises the hydrothermal and solvothermal conditions of medicinal plant-derived SCDs as mentioned. Such a method is eco-friendly, easy preparation and cost-effective which is highly recommended among researchers.

Pyrolysis is a popular method in CD fabrication through the thermal decomposition of carbon resources. It involves the heating of carbon resources at high temperatures typically in an inert atmosphere. During this approach, the chemical bonds and rearrangement of atoms in the precursors occur. The size and morphology of CDs obtained from pyrolysis can be influenced by reaction time and concertation of precursors, alongside temperature. Fennel seeds were used as a carbon precursor to synthesize mono-dispersed SCDs for the highest temperature at 500°C for 3 hours [49] as stated in Table 2. The large size of CDs form when high temperatures and prolonged time are taken, while the smaller size of CDs are synthesized when a short period and lower temperature are initiated for pyrolysis [50]. Due to its straightforward and minimal requirement of equipment that can be applied to a wide range of materials, it is a valuable approach and preferred choice for the production of carbon dots with tailored properties. Microwave treatment is one of the fastest methods to synthesize CDs that involves subjecting carbon sources to rapid heating and carbonization through irradiation of electromagnetic radiation with a 1 mm to 1m wavelength range [51]. The dipolar polarisation of particles in suspension and the movement of material waves are the two causes of the microwave effect. Following irradiation, a lot more particles shift to realign

Table 1. The Fabrication of Medicinal Plants-Derived SCDs via Hydrothermal and Solvothermal Methods.

Carbon source	Part	Temperature (°C)	Time (h)	Reference
Aloe	Stem	180	11	[43]
Brassica oleracea	Flower	120	5	[56]
Mustard	Seed	180	4	[45]
Allium cepa (onion)	Root	180	4	[57]
Panax notogingseng	Root	180	12	[58]
Bamboo	Stem	180	3	[59]
Neem	Leaf	150	4	[16]
Osmanthus fragrans	Flowers	180	9	[60]
Rose	Flower	180	5	[53]
White pepper	Seed	150	4	[46]
Gingko biloba	Root	200	10	[59]
Henna	Leaf	180	12	[61]
Pinellia ternata	Stem	180	9	[62]
Tomato	Fruit	150	2	[63]

Table 2. The Fabrication of Medicinal Plant-Derived SCDs via Pyrolysis Method

Carbon source	Part	Temparature	Time (h)	Reference
Fennel	Seed	500	3	[64]
Watermelon	Fruit	220	2	[65]
Gynostemma	Leaf	400	4	[66]
Zingiberis rhizoma	Root	350	1	[67]
Paeoniae radix alba	Root	350	1	[60]
Lonicarae japonicae flos	Flower	350	1	[68]
Radix sophorae flavescentis	Leaf	350	1	[38]
Schizonepetae spica	Leaf	350	1	[19]
Artemisiae Argyi folium	Leaf	350	1	[69]

themselves, causing collisions and an upsurge in the temperature of the resulting solution [52]. Rose was pulverised into fine powder, and mixed with distilled water and Phosphorus pentoxide as a phosphor dopant well before 10 minutes of stirring. The solution undergoes microwave irradiation until the color transitions from red to brown [53]. However, studies showed CD fabrication that solely depends on microwave treatment results in low QY. To address this limitation, a combination of other approaches like pyrolysis, hydrothermal and carbonization was established through Gul and his team using bananas as a carbon source. The banana peels were carbonized in the microwave at 80°C for half a day before the grinding process, whereby CDs derived from fresh banana peels to synthesise CDs through microwave treatment alone at 500W in a Teflon microwave showed low QY. Filtration and centrifugation as a final step are performed to remove large particles and isolate CDs with higher QY [54]. Microwave-assisted hydrothermal treatment for the synthesis of CDs from coconut without adding chemicals was conducted at 800W. It was applied in the bioimaging of fungal cells as it exhibits blue and green fluorescence images [55].

Sustainable CDs from medicinal plant matrices

Medicinal plant matrices have become a growing asset in molecular biology. These plants have many biologically active chemicals, such as proteins, enzymes, and nucleic acids, which can be separated and investigated for medicinal characteristics that modify and change DNA using molecular biology techniques supporting drug-making processes and therapies [70]. The multitude of medicinal plant matrices highly shows all the benefits of molecular biology. The distinct medicinal plant is a group of bioactive chemicals including chromatography, electrophoresis, and immunoprecipitation used for the extraction and purification of these small molecules. According to Okla et al. [71], chemicals also have the potential to be produced employing molecular biology methods for concentrated medicinal uses. Similarly, it may alter the gene sequence of a substance to boost its medicinal characteristics and tweak the protein's structure to optimize its durability and accessibility for creating new drugs and treatments. In addition, it has minimal side effects that can contain drugs [71]. The utilization of medicinal plants has become extensively advertised in developing nations due to their containing therapeutic effects employed as medical medicines. Moreover, the key elements of medicinal plants are substitutes for different therapeutic objectives using several drugs to treat a range of illnesses. Besides, SCDs are a kind of antibody segment made from a single chain of amino acids and have been displayed to be extremely successful in the treatment of quite a few problems. According to Belwal et al. [72], these SCDs have been extracted and synthesized from medicinal plants using molecular biology techniques, permitting the production of innovative medicinal medicines. Medicinal plants have been beneficial in offering natural cures for maladies [73]. The usage of these plants has been considered a key component of medicine. Different types of chemicals are viewed in these plants which have crucial medicinal qualities used to advance contemporary medicine. Antibodies are of special relevance within the chemicals observed in medicinal plants based on their capacity to recognize certain infectious agents. SCDs are molecules of antibodies with the antigen-binding potential of complete antibodies in tiny sizes. SCDs tend to be stable and simple to make in bacteria production methods. They can be shown to have multiple advantages compared to whole antibodies, such as improved tissue piercing, smaller immunity, and more effective pharmacokinetics [74].

Plant matrices are employed as carbon precursor sources to represent the alignment of the medicinal plant matrices. Implementing medicinal plant matrices for SCD development entails extracting antibodies from plant tissue and designing those antibodies into single-chain sections [75]. The extraction method includes the extraction of plant tissue, which involves homogenate and antigen separation, and also purifying the antibodies by applying such effective biological matrices or settings properly. A whole lot of research is being performed on medicinal plant-derived SCDs as it is the best source of pharmaceutical compounds for the development of synthetic medications. Complex matrices in the review imply medicinal plant extracts. However, the extracts will be fractionated to remove undesirable components based on the methods used [76]. Extracts can be essentially found in three different spots which are dissolved in the exterior phase, entrapped, and also absorbed on the surface

of the carrier, depending on lipophilicity and preferred nanostructure [77]. Applying medicinal plant matrices for SCD development offers multiple advantages over conventional antibody production methods. Medicinal plants are renewable resources and their application in antibody manufacturing is for a long time. According to Peláez et al. [78], employing plants as an antibody source can be less expensive than common antibody production techniques like hybridoma technology. SCDs promote the development of medicinal medicines with upgraded pharmacokinetics and lower immunogenicity [79]. The bioactive compounds like tannins, alkaloids, flavonoids, and glycosides give SCDs good therapeutic properties. The choice of menstruum and the composition of bioactive compounds differs according to the portion of the plant that needs to be extracted (Figure 3). The plant matrix employed a significant effect on the features of the resultant carbon precursor. Carbon precursors have piqued the interest of the experimenter due to their possible uses in power storage, catalysis, and restoration of the environment nowadays. Plant matrices are rich in carbon precursors such as lignin, cellulose, and hemicellulose [80] which are applied to synthesize these compounds including bamboo [81], mushrooms and coconut [82]. Flavonoids and phenolic chemicals which are rich in Trapa bispinosa peel, have antioxidants and anti-inflammatory properties that could be particularly advantageous for biological applications [83]. Similarly, the abundance of polysaccharides in ginseng root could render this plant matrix a desirable source of carbon precursors for power storage purposes. In addition, polysaccharides have a high charge ability to store power that can enhance the extraction process satisfying the molecular biology concepts [84]. Numerous processing techniques such as maceration, sonification and Soxhlet extraction are frequently used in galenical development during the production of SDCs as a crucial factor to achieve targeted nanoparticles. Furthermore, the application of medicinal plants in medication development could culminate in monetary benefits also. The association with molecular state and solvents in plant matrices contributes to the optical bandgap.

Aqueous extraction

Carbon precursors can be extracted from medicinal plant matrices employing techniques of aqueous extraction. The aqueous extraction is a typical technique for extracting bioactive chemicals from medicinal plant matrices. Water is a polar liquid capable of absorbing compounds of proteins, polysaccharides, and tiny chemical molecules [85]. Aqueous extracts include those that the sole extraction agent is water preferred for several reasons, namely affordability, ease of conducting the process, the need to minimize certain groups of contaminants, as well as sustainability considerations. Water functions as a solvent in this process to extract the necessary chemicals from plant tissues of proteins, polysaccharides, and phenolic chemicals [86, 87]. The accumulated aqueous extract can be explored further using multiple molecular biology methods. Aqueous extraction is a multi-step method where the plant fiber undergoes a drying process to dissolve any dirt, particles, or dampness. The dry material is next bombarded into a fine paste with the help of a pestle and mortar by the motorized mixer. The powder is mixed with a liquid and shaken for some time to enable the bioactive chemicals to sink within the solvent. The extracted liquid may be maintained at ambient temperature or chilled later. The correlation between water extracts and CDs is to significantly boost its stability and solubility. Flavonoids are used as reducing agent because of their comparatively small affinity to metal surfaces accomplishing easy ionic absorption and obtaining antioxidant properties. Tannin consisting of crystalline properties triggers a stimulation effect in the photocatalytic process. Moreover, antiviral, antitumor and anti-bacterial properties contribute to the application of CDs in the healthcare field [88]. For instance, certain tannins have been shown to block the proliferation

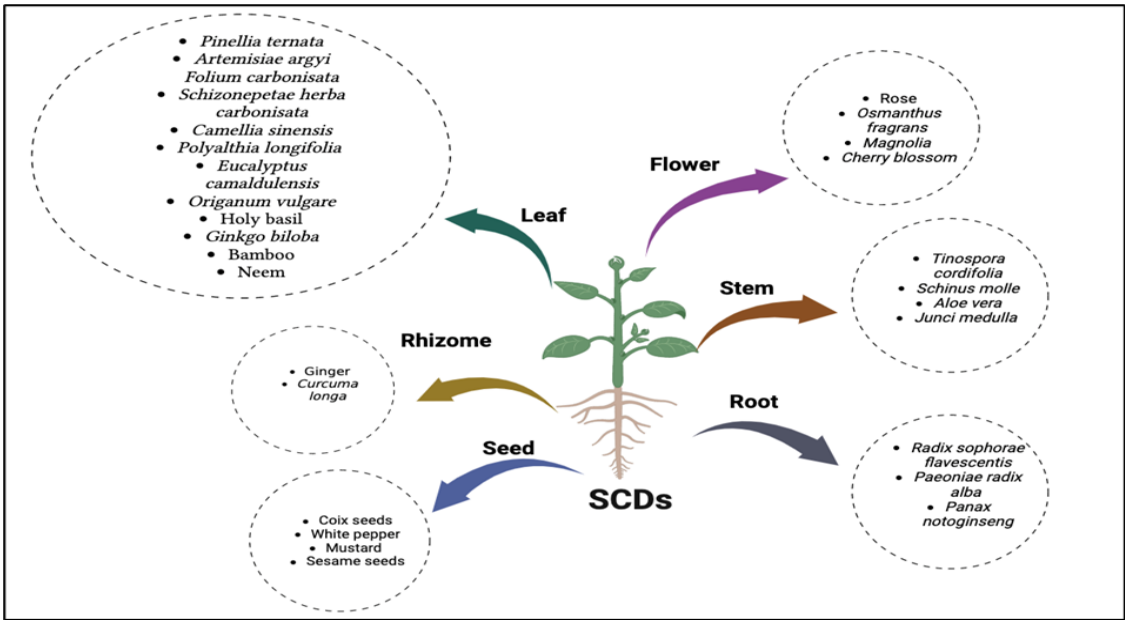

Figure 3. Collection of Different Parts of Medicinal Plants Used for Fabrication of SCDs

Table 3. The Overview of SCD Synthesis from Medicinal Plants via Aqueous Extracts and Their Respective Bioactive Compounds.

Carbon precursors	Part Used	Bioactive compounds	Application Field	References
Trapa bispinosa	Peel	Flavonoids (Quercetin, Pinobanksin, Rhamnetin) Phenolic compounds (Gallic acid, ferulic acid, ellagic acid)	Drug delivery	[83]
Camellia sinensis	Leaf	Catechin, epicatechin epigallocatechin	Cell imaging	[94]
Ginseng	Root	Polysaccharide (Pectin, glucans, galacturonic acid)	Fluorescence sensor and imaging	[84]
Centella asiatica	Leaf	Saponins (Asiaticoside, Madecassoside)	Drug delivery	[93]

of HIV. Other phenolic compounds like Saponins contribute immensely to the growth and maintenance of sustainability since it has the least damaging impact with a protective inhibitory effect [89]. Trapa bispinosa has antioxidants and phenolic substances in its peel and is considered a bioactive compound as a flavonoid and phenolic compound [83] without adding any external oxidizing agent. With prominent fluorescence and CDs ranging 5 to 10 nm collaborated well in cancer studies. CDs produced with this extraction have shown impeccable fluorescence characteristics and quantum efficiency, as CDs from Trapa bispinos appeal extract demonstrated outstanding biocompatibility with high concentrations at 80.32% via the cytotoxicity of SCDs on MCDK cells [83]. Protein evaluation, expression evaluation, and metabolic monitoring are such approaches. Protein analysis can be utilized to recognize each protein present in the extract and measure its molecular size, alignment, and shape [87]. Aqueous extraction has been suggested for isolating carbon precursors from four plant matrices. There are distinct methods of extraction to support the critical analysis of medicinal plants supporting further studies. In addition, sometimes it shows that molecules are less liquid in water, extraction with a supercritical fluid and extraction with solvent might be more desirable in molecular biology [90]. It represents a tiny subset of the diverse plant matrices and bioactive molecules to synthesize carbon precursors. The expression of enzymes associated with the production of bioactive chemicals in plants can be examined via gene expression research. Metabolite profiling is a technique to find and measure phenolic chemicals, alkaloids, and terpenoids that exist in extracts [91]. Camellia sinensis exhibits catechins and epicatechins in its leaves and notified bioactive compounds such as catechin, epicatechin, and epigallocatechin [92]. On another side, Table 3 finds another component of Ginseng root composed of pectin, glucans, and galacturonic acid as well as observes the bioactive compounds such as polysaccharides [84]. It has been suggested that developing SCDs with the help of organic polysaccharides can contribute to the development of selective therapies for breast cancer studies. Kwon et al. [93] expressed that Centella asiatica used a leaf that includes saponins of asiaticoside and madecassoside defining the carbon precursors satisfying the perspective of aqueous extraction concepts in molecular biology. The existing studies of SCDs from medicinal plants and the bioactive compounds have been attempted in Table 3. With these identified precursors, aqueous extraction has been executed to isolate bioactive chemicals, making it a flexible method for drug discovery and development.

Hydroalcoholic extracts

Hydroalcoholic extracts obtain the active ingredients of medicinal plants. These extracts are made by dissolving the plant material in a solution of liquid, often ethanol, and extracting the active ingredients. Besides, medicinal plants have been utilized for curing maladies, and hydroalcoholic extracts concentrate the chemicals of these plants. These extracts have been established to possess medicinal qualities such as anti-inflammatory, antibacterial, and antioxidant capabilities. Similarly, hydroalcoholic extracts can be controlled to ensure each quantity encompasses a comparable quantity of active chemicals. Aside from that, hydroalcoholic extracts tend to be readily metabolized by the body tissues instead of aqueous extracts. It happens due to ethanol-containing extract assisting away from plant material, enabling the active chemicals to be produced and consumed rapidly. In addition, the efficiency of carbon precursors can be affected by parameters like carbonization temperature, contaminants, and specific applications. Based on Table 4, it has shown plant species such as Echinops persicus, Aegle marmelos, Uapaca guineensis, Lepisanthes rubiginosa, Entandrophragma angolense, Camellia sinensis, and Syzygium aromaticum have been shown to contain carbon precursor potential and the bioactive compounds that exist in different sections of plants for evaluation. In this regard, the Iranian perennial herb plant Echinops persico has roots that contain tannins and flavonoids such as kaempferol and quercetin. In addition, tannins contain antioxidant, anti-inflammatory, and antibacterial effects in producing medicine to treat diseases. Moreover, this substance is more effective in supporting such illnesses using this component which is cost-effective also.

Hydroethanolic mixtures can extract more lipophilic compounds than aqueous ones due to the lower dielectric constant of ethanol. In this way, higher amounts of extract, expressed in terms of dry weight, can be incorporated with better entrapment. Ethanol extract of Aegle marmelos that grows in Southeast Asia contains a wide spectrum of antibiotic compounds and secondary metabolites such

Table 4. The Overview of SCD Synthesis from Medicinal Plants via Hydroalcoholic Extracts and Their Respective Bioactive Compounds.

Carbon precursors	Part Used	Bioactive compounds	Application Field	References
Echinops persicus	Root	Tannins, kaempferol, quercetin	Bio-imaging	[99]
Aegle marmelos	Leaf	Tannins (Aegeline, marmaline)	Fluorescence sensor	[95]
Uapaca guineensis Lepisanthes rubiginosa Entandrophragma angolense	Bark Stem Leaf	Flavonoid (Kaempferol, Quercetin, rutin)	Anti-cancer and pH detection	[100, 101]
Camellia sinensis (tea) Syzygium aromaticum (clove) Elettaria cardamomum Black pepper Fenugreek Zingiber officinale roscoe (Ginger)	Leaf Seed	Phenolic compounds (Catechin, gallic acid, eugenol, piperine, orientin, isovitexin, zingerone, quercetin, paradols, shogaols)	Anti-cancer, fluorescent protein crystals, drug delivery and bio-imaging	[93, 97, 102]

as angeline and marmalade exhibit anti-inflammatory, anti-diabetic, and fat-burning effects. Aegle marmelos is getting valuable results through antimicrobial and antifungal activities that act as a defence mechanism against microorganisms. The maximum suppression for ethanol extract of Aegle marmelos was against P.vulgaris at 18 mm. CDs from fruits displayed low toxicity with high-intensity fluorescent properties [95]. Similarly, phenolic compounds are defined as bioactive chemicals which are enriched with antioxidant, anti-inflammatory, and anticancer effects. Both the water extract and ethanol extract of black pepper exhibited strong antioxidant activity [12]. In this regard, tea leaves, black pepper, and fenugreek can use their seeds valuing phenolic chemicals like catechin, gallic acid, and quercetin as shown in Table 4. Besides, when the CDs derived from spices integrated into cells produce excellent photoluminescence capabilities that signify against the predominant color of the targeted cells while minimizing disruption from undesirable cells that adversely affect fluorophores [96]. High cancer prevention, antiviral and hepatoprotective measures displayed by Lepisanthes rubiginosa can be warranted for in vivo studies. Kaempferol and quercetin are bioactive molecules that contain antioxidant, anti-inflammatory, and anticancer properties that can mitigate the deficiency of antioxidants in the human body [97]. Moreover, these kinds of medicinal plant components can be useful to produce drug delivery processes properly. Camellia sinensis (tea), Syzygium aromaticum (clove), Elettaria cardamomum (cardamom), black pepper, fenugreek, and Zingiber officinale roscoe (ginger) are also effective components that are natural electrical configuration that works in conjunction with photocatalytic process satisfying the purification system respectively [98]. Aegle marmelos is mostly visible in Africa and has an effective role in cooperating in the process of drug addiction as in painkillers [95] and cell imaging to detect cancer cells in mice [60]. Medicinal plant materials are effective as carbon precursors, and their bioactive components influence their carbonization capacities.

Alcoholic extracts

The alcoholic extract is the herbal preparation of the active parts of medicinal plants using a solvent (Table 5). These extracts can be prepared from plant components, comprising leaves, stems, roots, and flowers in tinctures, infusions, and decoctions. In this prospect, it is considered alcohol is a useful solvent in bioactive chemicals creating medical plant treatments. Alcohol extends such duration as a natural preservative and inhibits microbiological development considering the key approaches of the procedures of the medicinal plant [103]. In addition, alcohol can dissolve both water-soluble and lipid-soluble components that can cooperate to produce drugs that are used in digestive disorders, respiratory problems, and skin-related illnesses as medicines [104]. Mulberry leaf considers carbon procedures with 73% QY and strong fluorescence under ultraviolet light. CDs from mulberry possess anti-inflammatory activity as traditional medicine in China is used to treat skin ulcers, general malaise, and bleeding [24, 105]. An effective antioxidant component of chlorogenic acid is enriched with anti-inflammatory and anti-diabetic that affect skin factors [106]. Rutin serves as a flavonoid mixing with immunomodulatory, anti-inflammatory, and anti-cancer that affects skin and health growth [24]. Morusin constitutes prenylated flavonoids combined with anticancer, anti-convulsant by treating seizures, and neuroprotective activities. The

Table 5. The Overview of SCD Synthesis from Medicinal Plants via Alcoholic Extracts and Their Respective Bioactive Compounds.

Carbon precursors	Part Used	Bioactive compound	Application Field	References
Mulberry	Leaf	Chlorogenic acid, rutin, moracins	Drug delivery, fluorescence ink	[24]
Curcuma longa	Rhizome	Phenolic compounds Curcumin	Photoluminescence sensor	[109]
Orthosiphon stamineus	Leaf	Phenolic compounds (Quercetin, tannic acid)	Pollution control and photocatalyst	[103]
Solidago microglossa	Leaf	Gallic acid, quercetin	Drug delivery	[110]

proliferation and inhibition of growth of lung cancer cells by down-regulating expression of COX-2 [107]. Curcuma longa has been considered the most popular spice as well as antiseptics, and food coloring ingredients. In addition, these roots are also edible as an antibiotic that strengthens the inner body parts of the human body. Besides, curcumin has been enriched in high quantities in turmeric, working as an anti-inflammatory, and anticancer activity [108, 109]. Turmeric roots comprise phenolic chemicals to curcumin satisfying its wide applications in the pharmaceutical and beauty sectors Orthosiphon stamineus also has a local name, cat's whiskers, which is a medicinal plant employed in conventional medicine for treating diseases of kidney stones, hypertension, anxiety, and diabetes. CDs of Orthosiphon stamineus leaf have mostly been used in the development of an antibacterial wound dressing. The resulting CDs loaded with quercetin and tannic acid were incorporated into a hydrogel wound dressing that potentially enhanced wound healing by exhibiting antioxidant properties as well [103]. A polyphenol of tannic acid possesses antibacterial and antioxidant effects to support people in increasing the body's immune system. Solidago microglossa is also a local identification as a golden rod which is mostly found in North American native perennial plants and has been evaluated as a fluorescent probe for metal ion detection by Zheng et al. [21]. In 2019, Eskalan and his colleagues confronted this CDs could potentially be used in cancer diagnosis and treatment as their potential as imaging agents has been evaluated. The seeds are utilized for treating diseases as medicine that can be used for preventing different kinds of illnesses such as urinary infections, arthritis, and gout illness. Besides, a flavonoid component of quercetin is combined to prevent cancer effects in the body. These bioactive chemicals are mainly utilized in the industry of pharmaceutical and nutrition supporting people by suggesting medical plant-based substitutes to prevent their illnesses.

Characterization techniques of sustainable carbon dots

The physicochemical properties of nanoparticles are keys to understanding their cellular uptake, access to targets and capability to cause damage to cells and tissue. For traditional drugs such as small molecules, the methodologies involved with characterization have been well established and standardized to define their properties such as molecular weight, chemical composition, purity, solubility, and stability [111]. Nanoparticles have a large difference in both physical and chemical properties and these properties affect the biological activity of nanoparticles. The bioactivity may depend on parameters such as particle size, shape, aggregation state, size distribution, surface area, charge, and functionality. Most engineered nanoparticles such as CQDs have multiple functionalities including targeting, imaging and therapeutic components that can affect biological activity. Therefore, standardized methods to define these nanoparticles have to be established.

With a comprehensive knowledge of the charter addition, SCDs have numerous characterization strategies. The physiochemical qualities of CDs have been thoroughly researched of how it associated with their unique morphology. Exploring the benefits and drawbacks of a variety of methods, including microscopy, spectroscopy, and diffraction techniques is highly recommended to characterize SCDs from medicinal plants. It is an important addition to the science since the physiochemical characteristics of CDs play an important part in the prospective applications which will be used in nanotechnology firms.

Characterization of SCDs by microscopy

A variety of different microscopic approaches are used to describe the form of CDs. By analyzing the nanoparticles, it is convenient to directly determine the size of particles using these techniques. Microscopies ranging from atomic force microscopy (AFM), Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are generally utilized to characterize CDs. It is crucial to highlight these microscopy-based approaches are remarkably accurate and dependable, and involve meticulous sample preparation to acquire good images is challenging. This is due to the agglomeration of CDs sample on the matrix and vacuum conditions in the chamber leading to significant possibility to result in imaging distortions.

Atomic force microscopy

Atomic Force Microscopy (AFM) provides a high-resolution scanning probe microscopic technique where, considering the contact that exists between an edge and sample surface, a topological image can be generated. A conventional AFM delivers details from the images of CDs in two-dimensional (2D) and three-dimensional (3D), where the heights of particles on 2D visuals can be randomly computed and the morphology of CDs is determined by 3D images. AFM is composed of a laser, a scanner, a 4-quadrant photodiode, and a cantilever with a tiny probe at the free tip makes it easier to characterize CDs by acquiring images of their dimensional surface at less than 1nm precision (Figure 4).

Scanning electron microscope

Scanning Electron Microscopy (SEM) is configured to gather images with good spatial detail. A sample of CDs will be positioned upon the surface of a highly charged electron beam resulting electron buildup image that can be used to recover data information on their crystalline, topography, morphology, and orientation phase. SEM can be used for elemental analysis of CDs using energy-dispersive X-ray spectroscopy (EDS) by detecting and analyzing X-rays emitted by the sample when exposed to an electron beam [57]. In a study by Cheng et al. [112], synthesized walnuts as precursors showed a uniform spherical shape and 10nm diameter using SEM [112]. Another research reported that the CDs derived from glucose had a high degree of crystallinity through images of SEM [77]. However, the inability to capture immense CDs is a drawback of the technology. The regularity of the CD dispersion can be examined along with the existence or absence of CD particles using SEM and also TEM as a good substitute. TEM holds a higher resolution

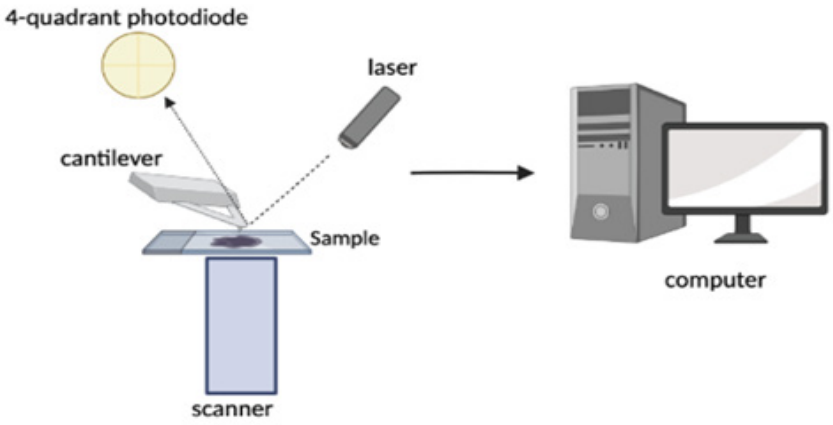

Figure 4. The Graphic Demonstration of Atomic Force Microscopy. The cantilever deflects as the probe tip scans the sample surface and the position-sensitive photodetector measures

approximately 0.2 nm rather than SEM which ranges between 1 to 20 nm.

Transmission electron microscopy

Transmission Electron Microscopy (TEM) is a technique that mainly uses the electron beam, especially regarding the image of the nanoparticle sample and provides a higher resolution rather than the possibility with the "light-based imaging techniques". On the other hand, it can also be better mentioned that TEM is also performed as a method that helps in the direct measurement of the nanoparticle's size, morphology, size distribution, and grain size. As Lin et al. [27] reported, electron microscopy adds advanced materials. Moreover, TEM is one of the most essential factors as this technique helps in the characterization of all the nanomaterial. This is a quantitative method for determining the shapes, size as well as distribution of particles.

TEM is mainly used in the nanoparticles because this can enable the images of each nanomaterial especially for captured directly and also at a higher resolution [30]. Henceforth, this is considered the major suitable technique which adds value to analyzing all the properties of the morphology of every single nanomaterial. As suggested by Sun et al. [113], the precise size of the particle regarding bringing to such a field of images was mainly provided by this TEM, and at the same time, it also provides detailed information about the composition, morphology as well as crystallography of CDs. This is because it helps in the utilization of the energized electrons. It is evident very frequently that TEM is also employed at the broader level especially for studying surface imperfection and at the same time the lattice of CDs. Mazrad et al. [114] employed the TEM method for interlayer distance and in-plane space between lattice layers that describes the crystal structure of CDs correspondingly in Curcuma longa with an average diameter of 2.6 ± 0.5 nm. Numerous studies demonstrated that SCDs derived from medicinal plants such as bamboo [116] and tomatoes [115] displayed quasi-spherical or spherical shapes. High-resolution TEM (HRTEM) is often used to examine the exterior and lattice flaws in CDs as it creates a dispersed image when reflected and transmitted beams are integrated [57]. The HRTEM image of CDs synthesized from lettuce and tomato denotes that the size is within 1.5 to 2.7 nm with a lattice spacing value of 0.21 nm [117] as it imputes to 101 planes of graphitic carbon [118].

Characterization of SCDs via spectroscopy

Different types of spectroscopic techniques are suggested for the characterization of CDs such as Ultraviolet-visible spectroscopy (UV-Vis) [44], Photoluminescence spectroscopy which measures the light emissions [64], Infrared spectroscopy for detecting absorption and vibration of infrared radiation [119] and Raman spectroscopy that specifically measures the scattering of laser light that aids in identifying the presence of graphitic functional groups [13]. Besides, X-ray photoelectron spectroscopy evaluates the binding energy from the surface of CDs through radiation [120]. Recently, researchers approved that Nuclear Magnetic Resonance (NMR) spectroscopy exposes information about the atomic and molecular connectivity of CDs [47].

Ultraviolet-visible (UV-vis) spectroscopy

UV-vis spectroscopy is commonly recommended for evaluating the CD's optical properties. This is because the synthesized of the CDs by going to using a wide range of methods usually possesses a strong as well as powerful UV absorption which results in the absorption peaks differently [22]. The majority of CDs comprised of medicinal plants have absorbance between 280 to 360 nm that exhibit negligible absorbance in light spectrum emission from blue to red. Therefore, CD transactions were also performed under high-performance liquid chromatography and at the same time with the gel of electrophoresis regarding resolving CDs of different sizes as well as overall structure. The absorption of the band peak mainly centred on very much UV region which is around 250-300 nm and those were also known as the "typical π-π* transition peak" that was very common in most CDs [121]. SCDs from cauliflower, saffron, aloe and Citrus sinensis show sharp shoulder peaks at 280 nm, 275 nm, 278 nm, and 270 nm that correlate to C=C bonds of aromatic rings through the hydrothermal approach on UV region respectively [43, 56, 122]. UV-vis defuse the

reflectance of the spectroscopy which is combined with the chemo-metrics regarding the rapid discrimination [123]. As reported by Guo et al. [124], one of the most beneficial facts is that it plays a major role in the quality detection of CDs. The attribution of strong absorption peak to n-π* transition of C=O or C=N sp2 bonds was demonstrated during the isolation of CDs from rose at 360 nm using different types of matrices method [125]. In contrast, a study by Godavarthi et al. [126] indicates that certain plants for instance Sargassum fluitans exhibited two distinct bands at 226 nm and 280 nm below 300 nm π-π* and n-π* transition from the surface region of CDs. This exhibits the fact when substances absorb all the light, then they undergo excitation and at the same time de-excitation and provide results like energy level and bandgap of CDs at the production of the spectrum.

Fourier-transform infrared (FTIR) spectroscopy measurement

FTIR is such an extremely effective technique that helps conform the very identity of all pure compounds and is one of the most powerful instrument-based infrared spectroscopies. The analysis of FTIR provides both qualitative and quantitative information on all the organic as well as inorganic samples. Many researchers argued that the fact of CQD was mainly comprised of nitrogen, oxygen, hydrogen, and carbon. As mentioned by Tejwan et al. [84], multifaceted applications of the carbon dots were synthesized also from all renewable sources. Therefore, the surface of these CDs normally comprises a wide range of functional groups which include carboxyl groups, hydroxyl groups, carbonyl groups and so on which mainly depend on the different types of synthesis techniques. For example, FTIR spectra of CDs from peppermint showed prominent peaks at 2953 cm-1 and 2868 cm-1 signifying the existence of carbon-hydrogen bonds (CH3) and (CH2) groups. The pulsations of -OH stretching were attributed to a strong spectrum at 3404 cm-1. Comparative analysis with reference compounds can further enhance the understanding of functional groups present in medicinal plant-derived CDs. The presence of double bonds at the peak region of 1650 cm-1 to 1800 cm^{-1} associates with carbonyl groups such as aldehydes and conjugated systems in CDs derived from most plant sources. For instance, the bands that exist within 1700 - 1750 cm-1 are prompted by the vibration of C=O bonds [127]. Moreover, the basic theory of the analysis helps in absorbing light at different levels of frequencies for proper optical applications in sensors [128]. The rapid methods of sample preparation in FTIR bring advantages and help in describing the functionalization surface of CDs which were affordable.

Characterization of CDs via scattering and diffraction techniques

Dynamic Light Scattering (DLS)

Dynamic light scattering (DLS) techniques can be used for measuring overall particle size distribution as well as dispersity. To customize these particles as biomedical applicable nanoparticles, it is essential to characterize the nanoparticles at various conditions such as pH and temperature. DLS measures fluctuations in scattered light intensity providing hydrodynamic size under these conditions. However, it may be applicable for some nanoparticles which absorb the wavelength of the light source being used. CDs of Hibus Sabdariffa showed low hydrodynamic diameter (Dh) up to 50 nm when the calcination temperature rated the highest at 400°C [129]. Followed by X-ray diffraction (XRD) which is applied to study the crystalline structure of the carbon precursors [130]. Moreover, Bragg's formula, $2d\sin\theta = n\lambda$ is used extensively for the clarification of the three-dimensional structuring and characterization of the CDs [131]. Calcium-based compounds with good symmetrical structures are formed at the highest temperature and a crystalline diffractogram in broad peaks at 26.6°, 42.46°, 43.01°, 44.67°, 47.30° and 50.83° correspond to (002) diffraction pattern [132].

Zeta Potential

Zeta potential is very much known as the "electro-kinetic potential" which is for synthesizing the florescent of CDs measured especially by going to Zetasizer which obtains surface charge [133]. Zeta potential analysis provides information on net charge and distribution under physiological conditions. This surface characteristic is related to nanoparticles' solubility, aggregation tendency, biocompatibility, and ability to travel through biological barriers. Nanoparticles' surface is also responsible for interaction and binding with various proteins. Zulfajri and his team noticed that CDs from Averrhoa carambola extract surface charge obtained as the −15.21 mV charge that shows the presence of -OH and -COOH groups. Therefore, the value of this "ζ potential" very much relied on the short or long-term CD particle stability. It can be better mentioned that CDs along with the higher level of zeta potential both in negative as well as positive states were considered as stable electronically whereas, on the other hand, particles along with the "low zeta potential" tend to go towards aggregate or coagulate over the short time [134]. Henceforth, "ζ potential" with the low state resulted especially in the weak stability at the physic of CDs. It has been proven scientifically that while the "ζ carbon dots at its high", this exhibits the fact of repulsive forces which mainly exceeded attractive forces that were able to create and provide a stable as well as relatively firm system as well [135]. Moreover, the alkaline pH is greater than 7 which demonstrates the fact that seta potential remains highly negative reflecting the existence of stable anions. This is because the pH level was at a decreasing state which is below seven which is an "acidic region". Zeta potential becomes less negative to the values of which is until it becomes at the state of zero. The point of these zero chargers whereas the potential charges which are from the negative towards the positive value surround the CDs [34, 136]. Henceforth, it can be well said that with the greater pH level, the solid negative charge of the carbon dots was dominant as well as attracted positively and charged the heavy metals of the cations [137].

Applications of sustainable CDs in biomedicine

CDs are well known as the rising star regarding

carbon-based nanomaterials as well as their unique fascinating properties includes their outstanding light harvesting, photostability and biocompatibility, and low toxicity with strong up-conversion constitute their ideal use in an array of sectors [68]. Nanomaterials attracted considerable interest in a wide range of fields specifically in photocatalysis, drug delivery, photodynamic therapy, biological sensing, solar cells, anti-counterfeiting and so on. This paper is going to shed light upon and review the sustainability of the SCDs which are derived from the medicinal plant.

Biosensing/fluorescence sensing

Plant-derived CDs can be applied in biosensing for bioactive compound detection based on targeted molecules. Wang and colleagues demonstrated the use of CDs from papaya using different matrices as bacteria sensing agents to detect Escherichia coli (E. coli). Different effects on fluorescence emission shift were observed to achieve a standard curve with 0 to 9 x 107 cfu mL-1 [60]. Mechanisms like the inner filter effect (IFE), fluorescence resonance energy transfer (FRET), quenching effect, and electron transfer contribute to FL quenching. Ion and molecule detection from CDs play an important role in cell metabolism and DNA synthesis in biological systems [138]. Modification of fluorescence characteristics occurs upon energy transfer from CDs to ions. Fluctuation of Fe3+ is abnormal and leads to chronic heart failure in prolonged situations [139]. The study by Han et al. [140] benefited DNA and RNA detection in cells. The behavioral activity of single (DNA) and double-stranded (RNA) was tracked for a better understanding of dynamics and intracellular processes [140]. CQDs were modified as probes for penetration through various biological barriers and can have the capability for intracellular and in vivo imaging applications in conjunction. Due to FL quenching, a study presented label-free CD synthesis from tomato juice was used to create carcinoembryonic antigen (CEA) [63]. The conventional aim for several QD-based detectors for biomedical applications is cancer tumor indicators as early diagnosis. The Simarouba glauca leaves were used to hydrothermally synthesize blue fluorescence CDs that not only act as a detector for doxycycline but also exhibit fantastic human breast cancer cells (MCF-7) detector that can be further developed for analytical applications [141]. Chemical or fluorescence sensing is promising when functional groups from the surface of CDs associate with metal ions by energy transformation forming a different electron-hole [23, 142]. Recently, SCDs from Henna have shown good efficiency in the detection of methotrexate which is used for cancer therapy [61]. SCDs from Lantana camara, muskmelon, and pineapple, served as crucial probes in detecting metal ions such as Hg2+ [29], Fe3+ [143] and Pb2+ [144] in body fluids and human serum samples, where quenching levels can be modified to indicate selective ions as a "turn-off", "turn-on" sensors.

Drug delivery

Due to their excellent adaptability in altering versatile surfaces with different chemical molecules, CDs have shown immense potential as drug delivery agents [145, 146]. CDs can serve as carriers for drugs ranging from small molecules to nucleic acids. The surface of CDs can be modified to enhance drug loading capacity and control drug release kinetics as well. Surface functionalization of CDs with targeted ligands such as antibodies (site-specific drug delivery) will enable specific recognition and binding to the targeted cells. The ability of CDs to cross the blood-brain barrier (BBB) of the human body by passive diffusion is utilized in the application of this nano-particle in the case of drug delivery modifications [147]. Moreover, the yellow-coloured CDs as a molecular probe are used for the reduction of the vulnerability of Alzheimer's disease affected by the disposition of the β-amyloid plaques [124]. Wang et al. [148] successfully synthesized SCDs from Zingiber officinale Roscoe and discovered that it may limit the growth of liver cells (HepG2 cell lines) with the aid of curcumin present from these particular CDs. Inhibition of proliferation by increasing the production of reactive oxygen species (ROS) as a pro-apoptotic factor in HepG2 cells [126, 148]. This is because CDs shield normal cells from jeopardise while increasing the intracellular concentration of drugs in malignant cells.

Bioimaging

CDs are excellent candidates to serve as fluorescence imaging as it has a low radioactive and spatial resolution that enhances the capabilities for observing activities within living cells. CDs from Tulsi, the ancient medicinal plant a traditional dye for a better option in imaging was implied in detecting bacteria cells like E.coli and B.subtilis due to low toxicity [11]. SCDs derived from muskmelon were used as a probe in imaging fungal cells through confocal microscopic such as R.solani and A.flavus by displaying yellow (561 nm) and green (488 nm) color signals respectively. This revealed that CDs carry a non-toxic trait up to 1.0 mg/mL where no cytotoxicity properties were shown up to 0.4mg/mL precisely in several studies for fluorescence imaging [149]. Hibiscus sabdariffa CDs were used for the bio-imaging technique. This was proved when the CDs were infused with breast cancer cells (MDA-MB 231 cell lines), fluorescent emission was indicated at different ranges from 330 nm to 510 nm after 4 hours without interrupting the liveliness of the cells [150]. According to Atchudan and his team, great multicolour imaging was shown when utilizing CDs obtained by betel leaves in HCT 116 colon cancer cells. Through the use of Aloe vera as a carbon precursor in synthesizing amorphous CDs, it was effective as a fluorescent marker for cell imaging and exhibited apoptotic effects on MCF-7 cancer cells. A notable result to revolutionize bioimaging by providing highly sensitive imaging agents can be seen when a medicinal plant is used to derive CDs due to its natural use in a variety of biomedicine applications.

Phototherapy

Phototherapy using CDs has emerged as a promising approach as it provides tunable properties with improved outcomes. Photodynamic therapy (PDT) utilizes a combination of light that activates photosensitizer and oxygen to destroy diseased cells, especially superficial cancer cells. It is regarded as a cutting-edge safe procedure

that allows quick restoration of tissues without any drug resistance [151]. Mn2+ dropped from green tea was introduced as a (PDT) agent. Favorably by using this agent, more than 90% of HeLa cancer cell lines were killed within a short period of irradiation [152]. Photothermal therapy (PTT) is also a complementary method in cancer study according to [153]. It is a potential tumor therapy technique used under high temperatures through intense near-infrared (NIR) laser beams directly to the targeted cells [148]. With an efficiency of 39.3%, Alcea leaf and Cu-dopped derived CDs exhibit excellent photothermal quality and low cell necrosis. Moreover, an indication of apoptosis occurred when staining of the control cells with 41,6-diamidino-2-phenylindole showed lower fluorescence within the nuclei followed by obvious nuclear fragmentation [154]. Further studies are needed to optimize their properties and evaluate long-term biocompatibility as the application of CDs in photoinduced therapy is still in its early stages. Another study by Kim et al. [155] was conducted on doping sulfur CDs from flowers of Camellia japonica for (PTT) activity with 55.4%. Using Panax ginseng as a carbon source to synthesize SCDs inhibits cancer cells. A unique constitute (Ginsenoside) from ginseng is believed to carry anti-tumour and anti-inflammatory properties that help in increasing ROS and trigger apoptosis in MCF-7 and A375 cell lines through ROS-mediated pathways [58, 156, 157].

CDs in cancer therapy

Cancer remains a formidable global health challenge [158], with its prevalence and mortality rates steadily rising. Despite significant strides in cancer treatment, the overall 5-year survival rate for cancer patients remains dishearteningly low [159]. The imperative for novel therapeutic strategies that offer precise and effective cancer treatment has never been more urgent. Among the emerging innovations in cancer therapy, nanotheranostics, which seamlessly integrate diagnosis and therapy into a single nanoplatform, hold tremendous promise. In this context, carbon dots (CDs), a novel member of the carbonaceous nanomaterial family, have emerged as compelling candidates for nanotheranostics. Harnessing their unique optical properties and intrinsic theranostic attributes, CDs offer simultaneous bioimaging and cancer treatment capabilities, paving the way for innovative approaches to tackle the complex challenges posed by cancer [160].

Carbon dots (CDs) represent a paradigm shift in the landscape of nanotheranostics, offering a multifunctional platform for precise cancer diagnosis and therapy [161, 162]. These nanostructures have garnered significant attention for their versatility and potential in revolutionizing cancer treatment strategies. With their ability to serve as both imaging agents and therapeutic carriers, CDs present a novel avenue for targeted and personalized cancer therapy. Moreover, some CDs exhibit inherent anticancer properties, actively participating in photodynamic therapy (PDT) and photothermal therapy (PTT). While PDT relies on photosensitizers to generate reactive oxygen species (ROSs) under specific lighting conditions, leading to the oxidative destruction of cancer cells, PTT involves the use of photothermal agents to absorb photon energy and induce hyperthermia within the tumor site, resulting in irreversible damage to cancer cells. Importantly, the spatially adjustable light illumination in PDT and PTT enables precise targeting of tumor lesions while sparing healthy tissues, thus minimizing systemic toxicity a significant advantage over conventional chemotherapy and radiotherapy [163]. However, despite the promise of PDT and PTT, inherent limitations such as PDT's oxygen dependence and PTT's requirement for high laser power pose challenges to their therapeutic efficacy [164]. Addressing these limitations necessitates the development of multimodal treatment approaches that integrate the strengths of each technique, offering enhanced therapeutic outcomes while mitigating adverse effects. By leveraging the unique properties of CDs and integrating them into multimodal phototherapeutic strategies, researchers strive to overcome the hurdles encountered by standalone PDT and PTT, ushering in a new era of precision cancer therapy.

The advent of carbon dots (CDs) heralds a new dawn in cancer theranostics, offering a versatile platform for simultaneous bioimaging and targeted cancer treatment. With cancer continuing to exact a heavy toll on global health, the urgency to develop innovative and effective therapeutic interventions has never been greater. CDs, with their unique optical properties and intrinsic anticancer characteristics, hold immense promise as key players in the fight against cancer. Through the integration of CDs into multimodal phototherapeutic approaches such as PDT and PTT, researchers aim to surmount the inherent limitations of individual techniques, paving the way for more precise, effective, and personalized cancer treatment strategies. As efforts in cancer research continue to advance, the transformative potential of CDs in reshaping the landscape of cancer therapy remains a beacon of hope for patients and healthcare professionals alike.

Conclusion and suggestions for future research

In conclusion, the emergence of carbon dots (CDs) as a novel platform in cancer theranostics represents a significant advancement in the ongoing battle against this formidable disease. With cancer's prevalence and mortality rates continuing to rise, the urgency for innovative therapeutic strategies has never been greater. CDs, with their unique optical properties and intrinsic anticancer characteristics, offer a multifunctional approach to precise cancer diagnosis and therapy. By integrating CDs into multimodal phototherapeutic strategies such as photodynamic therapy (PDT) and photothermal therapy (PTT), researchers aim to overcome the limitations of individual techniques, paving the way for more effective and personalized cancer treatment strategies. Looking ahead, future research in the field of carbon dots derived from medicinal plants should encompass a wide range of topics. These include further exploration of potential toxicological effects, optimization of synthesis methods, scalability of production, environmental applications, combination with other nanomaterials, exploration of alternative therapeutics, assessment of long-term effects on human health, and investigation into energy storage and conversion. Moreover, addressing the scalability

of carbon dot production is crucial for translating these advancements from the laboratory to clinical settings. This research trajectory holds immense promise not only for advancing the potential applications of carbon dots but also for fostering the development of new technologies derived from natural resources. To achieve these goals, it is imperative to address the existing research gaps and ensure the safety and scalability of carbon dots for a variety of applications, thus ushering in a new era of precision medicine and sustainable technology.

Author Contribution Statement

SP, SS and HM lead the literature search and review. SS supervised and guided the process. SP prepared the first draft of the manuscript. SS and HM amended and refined the manuscript. All authors reviewed, and approved the final manuscript.

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Ethical Declaration

This manuscript is the review of previously published articles, reports, and documents. Therefore, ethical approval is not applicable to this review.

Conflict of Interest

All authors declare that they have no conflicts of interest.

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