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Phyto-Entrapped Carbon Dots as Emerging Nanomaterials for Anti-Cancer Activity

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Abstract

Phytoconstituent-loaded carbon dots (C-dots) represent an innovative approach in targeted cancer therapy, combining the therapeutic power of plant-derived compounds with the advanced capabilities of nanotechnology. These ultra-small, biocompatible nanostructures offer excellent fluorescence, tunable surface chemistry, and low toxicity, making them ideal for drug delivery, bioimaging, and theranostic applications. Traditional phytochemicals often face challenges, like poor solubility, low bioavailability, and high first-pass metabolism barriers, that C-dots help overcome. C-dots synthesized through eco-friendly methods from natural sources, such as fruit peels or plant waste, can be functionalized to enhance the therapeutic delivery of compounds like curcumin, berberine, and quercetin. They enable targeted delivery, controlled release, and improved cellular uptake, especially in hard-to-treat cancers such as brain tumors and triple-negative breast cancer. Studies show their utility in phototherapy, diagnostics, and real-time imaging. Despite promising in vitro and in vivo results, challenges remain in synthesis reproducibility, large-scale production, and clinical translation. This review emphasizes the potential of phytochemical-loaded C-dots in oncology, advocating for further research into scalable synthesis, bioactivity testing, and optimized delivery strategies to advance them toward clinical applications.

Keywords: Anti-cancer, carbon-dots, phytochemicals, nanotechnology, formulation

INTRODUCTION

A major source of medication comes from natural products, recognized as drugs in various pharmacopeia, yet the processes of isolation and extraction remain challenging. Approximately fifty percent of all pharmaceuticals available today are derived from natural sources. Within the realm of natural plant products, a category of semisynthetic, semipurified phytoconstituents is included due to its extensive therapeutic applications and the diverse chemical structures that can be achieved with minimal modifications. Instead of concentrating on a singular isolated component, extensive investigations are being carried out on crude extracts or fractions, which is fascinating for phytoconstituents. This approach fulfils various responsibilities, including the multitargeting effect; however, this action has been undertaken sporadically due to the lack of identification of the primary compounds [1, 2].

The delivery of phytoconstituents is an emerging area, driven by advancements in phytochemical and phytopharmaceutical science. Additionally, economic, political, social, and cultural factors may play a role in enhancing the acceptance of natural products as medicine. The delivery of plant constituents presents significant challenges and limitations, particularly concerning immunological responses, uptake efficiency at target tissues, high scaling costs, and unresolved environmental factors. In the development of the first line choice, the

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delivery of therapeutic molecules presents several challenges. Constituents are encountering issues such as poor aqueous solubility, inadequate permeability at the biological site, short circulation time in biological fluids, and significant first-pass metabolism by the liver. The phytoconstituents face various problems that require resolution through both classical and novel approaches, as illustrated in Figure 1.

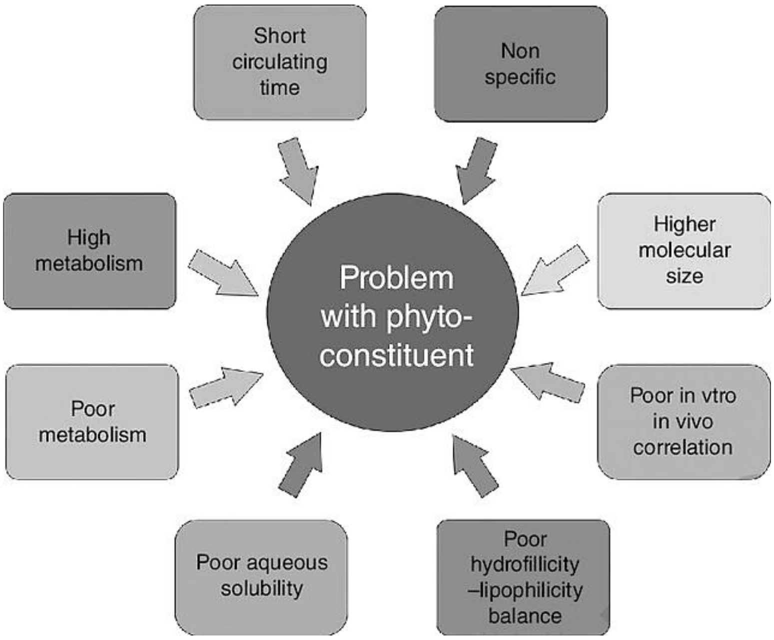

Figure 1. Issues with phytoconstituents need to be handled during delivery [1].

NANOTECHNOLOGY AS A SOLUTION FOR THE DELIVERY OF PHYTOCONSTITUENTS

The conventional delivery methodology for phytoconstituents encounters several challenges, including issues related to aqueous solubility, instability, and permeability. Issues related to plant constituents can be effectively addressed through a nanotechnological approach, leading to enhanced safety, improved efficacy, and greater patient compliance. Active phytoconstituents are found in different parts of medicinal plants. Nanotechnology facilitates the development of nanomedicines and nanocarriers by utilizing both pure active phytoconstituents and semi-purified extracts. The application of nanotechnology significantly enhances outcomes by minimizing toxicity and adverse effects while increasing therapeutic or pharmacological effects through the optimization of pharmacokinetic parameters. This accomplishment results from the modification of surface chemistry and properties, tailored to specific requirements. The concept of nanotechnology has been explored to address challenges concerning the activity, specificity, and bioavailability of phytoconstituents. The intricacies of phytochemicals can be effectively managed. Formulation at the nanoscale through release modification, surface landing techniques, enhancement of solubility, reduction of loading units, minimization of degradation processes, and improvement of absorption and bioavailability. The figure illustrates the anticipated objective of nano delivery carriers. The integration of nanotechnology with the delivery of phytoconstituents represents a significant advancement by improving effectiveness, selectivity, preventing degradation, and modifying release kinetics (Figure 2) [1, 2].

Cancer

Cancer encompasses a wide array of diseases marked by the emergence of atypical cells that proliferate without restraint and possess the capacity to invade and damage healthy bodily tissues. Cancer frequently possesses the capability to disseminate across the body. Cancer has become a leading contributor to global health issues due to its significant incidence and mortality rates. The overall 5-year survival rate for individuals diagnosed with cancer remains relatively low, even with significant advancements in treatment options. In 2018, approximately 9.6 million deaths were attributed to cancer, alongside 18 million new cases diagnosed. Projections indicate that by the end of the next two decades, the annual incidence of cancer cases will reach 22 million. Lung cancer is projected to take the lives of over 350 individuals each day, representing a staggering 2.5 times the mortality rate of colorectal cancer, the second leading cause of cancer-related deaths, and surpassing the combined fatalities of breast, prostate, and pancreatic cancers. In 2022, approximately 105,840 of the 130,180 lung cancer deaths, representing 81%, will be attributed to smoking-related causes, while an additional 3,650 fatalities will stem from exposure to second-hand smoke. If categorized separately, the additional 20,700 lung cancer deaths not linked to smoking would rank as the ninth most prevalent cause of cancer mortality for both genders combined. The complexities of cancer present a formidable challenge in contemporary medicine, highlighting the necessity for groundbreaking strategies in diagnosis and treatment. Nanotechnology has revolutionized the domain of cancer research, bringing forth sophisticated tools for accurate diagnosis, imaging, and treatment of tumors. Among the diverse range of nanomaterials investigated for their potential applications in cancer therapy, quantum-sized C-dots have recently attracted significant interest (Figure 3) [4–6].

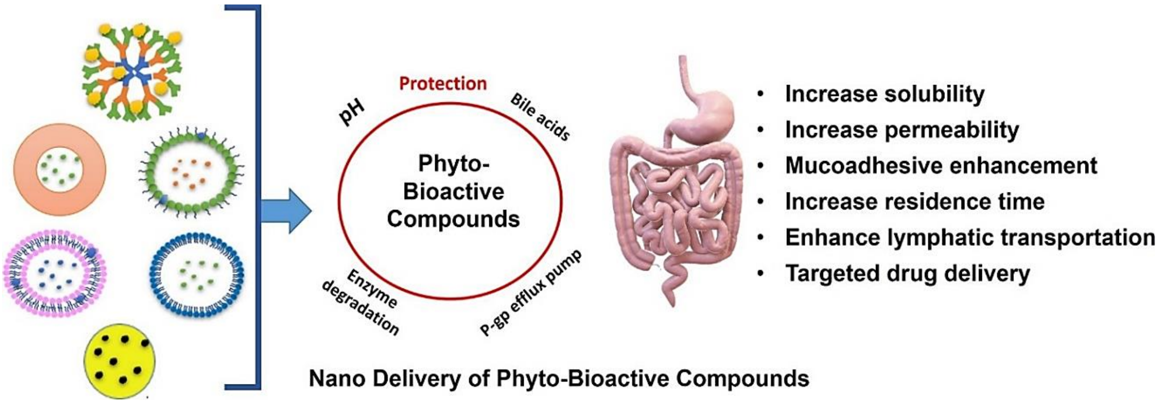

Figure 2. Nanotechnology as a solution for the delivery of phytoconstituents [3].

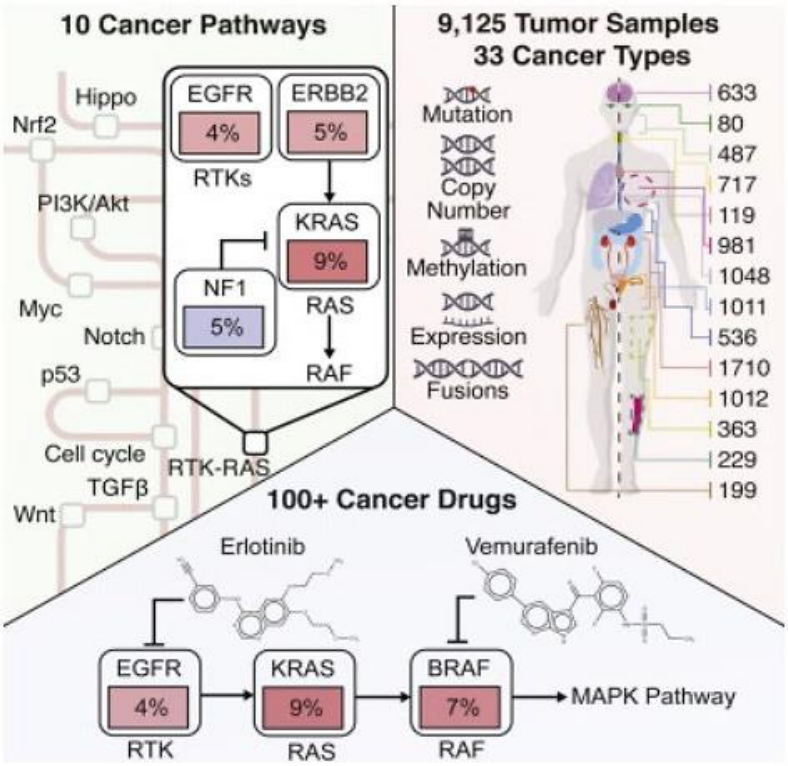

Figure 3. Basic cancer pathways.

These minuscule carbon structures, generally measuring between 1 and 10 nm, are part of a distinct category of nanomaterials that exhibit a range of properties ideal for use in biomedical applications. Their attractiveness stems from the capacity to meticulously regulate their dimensions and surface chemistry, facilitating the customization of essential characteristics such as solubility, stability, and bioavailability. Furthermore, the surface modification of carbon dots (C-dots) allows for customized interactions with biological entities, enhancing targeted drug delivery and optimizing cellular uptake. The intrinsic characteristics of quantum-sized C-dots position them as a highly promising foundation for the advancement of sophisticated cancer therapeutics.

CARBON DOTS: SYNTHESIS & APPLICATIONS

C-dots are nanoparticles that are quasi-spherical and measure less than 10 nm in size, classifying them as zero-dimensional entities. This carbon nanomaterial is regarded as the ideal choice due to its remarkably high yield, minimal toxicity, excellent light stability, outstanding biological compatibility, and low synthesis cost. Carbon nanodots, including NCDs, CQDs, and GQDs, represent the standard classifications for C-dots. Altering the surface of carbon nanoparticles with polymeric and organic compounds is essential to produce C-dots. These zero-dimensional nanoparticles, generally measuring under 10 nm, present significant potential for a variety of applications. C-dots are distinct, nearly spherical nanoparticles made up of sp2/sp3 hybridized carbon atoms. Moreover, carbon atoms facilitate the straightforward attachment of functional groups such as hydroxyl, carboxyl, and amine groups. Halogenation and cycloaddition represent significant chemical reactions employed to alter the surface characteristics of nanoparticles. Halogenation introduces halogens that can engage in further reactions with other groups, such as amines, leading to the formation of new functional structures. Meanwhile, cycloaddition facilitates the direct addition of a diverse range of functional groups. The adjustments made can customize the characteristics of nanoparticles for targeted applications across various domains such as healthcare, electronics, and materials science [3, 4].

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In the synthesis of C-dots, diverse waste materials serve as carbon sources. Examples include orange peels and tea stems, along with other environmentally friendly options such as paper waste, plant extracts, fruit juice, residual tea waste, and various food items derived from both animal and plant sources, including honey, meat, butter, and seafood. This reduces environmental pollution and improves economic advantages (Figures 4 and 5) [4, 5].

The primary focus of C-dots investigation encompasses metal ion adsorption, fluorescence detection, and wound healing. Additionally, it has been demonstrated that C-dots exhibit numerous antibacterial properties, with their mechanisms of action including oxidative stress, physical damage, and inhibition of bacterial metabolic processes. The incorporation of C-dots, derived from sustainable sources, can enhance food packaging by prolonging shelf life and preserving the quality and freshness of food products. C-dots can be readily produced using waste or environmentally friendly materials, such as fruits, peels, and leaves, as illustrated in Figure. The incorporation of active materials in food packaging enhances packaging functionality while also providing economic advantages and promoting sustainability by minimizing environmental impact through effective food preservation and waste reduction (Figure 6) [8, 9].

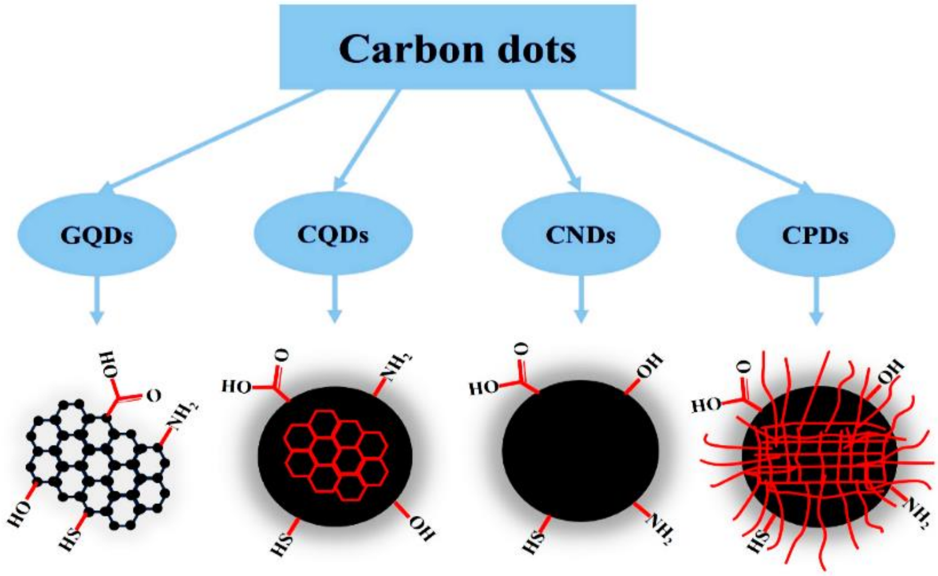

Figure 4. Types of carbon dots [4].

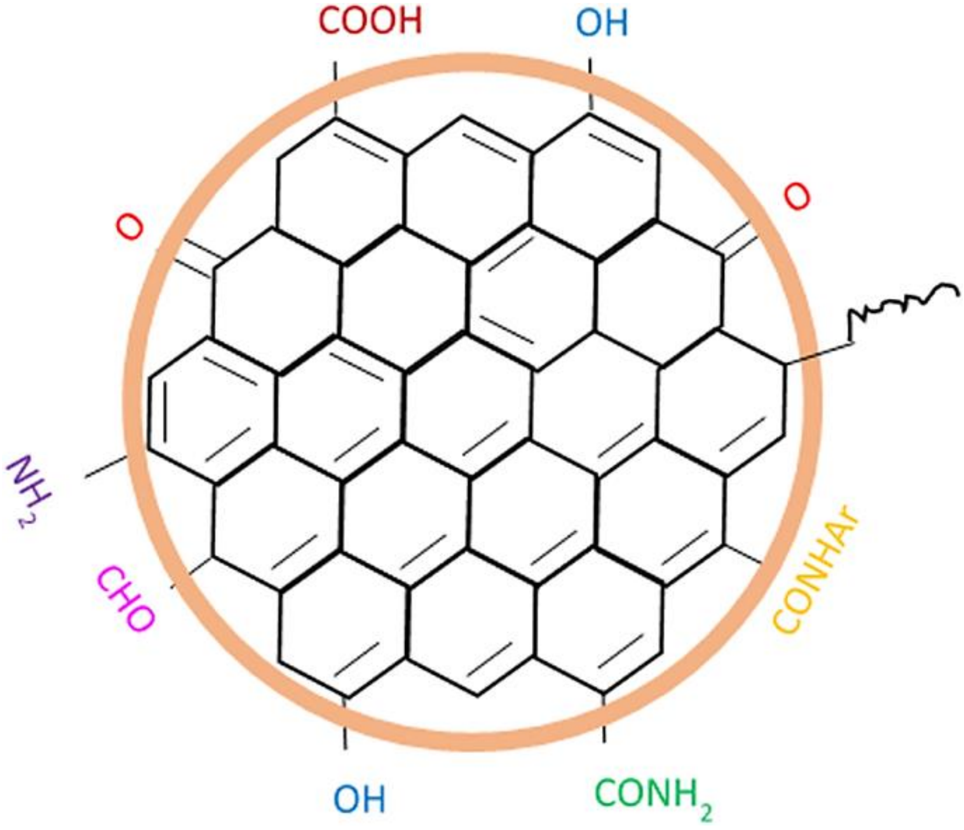

Figure 5. Structure of carbon dots [3].

Synthesis Methods

In the process of producing C-dots, various functional groups may be incorporated, such as hydroxyl, carboxyl, carbonyl, amine, and epoxy, among others. Furthermore, the incorporation of heteroatoms into C-dots using diverse biological, polymeric, and organic materials facilitates straightforward surface functionalization. Advancing our understanding, the characteristics of C-dots can be manipulated by modifying physicochemical properties through different precursors or alternative synthetic approaches [10]. To attain notable surface characteristics for solvency and their beneficial applications, it is essential to modify C-dots. The synthesis of carbon dots encompasses a variety of methods, each characterized by distinct variations and approaches. Presented below are several widely employed methods for the synthesis of C-dots (Figure 7) [11–15].

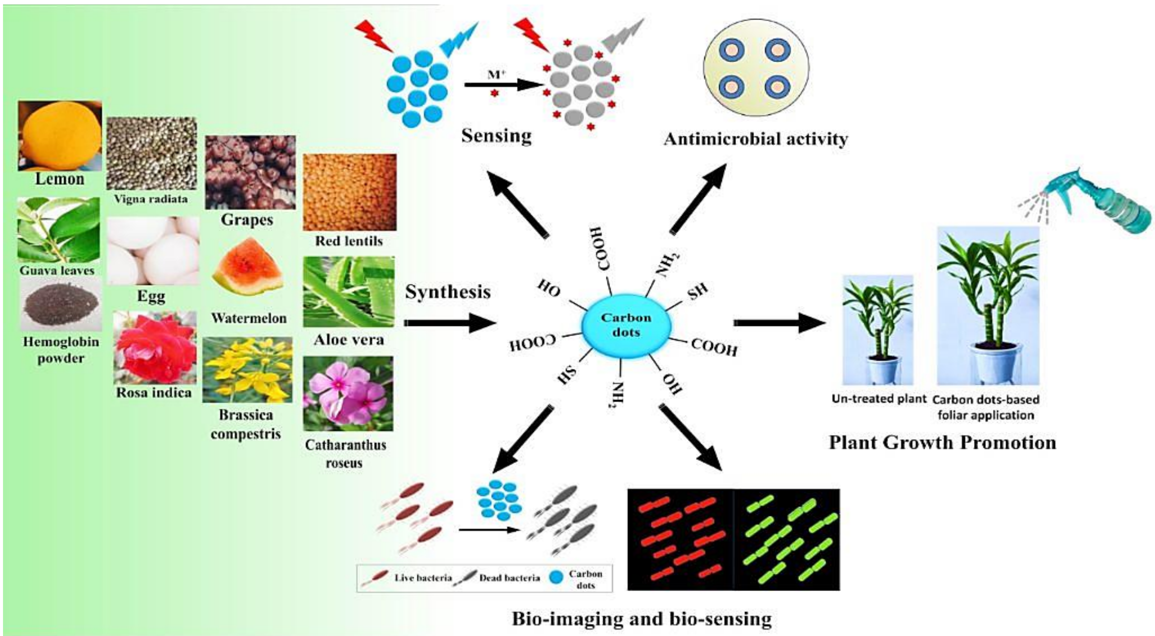

Figure 6. The environmentally friendly sources employed for the synthesis of C-dots and their applications [8].

Figure 7. Synthesis methods to prepare carbon dots.

Top-Down Method

These days, it's common practice to use top-down methods, like electrochemical processes, laser ablation, arc discharge, and ultrasonic treatment, to create C-dots from bulk carbon-based materials. Nevertheless, these techniques are usually used in high-energy, high-potential, and high-acidity settings [16]. These top-down methods are arduous due to the harsh conditions, as opposed to bottom-up processes [17–20].

Bottom-Up Approach

Given their many benefits, including their straightforward and convenient technique, cost-effectiveness, precise control, easy instrumentation, and promising practical applicability, bottom-up approaches are currently in vogue.

Thermal Method

One of the best techniques for creating C-dots is thermal breakdown, which entails pyrolyzing or carbonizing the large-sized carbonaceous precursors at higher temperatures. This approach has several advantages, including production of C-dots in copious quantities, affordability, shorter reaction times, increased precursor tolerance, solvent-free techniques, and simplicity of synthesis. Furthermore, the thermal technique can optimize the luminous properties of C-dots by regulating reaction conditions.

Microwave-Assisted Method

Microwaves encompass a broad spectrum of electromagnetic waves ranging from 1 mm to 1 m. The microwave-assisted approach generates a homogenous temperature for the even dispersal of C-dots and is simple, inexpensive, quick, and requires shorter reaction times.

Hydrothermal Method

This method of C-dots synthesis is economical, non-toxic, and eco-friendly. It entails the sealing of organic solvents as precursors and their reaction at greater pressures and temperatures in a hydrothermal reactor. The hydrothermal carbonization (HTC) process is capable of producing C-dots from a variety of raw materials, including proteins, chitosan, citric acid, glucose, and more.

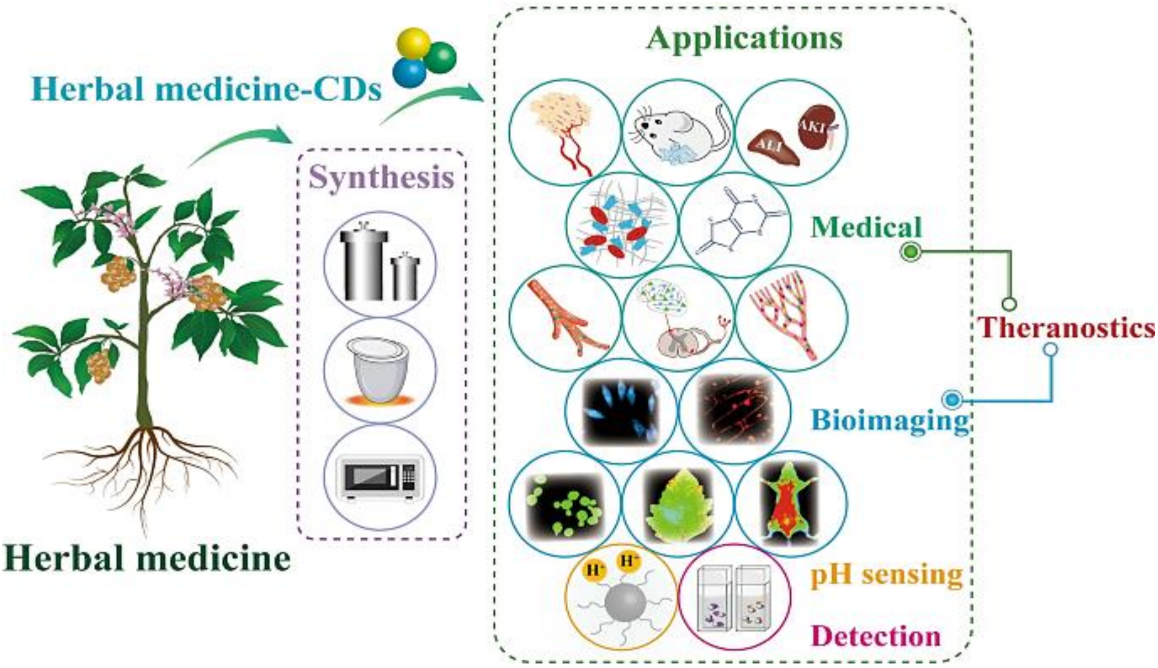

Figure 8. Herbal medicine-derived carbon dots [12].

Applications of Carbon Dots

C-dots have emerged as highly functional nanomaterials due to their photoluminescence, biocompatibility, environmental friendliness, and surface tunability. C-dots have provided a promising platform for biological, environmental, and energy-related applications such as bioimaging, biosensing, medical diagnosis, catalysis, multicolour light-emitting diode production, phototherapy, drug and gene delivery, food safety, and energy conversion owing to their innovative and fascinating multifunctional properties together with excellent biocompatibility and environmental friendliness (Figure 8). Their applications span diverse fields:

Bioimaging

C-dots serve as efficient fluorescent probes for cellular and in vivo imaging due to their bright and tunable emission, photostability, and low cytotoxicity, making them suitable alternatives to traditional quantum dots.

Biosensing

Their fluorescence is sensitive to analytes, enabling C-dots to detect metal ions, biomolecules, and pathogens. They are widely applied in FRET and turn-off/turn-on sensors.

Medical Diagnostics

C-dots, when conjugated with targeting ligands, enable precise imaging and early diagnosis of diseases, including cancer, due to selective accumulation in diseased tissues.

Phototherapy

They act as photosensitizers in photodynamic therapy (PDT) and photothermal agents in photothermal therapy (PTT), generating ROS or heat under light to destroy cancer cells.

Drug and Gene Delivery

Owing to their functionalizable surface, C-dots can carry drugs, DNA, or RNA, releasing them in a stimuli-responsive manner for targeted therapeutic action.

Catalysis

C-dots catalyze redox reactions and degrade pollutants under light, making them valuable in photocatalysis and electrocatalysis, especially in water splitting and pollution remediation.

LEDs and Optoelectronics

They are used in multicolored and white light-emitting diodes due to their strong, tunable luminescence, solution processability, and eco-friendly synthesis.

Food Safety

C-dots detect food contaminants such as pesticides, toxins, and pathogens via fluorescence sensing, contributing to rapid quality assurance [20–25].

Energy Conversion and Storage

Integrated into solar cells and supercapacitors, C-dots enhance light absorption, charge transfer, and stability, improving energy device performance.

Environmental Monitoring

They detect pollutants (e.g., heavy metals, phenols) and degrade organic contaminants through photocatalysis, promoting green environmental solutions.

PHYTOCHEMICAL LOADED IN CARBON DOTS

Phytoconstituent-loaded C-dots have emerged as a promising tool in the field of medicine, offering a wide range of applications in disease diagnosis, drug delivery, and therapy. C-dots, a unique class of fluorescent carbon-based nanomaterials, have gained significant attention due to their exceptional optical properties, biocompatibility, low toxicity, and facile surface modification. When these nanomaterials are loaded with bioactive plant-derived molecules – commonly referred to as phytoconstituents – they exhibit synergistic effects, making them highly suitable for biomedical applications. The convergence of green nanotechnology with phytochemistry has led to the development of phytoconstituent-loaded C-dots, which offer safe, sustainable, and multifunctional platforms for disease diagnosis, drug delivery, and therapeutic interventions (Figure 9) [26, 27].

Methods of Loading Phytoconstituents into Carbon Dots

The integration of phytoconstituents into carbon dots is a vital step in designing effective nanotherapeutic and diagnostic agents. The loading method not only affects the drug delivery efficiency and bioactivity but also governs the physicochemical properties, stability, and release profile of the final nanocomposite. Broadly, the incorporation of phytochemicals into C-dots can be achieved via two main approaches: in situ loading and post-synthesis loading. Each method involves specific strategies, depending on the nature of the phytoconstituents and the intended biomedical application [27–31].

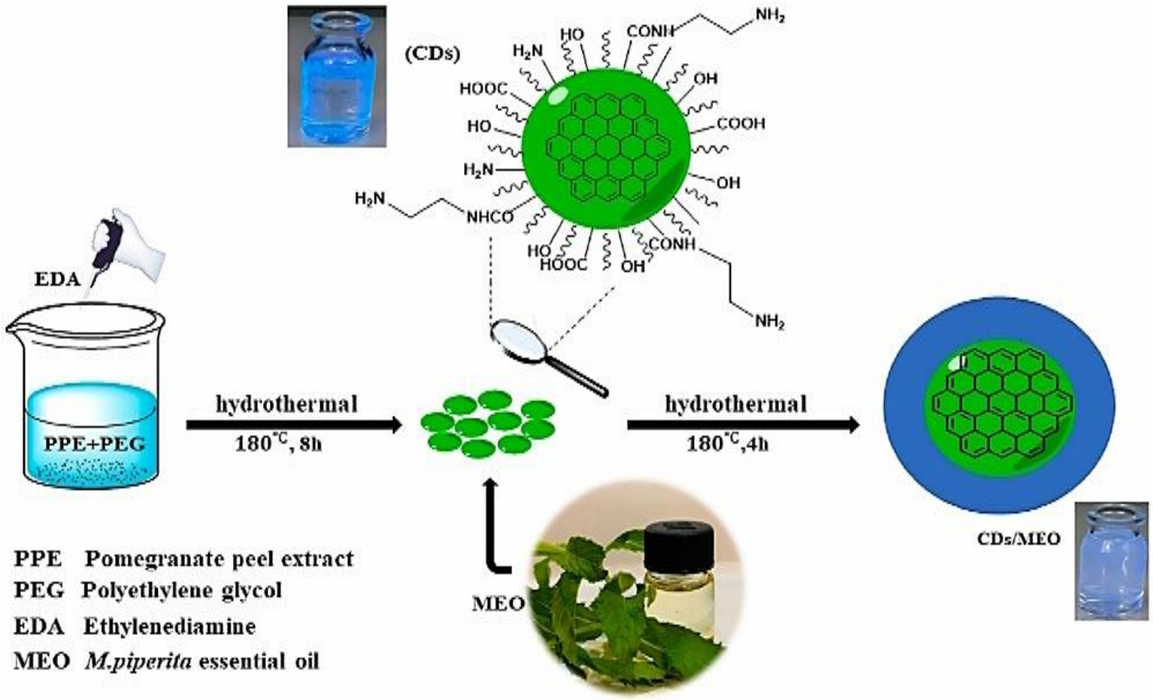

Figure 9. Phytochemicals loaded in C-dots [15].

In-situ Loading (One-Pot Synthesis Method)

In this approach, phytoconstituents are introduced during the synthesis of carbon dots. The phytochemical acts either as:

- a *carbon precursor* (main substrate), or
- a *co-reactant* (along with other precursors such as citric acid, PEG, or EDA).

Mechanism

During hydrothermal, solvothermal, or microwave-assisted carbonization processes, the phytoconstituents are integrated into the carbon framework. This results in a homogeneous distribution of bioactive molecules either embedded within or functionalized onto the surface of the C-dots.

Post-Synthesis Loading (Surface Adsorption or Conjugation)

In this method, C-dots are first synthesized using standard carbon sources. Phytoconstituents are then loaded onto the preformed C-dots using one of the following strategies:

Physical Adsorption

- Based on non-covalent interactions such as hydrogen bonding, π–π stacking, van der Waals forces, or electrostatic attraction.
- Simple mixing or sonication of C-dots with the phytochemical solution leads to spontaneous adsorption.

Chemical Conjugation

- Covalent bonding of phytoconstituents to functional groups on the C-dot surface using linkers such as EDC/NHS (for carboxyl-amine coupling).
- Offers more stable and controlled release profiles.

Encapsulation or Entrapment

- Phytochemicals are trapped within a polymeric or lipid coating formed over the C-dots.
- Used for unstable or hydrophobic plant compounds that require protection from degradation.

Solvent Evaporation and Emulsion Techniques

These techniques are occasionally employed when phytoconstituents are hydrophobic or volatile. The process involves:

- Dissolving phytochemicals and C-dots in suitable solvents,
- Creating an emulsion (e.g., oil-in-water),
- Evaporating the solvent under reduced pressure to form nanocomposites.

Such methods are particularly useful in food-grade or cosmetic formulations of phytochemical-loaded nanodots.

pH-Induced or Temperature-Induced Loading

This approach takes advantage of the pH- or temperature-responsive behaviour of certain phytoconstituents and functionalized C-dots. Loading is carried out under specific conditions (e.g., acidic pH or mild heat), followed by stabilization.

CONTEXT OF THE STUDY

C-dot has garnered significant attention as a nanocarrier owing to its ultrasmall size, excellent biocompatibility, robust fluorescence, and high drug-loading capacity. Recent advances in green synthesis methodologies leveraging phytoconstituents have facilitated the development of multifunctional C-dots exhibiting promising anticancer properties. However, despite these advancements, the application of phytochemical-loaded C-dots for targeted therapy in cancer remains insufficiently investigated. This study seeks to elucidate the therapeutic potential, targeting capabilities, and safety profile of phytoconstituent-loaded C-dots, aiming to address the limitations inherent in conventional cancer therapeutics and improve clinical outcomes (Tables 1 and 2) [30].

Table 1. Literature review.

S. N.	Author, Year, Journal	Title	Key Findings	Variables Used	Research Gap Addressed
1	Saini et al., 2024, *Curr. Pharm. Des. [13]*	Green synthesis of Curcumin-loaded C-dots	pH-sensitive release, strong anticancer effect	Curcumin-loaded C-dots, cancer cells	Limited in vivo validation
2	Bhattacharya et al., 2024, *Discover Nano [20].*	Quantum-sized C-dots in brain cancer	Emphasized brain cancer targeting	Quantum-sized C-dots	Need exploration in brain therapy
3	Kadyan et al., 2025, *Materials Advances [4]*	GQDs from *Azadirachta indica*	Antioxidant & antimicrobial effect	Neem leaves, microwave method	Lack of synergistic bio-computational studies
4	Sonowal et al., 2024, *Future J. Pharm. Sci. [28]*	Citrus C-dots with curcumin	Enhanced curcumin cytotoxicity	Citrus C-dots, liposomes	Curcumin bioavailability issues
5	Amloy et al., 2024, *J. Metals, Materials & Minerals*	Mangosteen-derived C-dots	Bright red fluorescence, selective cancer uptake	Mangosteen peel	Need eco-friendly imaging agents
6	Wang et al., 2024, *PubMed*	ZnO-doped C-dots for TNBC	Inhibited TNBC via MAPK pathway	Citric acid, ZnO, MDA-MB-231	Need effective TNBC therapies
7	Sun et al., 2024, *J. Nanobiotech*	C-dots for photodynamic therapy	ROS generation & tumor inhibition	C-dots, ROS, light	Role as PDT sensitizers underexplored
8	Kazeminava et al., 2024, *Sci. Reports*	Folic acid-based C-dots in exosomes	Enhanced breast cancer targeting	Folic acid C-dots, exosomes	Breast-targeted co-delivery methods
9	Algarra et al., 2024, *ACS Omega*	C-dots for glioblastoma	Effective brain-targeted delivery	Glioblastoma, multifunctional C-dots	Need to cross BBB efficiently

10	Fahmi et al., 2023, *Nanotheranostics*	Chalcone-loaded C-dots	Reduced HeLa viability, good bioimaging	Chalcone, C-dots	Long-term safety untested
11	Kajani et al., 2023, *RSC Advances*	C-dots in mesoporous silica	Cancer delivery + real-time imaging	C-dots, silica, folate	Poor targeting in traditional DDS
12	Mishra et al., 2023, *ACS Omega*	C-dots–silver hybrid for colorectal cancer	Dual anticancer and imaging effect	Silver, C-dots, HCT116 cells	Need multifunctional platforms
13	İlhan, 2023, *JIST*	Ginger/chitosan hybrid C-dots	Antiproliferative effects on HeLa cells	Ginger, chitosan, HeLa	Lack of hybrid green nanocarriers
14	Hatimuria et al., 2023, *Catalysts*	Green C-dots for biosensing and therapy	Dual sensing and anticancer use	Plant precursors, C-dots	Rare dual application reports
15	Hui, 2023, *J. Nanoparticle Res.*	C-dots: biomedical use review	Comprehensive applications	C-dots, surface groups	Needs phytochemical specificity
16	Wang et al., 2022, *J. Nanobiotech*	Tryptophan-sorbitol C-dots	Liver cancer imaging and therapy	HepG2 cells	Lack of liver-targeted green C-dots
17	Kanwal et al., 2022, *Beilstein J. Nanotech*	Green C-dots 2015–2022 review	Synthesis & biomedical uses	C-dots, green methods	Poor synthesis consistency
18	Sarwa et al., 2022, *Phytoantioxidants*	Nanoformulations of herbal actives	Enhanced delivery and solubility	Herbal actives, C-dots	Traditional systems lack targeting
19	Calabrese et al., 2021, *IJMS*	C-dots in brain tumor therapy	Reviewed DDS for brain targeting	C-dots, brain tumors	BBB targeting needs exploration
20	Mohapatra et al., 2022, *J. Cluster Sci.*	Piper longum C-dots	Cancer imaging, radical scavenging	Piper leaf C-dots	In vivo structure–function data limited
21	Sciortino et al., 2018, *J. Cluster Sci.*	C-dots photophysics	Optical tuning explained	Size, excitation, dopants	Application-driven tuning lacking
22	Ensafi et al., 2017, *Sens. Actuators B*	Saffron C-dots for imaging/sensing	Low toxicity, high fluorescence	Saffron, prilocaine	Few dual-use green synthesis reports
23	Arsalani et al., 2023, *Front. Chem.*	C-dots–PEG for methotrexate delivery	Enhanced nuclear delivery	PEG-C-dots, methotrexate	Efficient cancer targeting needed
24	Frederic et al., 2023, *IJMS*	Pediatric brain tumor treatment	C-dots show targeting potential	Pediatric brain tumors	Clinical use still unexplored
25	Travieso et al., 2023, *J. Res. Students*	Chalcones and C-dots in GBM	Synergistic glioblastoma treatment	C-dots, chalcones, GBM	Lack of bis-chalcone C-dot studies
26	Sattariazar et al., 2023, *Mat. Chem. Phys.*	C-dots from pomegranate + *Mentha* oil	Strong fluorescence, controlled release	Polyphenol C-dots, essential oils	Few in vivo efficacy studies

Table 2. List of phytoconstituents for anticancer activity [18–30].

No.	Phytoconstituent	Source Plant
1	Berberine	*Berberis aristata*
2	Curcumin	*Curcuma longa* (Turmeric)
3	Quercetin	*Allium cepa, Moringa oleifera,* etc.
4	Resveratrol	*Vitis vinifera* (Grapes)
5	Epigallocatechin gallate (EGCG)	*Camellia sinensis* (Green tea)
6	Genistein	*Glycine max* (Soybean)
7	Aloin	*Aloe vera*
8	Ginsenosides	*Panax ginseng*
9	Rutin	*Fagopyrum esculentum* (Buckwheat)
10	Caffeic acid	*Coffea spp., Thymus vulgaris*
11	Luteolin	*Celery, Peppers*
12	Mangiferin	*Mangifera indica* (Mango leaves)
13	Gymnemic acids	*Gymnema sylvestre*
14	Myricetin	*Myrica spp., Teas*

CONCLUSIONS

Phytoconstituent-loaded C-dots represent a promising advancement in sustainable, biocompatible, and multifunctional nanotechnology, showcasing considerable potential for targeted cancer therapeutics. The nanostructures, created using environmentally friendly techniques, utilize the healing properties of bioactive compounds from plants and display distinctive physicochemical traits, including their ultra-small size and fluorescence that depends on excitation. The inherent luminescence of these C-dots enables real-time imaging and localization at both cellular and tissue levels, rendering them exceptionally appropriate for concurrent diagnostic and therapeutic – theranostic applications. In the realm of challenging and hard-to-reach cancers, such as brain tumors, phytoconstituent-functionalized C-dots, present a compelling alternative to traditional treatments by facilitating efficient transport across the blood–brain barrier while reducing systemic toxicity.

Future studies will concentrate on the careful refinement of synthesis protocols to ensure consistent results and scalability, both of which are crucial for clinical application. The functionalized C-dots will be subjected to thorough assessment for cytotoxicity, bioimaging efficiency, and anticancer activity through validated in vitro and in vivo models. Additionally, thorough phytochemical screening and drug-loading experiments will be conducted to identify and integrate the most effective plant-derived compounds that specifically address brain tumor pathophysiology. The primary aim of this study is to enhance the domain of nanomedicine through the collaboration of diverse knowledge from materials science, pharmacognosy, and oncology. This approach aims to facilitate the creation of safe, targeted, and clinically applicable nanotherapeutic systems that have the potential to revolutionize existing paradigms in cancer management.

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