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Green Synthesis and Characterization of CdS Nanoparticles Using Zingiber Officinale Extract: A Comprehensive Review

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Abstract:

Green synthesis of nanoparticles is an eco-friendly, cost-effective method utilizing biological resources like plant extracts, bacteria, or fungi to reduce metal ions into nanoparticles. It replaces toxic chemicals with natural agents, producing stable, biocompatible, and smaller nanoparticles for biomedical and environmental applications. This review focuses on the biosynthesis and characterization of cadmium sulfide (CdS) nanoparticles using aqueous extract of Zingiber Officinale (Ginger). The green synthesis of cadmium sulfide nanoparticles (CdS NPs) using ginger (Zingiber officinale) extract is a sustainable "bottom-up" approach that uses plant bioactive compounds as both reducing and capping agents. This method eliminates the need for hazardous chemicals and produces stable, crystalline nanoparticles. Compared to conventional chemical and physical methods, this green synthesis approach offers advantages including cost-effectiveness, simplicity, and the avoidance of toxic reagents. The review critically analyses essential factors affecting nanoparticle synthesis, including pH, temperature, reaction duration, and extract concentration, which significantly influence particle size, morphology, and yield. The characterization of cadmium sulfide (CdS) nanoparticles synthesized using ginger involves several analytical techniques to confirm their formation, purity, size, and structural properties. Key methods include UV-Visible Spectroscopy, X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR) Spectroscopy, and Electron Microscopy (SEM/TEM). CdS nanoparticles demonstrate significant potential in diverse biological and industrial applications, including anticancer & cytotoxicity, antimicrobial & antifungal activities, photocatalysis properties, reducing agents and capping & stabilizing agents. Overall Green-synthesized CdS nanoparticles using ginger extract have significant applications in environmental protection, particularly in water treatment, wastewater remediation, and sustainable agriculture.

Keywords: Green synthesis, Cadmium sulfide, *Zingiber officinale* extract, Plant-mediated, Phytochemicals, Eco-friendly, Biogenic.

Introduction:

Herbal roots are potent, nutrient-dense parts of plants used in Ayurvedic and modern herbal medicine for therapeutic benefits, including immune support, digestion, stress reduction, and skin health. Common examples include turmeric, ginger, ashwagandha, licorice, and ginseng. They are often available raw or as powders and used in traditional medicine, skincare, and hair care. Ginger (*Zingiber officinale*) is a tropical, aromatic, herbaceous perennial plant cultivated for its pungent underground stem, or rhizome. Known for culinary, medicinal, and antioxidant properties. Ginger contains several key active compounds, primarily gingerols, which are abundant in fresh ginger and provide potent antioxidant and anti-inflammatory effects. When ginger is dried or heated, gingerols dehydrate into shogaols, which are twice as pungent and may possess even stronger biological activity. Additionally, paradols form from shogaols through hydrogenation, contributing further antioxidant and antimicrobial properties to ginger's primary health benefits. Ginger-derived nanoparticles are highly valued for their improved biocompatibility and stability. These nanoparticles show potent antibacterial and antifungal effects against pathogens like *E. coli* and *S. aureus*. Studies indicate that ginger-synthesized nanoparticles can inhibit the growth of cancer cells, including liver and breast cancer cell lines.

Literature review:

Hullavarad and team presented a comprehensive review on CdS nanotechnology, covering various synthesis routes, nanostructures (nanoparticles, nanowires), and applications in electronics and drug delivery systems. This work established the foundation for understanding CdS nanomaterials and their technological importance [1].

Muruganandam and team synthesized CdS nanoparticles using a chemical method with polyvinylpyrrolidone (PVP) as a capping agent. Their study shows the Particle size is in the range of 2.5–6 nm, Structural confirmation using XRD and TEM and Influence of doping (Zn^{2+}) on optical and thermal properties [2].

Voitekhovich and team developed a novel approach using thiotetrazole surfactants for CdS nanoparticle synthesis. Their work emphasized the Controlled surface chemistry, Easy removal of surfactants via thermolysis and Improved material purity and stability [3].

Ayodhya and team reported a sonochemical synthesis method using tryptophan as a capping agent. Their work demonstrates the Formation of stable CdS nanoparticles, enhanced photocatalytic and electrical properties and Importance of ultrasonic irradiation in reducing particle size [4].

Di Luccio and team studied controlled nucleation and growth of CdS nanoparticles in polymer matrices, showing Temperature-dependent growth (200–300°C), Influence of annealing on crystal structure and size and Formation of nanocomposites with improved optical properties [5].

Mali and team synthesized CdS-sensitized TiO_2 nanostructures using hydrothermal and SILAR methods. Their study included Characterization using XRD, SEM, FTIR, Raman spectroscopy and Enhanced light absorption and improved photocatalytic/solar performance [6].

Yanchuk and team investigated CdS nanocrystals synthesized via electrochemical methods and reported the Structural analysis using XRD and SEM, Strong dependence of nonlinear optical properties on particle size and Applications in photonics and optical devices [7].

Susha Naranthatta and team demonstrates a green synthesis approach to create cadmium sulfide (CdS) nanoparticles using medicinal plant extracts, specifically *Ocimum tenuiflorum*, to mitigate cytotoxicity. The surface-modified CdS nanoparticles showed reduced toxicity compared to unmodified versions, making them viable for bioimaging [8].

Aishwarya Shivashankarappa and team concludes that *Escherichia coli*-synthesized CdS nanoparticles are highly effective antibacterial and anticancer agents, providing a stable, eco-friendly alternative for biomedical applications such as drug targeting and bio-imaging [9].

Huang M and team investigates how the specific crystal facets exposed on cadmium sulfide nanoparticles (CdS-NPs) influence their dissolution when exposed to light. The findings emphasize that the environmental fate and toxicity of cadmium sulfide nanomaterials are controlled by their crystal habit, which should be considered when assessing the risks of anthropogenic and biogenic CdS in natural environments [10].

Dabhane and team examines environmentally friendly ("green") methods for synthesizing cadmium sulfide (CdS) nanoparticles, highlighting the use of plants and microorganisms. It covers characterization techniques (XRD, SEM, TEM) and applications in photocatalysis, bio-sensing, and drug delivery, emphasizing biogenic routes over hazardous chemical methods [11].

Varmazyari and Baris (2022) reported a rapid, eco-friendly, and cost-effective biosynthesis of Cadmium Sulfide (CdS) nanoparticles (NPs) using the culture supernatants of *Viridibacillus arenosi* K64. This study demonstrates the use of a Gram-positive bacterium for producing CdS quantum dots via an extracellular mechanism. The results indicated the formation of stable, fluorescent CdS quantum dots [12].

Research Methodology:

The green synthesis of cadmium sulfide (CdS) nanoparticles using ginger (*Zingiber officinale*) extract begins with the preparation of a natural reducing and stabilizing agent. Fresh ginger rhizomes are thoroughly washed with distilled water, peeled, and sliced or ground into a paste. Approximately 10g of this ginger is boiled in 100 mL of distilled water for 20–30 minutes at temperatures between 60°C and 100°C to extract essential phytochemicals. The resulting mixture is filtered through Whatman No. 1 paper and centrifuged at 5,000–12,000 rpm to obtain a clear aqueous extract, which is then stored at 4°C. For the synthesis procedure, a "one-pot" reaction is employed by mixing the ginger extract with a cadmium precursor solution, such as 0.1 M cadmium sulfate or a specific concentration of cadmium acetate, under constant magnetic stirring. A sulfur source, like sodium sulfide (Na_2S) or thiourea, is added dropwise to this mixture. The solution is stirred for several hours, often at 60°C or room temperature, until a distinct color change from pale yellow to bright yellow or orange confirms the formation of CdS nanoparticles. Once synthesized, the nanoparticles are collected and purified through centrifugation at 8,000–10,000 rpm for 15–30 minutes. The resulting precipitate is washed several times with deionized water or ethanol to remove any unreacted precursors or phytochemicals before being dried in an oven at 50–60°C or through lyophilization to produce a stable powder. Finally, the nanoparticles are characterized using UV-Visible spectroscopy to confirm absorption peaks between 300 nm and 500 nm, XRD to determine crystalline structure and size via Scherrer's equation, FTIR to identify stabilizing functional groups like gingerols, and SEM or TEM to analyze their specific morphology and dimensions.

Expected Outcomes:

Cadmium sulfide (CdS) nanoparticle formation is typically indicated by a visible color change in the reaction mixture, shifting from a pale or greenish hue to dark yellow or orange. This transition suggests the reduction of cadmium ions and the successful synthesis of CdS nanoparticles. The resulting particles are generally spherical in shape. When synthesized via hydrothermal methods, their size usually ranges from 2 to 10 nm, though depending on extraction and reaction conditions, sizes can extend from 30 to 120 nm. These nanoparticles exhibit

good colloidal stability, often characterized by a negative zeta potential (around -24.9 mV or lower), which prevents aggregation due to electrostatic repulsion provided by negatively charged organic capping agents. X-ray diffraction (XRD) analysis typically confirms their crystalline nature, showing broadened peaks characteristic of nanostructured materials. CdS nanoparticles synthesized using ginger extract are considered less toxic than those produced through conventional chemical methods, making them more suitable for biological applications. They demonstrate significant antimicrobial activity against a range of pathogens, including Gram-positive bacteria such as *Staphylococcus aureus*, Gram-negative bacteria like *E. coli* and *Pseudomonas aeruginosa*, and fungi such as *Aspergillus niger*. The presence of bioactive compounds from ginger, particularly phenols and flavonoids, on the nanoparticle surface enhances their antioxidant properties, enabling effective free radical scavenging. Additionally, these nanoparticles show promising anticancer potential by inducing cell death in breast cancer cell lines while exhibiting lower toxicity toward normal cells. As a semiconductor material, CdS nanoparticles synthesized using ginger also display photoluminescent properties, emitting multiple colors in the visible spectrum. This makes them highly suitable for applications in bioimaging and biosensing.

Conclusion:

Wrapping up the green synthesis of cadmium sulfide (CdS) nanoparticles with ginger extract, this approach really shows how powerful phytochemicals can be as natural reducing and stabilizing agents. With ginger doing the heavy lifting, you end up with stable, crystalline nanoparticles that outshine those made with conventional chemicals—especially when it comes to their biomedical and environmental uses. A few key takeaways: Ginger's bioactive compounds—think gingerols, shogaols, flavonoids, and phenols—not only reduce cadmium salts to CdS, they also cap the nanoparticles, so there's no need for harsh, toxic surfactants. When you check the nanoparticles: - UV-Vis spectroscopy gives a clear, blue-shifted peak, a telltale sign of tiny, well-formed particles thanks to quantum confinement. - XRD analysis confirms they're crystalline—usually either cubic or hexagonal in structure. - With SEM or TEM, you'll notice the nanoparticles are mostly spherical and pretty evenly spread out, typically landing somewhere in the 5–100 nm range depending on how the reaction's run. On the biomedical front, these CdS nanoparticles show strong antibacterial activity. They break down both Gram-positive and Gram-negative bacteria by damaging their cell membranes. Plus, when tested against cancer cells like colorectal cancer lines, the green-synthesized nanoparticles pack a stronger punch than bulk CdS, but they're still more biocompatible than those made with harsher chemicals. All of this makes the green synthesis route not just environmentally friendly, but practical and scalable, too. It opens up new, sustainable ways to make antimicrobial agents, biosensors, and even photocatalysts that help break down industrial dyes. So, using ginger isn't just a novel twist—it's a real step forward for greener nanotechnology.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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