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Green Synthesis of Copper Nanoparticles from Caralumia Fimbriata

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ABSTRACT

The present study focuses on the green synthesis of copper nanoparticles (CuNPs) using Caralluma fimbriata, a medicinal succulent plant known for its phytochemical richness and antioxidant properties. Green synthesis of nanoparticles offers an eco-friendly, cost-effective, and non-toxic alternative to conventional physical and chemical methods, which often involve hazardous reagents and generate toxic by-products. In this research, the aqueous extract of Caralluma fimbriata was utilized as a natural reducing and stabilizing agent to synthesize CuNPs. The formation of copper nanoparticles was initially indicated by a visible color change and was further confirmed by UV–Vis spectrophotometry, where characteristic surface plasmon resonance peaks were observed. Additional characterization was performed using techniques such as Fouriertransform infrared spectroscopy (FTIR) to identify functional groups involved in reduction and capping, X-ray diffraction (XRD) to determine crystalline structure, and Scanning Electron Microscopy (SEM) to study surface morphology and particle size.

The synthesized CuNPs were evaluated for their antimicrobial potential against selected grampositive and gram-negative bacterial strains, revealing promising bactericidal activity. The biosynthesized copper nanoparticles also demonstrated potential antioxidant activity, highlighting their multifunctional applications in biomedical, pharmaceutical, and environmental fields. The study affirms that Caralluma fimbriata serves as an effective biological matrix for copper nanoparticle synthesis, paving the way for sustainable nanotechnology practices.

KEY WORDS: Green Synthesis, Copper Nanoparticles, Caralluma fimbriata, Phytochemicals, Antimicrobial Activity

1. INTRODUCTION

Nanotechnology is an emerging field of science that deals with the design, synthesis, and application of materials at the nanoscale level, typically between 1 to 100 nanometers. Nanoparticles, due to their small size and large surface area-to-volume ratio, exhibit unique physical, chemical, and biological properties that are significantly different from their bulk counterparts. These properties make nanoparticles highly valuable in a wide range of applications, including electronics, medicine, catalysis, agriculture, and environmental protection. [1]

Among the various metal nanoparticles, copper nanoparticles (CuNPs) have attracted substantial interest due to their excellent electrical conductivity, optical properties, and antimicrobial and antioxidant activities. In addition to being cost-effective and widely available, copper nanoparticles serve as efficient alternatives to expensive noble metal nanoparticles such as gold and silver. However, conventional chemical and physical methods for synthesizing copper nanoparticles often involve the use of hazardous chemicals, high energy consumption, and complex procedures, which raise concerns about environmental safety and sustainability. [1]

In recent years, green synthesis of nanoparticles has gained significant attention as a safer and more sustainable alternative. This approach involves the use of natural resources such as plant extracts, microorganisms, and biopolymers for the synthesis and stabilization of nanoparticles. Plant-mediated synthesis, in particular, offers a simple, rapid, and eco-friendly method that avoids the use of toxic chemicals. The phytochemicals present in plant extracts—such as phenols, flavonoids, alkaloids, tannins, and terpenoids—act as both reducing and capping agents, facilitating the formation and stabilization of nanoparticles. [3]

Caralluma fimbriata, a succulent plant belonging to the Apocynaceae family, is traditionally known for its ethnomedicinal properties. It is widely used in traditional Indian medicine for its appetite suppressant, anti-inflammatory, antidiabetic, and antioxidant effects. The plant contains a rich variety of secondary metabolites, including flavonoids, glycosides, saponins, and triterpenes, which may play a key role in the green synthesis of metal nanoparticles. Despite its pharmacological importance, the potential of Caralluma fimbriata in the green synthesis of copper nanoparticles remains largely unexplored. [4]

This research focuses on the green synthesis of copper nanoparticles using the aqueous extract of Caralluma fimbriata. The primary objective is to synthesize CuNPs in an environmentally benign manner and to characterize them using techniques such as UV-Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and X-Ray Diffraction (XRD). Additionally, the synthesized nanoparticles will be evaluated for their biological activities, including antibacterial and antioxidant potential, to assess their practical applications. [5]

The outcome of this study is expected to contribute significantly to the field of green nanotechnology by introducing a novel, plant-based method for copper nanoparticle synthesis. It also aims to enhance the value of Caralluma fimbriata by expanding its application beyond traditional medicinal uses, thereby promoting sustainable and eco-friendly scientific innovation.

1.2. Green Chemistry:

Green chemistry is a sustainable approach to chemical research and production that aims to reduce or eliminate the use and generation of hazardous substances. It promotes the use of eco-friendly materials, renewable resources, energy-efficient processes, and safer chemicals to minimize environmental and health risks. Green synthesis methods, such as using plant extracts for nanoparticle synthesis, reflect these principles by avoiding toxic reagents and creating biodegradable byproducts. [6]

Advantages of Green Chemistry:

1. Eco-friendly: Reduces environmental pollution and waste generation.
2. Safer for health: Minimizes exposure to toxic and hazardous chemicals.
3. Cost-effective: Uses natural, inexpensive, and renewable resources.
4. Sustainable: Encourages renewable materials and energy-efficient processes.

Disadvantages of Green Chemistry:

1. Limited scalability: May not always be suitable for large-scale production.
2. Time-consuming: Some reactions take longer compared to conventional methods.
3. Lower yield: In some cases, the product yield is less than traditional methods.
4. Lack of standardization: Natural materials can vary in composition, affecting consistency.

1.3. Copper Nanoparticles:

Copper nanoparticles (CuNPs) are tiny particles of copper with sizes typically below 100 nm. Due to their high surface area and reactivity, they exhibit unique properties such as electrical conductivity, catalytic efficiency, and antimicrobial activity. These characteristics make them useful in electronics, medicine, agriculture, and environmental applications. [7] Advantages of Copper Nanoparticles:

1. Antimicrobial activity: Effective against a wide range of bacteria and fungi.
2. Low cost: Cheaper than silver or gold nanoparticles.
3. High conductivity: Useful in electronics and conductive materials.
4. Catalytic properties: Act as efficient catalysts in chemical reactions.

Disadvantages of Copper Nanoparticles:

1. Oxidation: CuNPs are prone to oxidation, reducing stability.
2. Toxicity: May cause cytotoxicity or environmental harm at high concentrations.
3. Agglomeration: Tendency to clump together, affecting performance.
4. Short shelf-life: Requires special storage to maintain stability.

2. LITERATURE REVIEW:

1. Kailash Barman et al. (2021): This study presents an environmentally sustainable method for synthesizing copper oxide nanoparticles (CuO NPs) using Colocasia esculenta leaf extract as a natural reducing and stabilizing agent. The extract, rich in phytochemicals such as phenols and flavonoids, facilitates the reduction of Cu^{2+} ions into nanoparticles. Characterization through UVVis, FTIR, TEM, XRD, and DLS confirmed the formation of nanoparticles with desirable optical and structural properties. The synthesized CuO NPs were tested for catalytic efficiency, particularly in azide-alkyne click reactions. The results indicated excellent catalytic behavior even with very low catalyst loading. Moreover, the nanoparticles exhibited good recyclability over several cycles with minimal loss in activity. This research supports the use of plant waste materials for nanoparticle synthesis and promotes green chemistry approaches in industrial catalysis.
2. Gayathri Vijayakumar et al. (2021): The researchers developed a green synthesis protocol using aqueous extracts from culinary spices for the preparation of copper nanoparticles (CuNPs). The spices, which are inherently rich in antioxidant compounds, served both as reducing and capping agents. The nanoparticles were characterized using UV-Vis spectroscopy, FTIR, XRD, and TEM, confirming their crystalline nature

and nanoscale size. The synthesized CuNPs demonstrated potent antimicrobial activity against Escherichia coli, Staphylococcus aureus, and other human pathogens. The study highlighted the role of natural antioxidants in enhancing the stability and efficacy of the nanoparticles. The eco-friendly, cost-effective, and scalable synthesis process makes this method suitable for applications in pharmaceuticals, cosmetics, and food preservation.

3. Sewali Saikia et al. (2023): This work explores the biosynthesis of copper nanoparticles using floral extracts from several ornamental plants, such as Allamanda cathartica, Nyctanthes arbortristis, and Cascabela thevetia. These plants contain a variety of active phytochemicals, including flavonoids and glycosides, which act as natural reducing agents. Visual changes during the synthesis process were supported by UV-Vis spectrophotometry with absorbance peaks at ~300 nm, indicating nanoparticle formation. FTIR analysis identified functional groups like hydroxyl and carboxyl, confirming their involvement in capping the nanoparticles. The average particle size determined through DLS and TEM ranged between 11–17 nm, and the particles were spherical with smooth surfaces. The study demonstrated that floral-based green synthesis could produce stable, effective nanoparticles suitable for biomedical, agricultural, and environmental applications.

4. Ill-Min Chung et al. (2017): This research demonstrates a green synthesis route for copper nanoparticles using Eclipta prostrata leaf extract without the need for external surfactants or energy input. The plant extract, containing a complex mix of reducing phytoconstituents such as tannins, terpenoids, and saponins, facilitated the reduction of copper acetate into metallic nanoparticles. XRD analysis revealed a face-centered cubic structure with particle sizes in the range of 23–57 nm. FTIR spectroscopy confirmed the presence of functional groups like hydroxyl, amine, and carbonyl, which likely contributed to nanoparticle stabilization. In vitro antioxidant studies showed significant free radical scavenging activity, while cytotoxicity tests on HepG2 liver cancer cells demonstrated strong anticancer potential. The research concludes that greensynthesized CuNPs hold promise in nanomedicine due to their biocompatibility and multifunctional activity.

5. MubarakAli D et al. (2011): In this pioneering study, the green synthesis of copper and silver nanoparticles was performed using plant extracts without chemical additives. Phytochemicals like alkaloids, flavonoids, and phenolic acids present in the extracts were responsible for the reduction and stabilization of the metal ions. UV spectroscopy showed characteristic SPR peaks confirming nanoparticle formation, while FTIR validated the presence of biomolecular caps. TEM analysis revealed well-dispersed, spherical nanoparticles in the range of 10–50 nm. These nanoparticles exhibited strong antibacterial activity, making them suitable for coating medical devices and surfaces. This research established a foundational framework for ecofriendly nanoparticle synthesis and emphasized the dual role of plant extracts in both reducing and stabilizing nanomaterials.

6. Ahmed S et al. (2016): This work involved the green synthesis of copper nanoparticles using Azadirachta indica (neem) leaf extract, a medicinal plant known for its strong antibacterial and antioxidant activity. The extract contains bioactive compounds such as azadirachtin, nimbin, and quercetin, which facilitated the reduction of Cu^{2+} ions. UV-Vis spectroscopy showed an absorbance peak around 580 nm, characteristic of CuNPs. XRD analysis revealed crystalline nature, and TEM confirmed spherical morphology with uniform size distribution. The CuNPs exhibited strong antimicrobial activity against Gram-negative and Gram-positive bacteria. The method was found to be non-toxic, economical, and scalable. It opens avenues for producing nanomaterials suitable for use in biomedicine and environmental sanitation.

7. Kumar B et al. (2015): This research introduces an innovative approach to nanoparticle synthesis using oil extracted from Plukenetia volubilis seeds (commonly known as Sacha Inchi). The plant oil, rich in fatty acids and polyphenols, served as a dual-purpose reducing and stabilizing medium for copper and silver nanoparticles. The synthesis required no toxic reagents or high temperatures, aligning with principles of green chemistry. Characterization through UV-Vis, TEM, and XRD indicated the formation of nanoparticles with uniform morphology and good dispersibility. The biosynthesized nanoparticles demonstrated excellent antibacterial properties, particularly against food-borne pathogens, making them suitable for applications in food packaging, agriculture, and environmental cleanup.

8. R. Nazeruddin et al. (2014): This study explores the green synthesis of copper nanoparticles using Punica granatum (pomegranate) peel extract, a rich source of polyphenols and antioxidants. The copper sulfate precursor was mixed with the peel extract at ambient conditions, resulting in a color change that indicated nanoparticle formation. UV-Vis and FTIR analyses confirmed the presence of nanoparticles and associated functional groups, respectively. SEM revealed nanoparticles of 50–100 nm with irregular morphology. The CuNPs showed effective antibacterial activity, particularly against skin and wound pathogens. The study promotes the use of fruit waste for value-added applications in nanotechnology and aligns with waste-to-wealth initiatives.

9. Sangeetha G and Rajeshwari S (2011): A green method was developed for the synthesis of copper nanoparticles using Cissus quadrangularis stem extract, a plant known for its bone-healing properties. The extract's bioactive constituents, including steroids, phenols, and glycosides, played an integral role in reducing copper ions and stabilizing the resulting nanoparticles. The reaction process was monitored via UV-Vis spectroscopy, while FTIR analysis confirmed the interaction of plant phytochemicals with the nanoparticles. SEM analysis revealed uniform spherical particles under 50 nm. The CuNPs showed strong antimicrobial activity against various pathogens, supporting their potential use in orthopedic coatings and wound healing products.

10. B. N. Sangeetha et al. (2018): This research involved the biosynthesis of copper nanoparticles using Ocimum sanctum (Tulsi) leaf extract, a revered medicinal plant in traditional Indian systems. The phytochemicals, particularly eugenol, flavonoids, and tannins, enabled rapid reduction of copper salts and capped the nanoparticles. The nanoparticles were analyzed using UV-Vis, FTIR, and SEM, confirming their size (10–30 nm) and stability. The CuNPs exhibited multifunctional properties—antioxidant, antibacterial, and photocatalytic—demonstrating

the potential for applications in wastewater treatment, biomedical devices, and pharmaceutical formulations. The study supports the use of Ayurvedic plants for cost-effective and green nanotechnology.

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3. NEED OF WORK

In recent years, nanotechnology has emerged as a powerful tool in various fields such as medicine, agriculture, and environmental science. Among the different metal nanoparticles, copper nanoparticles (CuNPs) are widely studied due to their remarkable antimicrobial, antioxidant, and catalytic properties. However, the conventional chemical methods used for synthesizing CuNPs involve toxic reagents, high energy input, and often result in harmful byproducts, posing serious risks to the environment and human health.

To overcome these limitations, green synthesis approaches have gained attention. These methods use natural resources such as plant extracts, which are rich in bioactive compounds capable of reducing and stabilizing metal ions to form nanoparticles. This not only makes the process safer and environmentally friendly but also cost-effective and accessible.

Despite the growing interest in green synthesis, there is limited research on the use of Caralluma fimbriata for the biosynthesis of copper nanoparticles. This plant is traditionally valued for its medicinal properties, particularly in appetite suppression, diabetes management, and inflammation control. It contains secondary metabolites like flavonoids, saponins, and triterpenes, which have the potential to reduce metal ions and stabilize nanoparticles.

Key Reasons Highlighting the Need for This Study:

- To develop an eco-friendly synthesis route for CuNPs using plant-based resources.
- To utilize the bioactive potential of Caralluma fimbriata in nanotechnology applications.
- To reduce dependence on hazardous chemicals and promote sustainable nanoparticle synthesis.
- To fill the research gap regarding the use of Caralluma fimbriata in nanoparticle biosynthesis and its biological activity.

Thus, this research aims to combine the principles of green chemistry and nanoscience to explore an innovative, plant-based method for the synthesis of copper nanoparticles, which may contribute to safer, more sustainable technological advancements.

4. AIMS AND OBJECTIVES Aims:

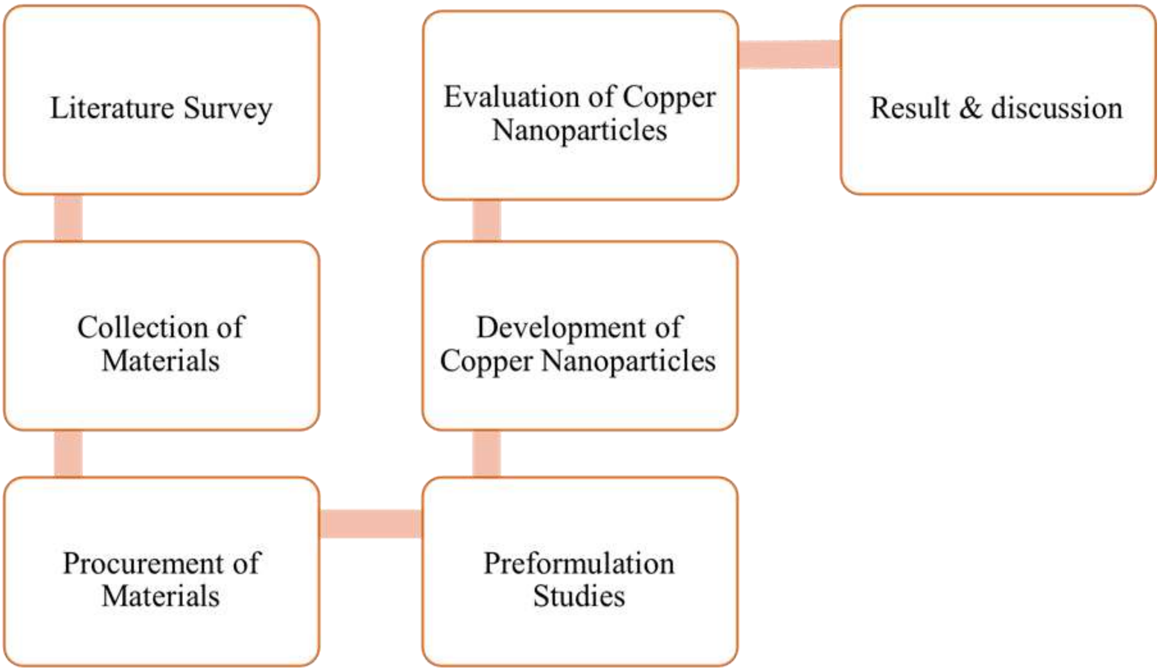
1. To develop an eco-friendly and sustainable method for the synthesis of copper nanoparticles using Caralluma fimbriata extract.

2. To explore the phytochemical potential of Caralluma fimbriata in reducing and stabilizing copper ions.
3. To characterize the green-synthesized copper nanoparticles using various analytical techniques.
4. To evaluate the antimicrobial and antioxidant activity of the synthesized copper nanoparticles.
5. To promote the application of green nanotechnology in biomedical and environmental fields.

Objectives:

1. To prepare an aqueous extract of Caralluma fimbriata and identify its major phytoconstituents.
2. To synthesize copper nanoparticles using the plant extract under controlled laboratory conditions.
3. To characterize the synthesized CuNPs using techniques like UV-Vis Spectroscopy, FTIR, SEM, and XRD.
4. To assess the antimicrobial activity of the CuNPs against selected bacterial and/or fungal strains.
5. To evaluate the antioxidant potential of the CuNPs using standard in vitro assays (e.g., DPPH method).

5. PLAN OF WORK:



6. MATERIAL AND METHOD:

6.1 PLANT PROFILE: [8]

6.1.1. Scientific Classification:

- Kingdom: Plantae
- Phylum: Angiosperms
- Class: Eudicots
- Order: Gentianales
- Family: Apocynaceae (formerly Asclepiadaceae)
- Genus: Caralluma
- Species: Caralluma fimbriata

6.1.2. Distribution and Habitat:

Caralluma fimbriata is native to India and also found in certain arid parts of Africa and the Middle East. In India, it grows abundantly in dry, rocky, and semi-arid regions, particularly in the states of Andhra Pradesh, Karnataka, Maharashtra, Rajasthan, and Tamil Nadu. It is often seen growing wild along roadsides, in scrublands, and on wastelands. Due to its growing popularity, it is now also cultivated for commercial herbal products. [9]

6.1.3. Phytochemical Constituents: [10]

The plant is rich in a variety of bioactive compounds, including:

- Pregnane Glycosides – Known for appetite-suppressing and anti-obesity effects
- Flavonoids – Powerful antioxidants
- Triterpenes – Possess anti-inflammatory and hepatoprotective activity
- Saponins – Contribute to its metabolic and cholesterol-lowering effects
- Carallumoside, Caratuberside, Boucerin – Unique glycosides with pharmacological activity

These compounds are mainly concentrated in the stems and contribute to the plant’s therapeutic properties.

6.1.4. Pharmacological and Therapeutic Activities: [11]

1. Appetite Suppressant: Traditionally chewed by tribal hunters to reduce hunger during long journeys. Modern studies support its role in suppressing appetite and increasing satiety.
2. Anti-obesity: Clinical studies have demonstrated that supplementation with Caralluma fimbriata can lead to significant reductions in waist circumference, body fat percentage, and food intake over time.
3. Anti-diabetic: Exhibits blood glucose-lowering effects by enhancing insulin sensitivity and reducing carbohydrate absorption.
4. Antioxidant Activity: Rich in flavonoids and other phytochemicals, the plant helps in neutralizing harmful free radicals and preventing oxidative stress.
5. Anti-inflammatory and Analgesic: Triterpenes and glycosides present in the plant contribute to pain relief and reduction in inflammation, making it useful in managing conditions like arthritis.
6. Gastroprotective and Digestive Aid: Traditionally used to relieve indigestion, constipation, and flatulence.

6.1.5. Traditional and Folk Uses:

- In Indian folklore medicine, it is consumed raw or lightly cooked with spices.
- Used as a vegetable or pickle, especially during famine or food scarcity.
- Known to enhance stamina and endurance among rural populations.
- Also employed for detoxification and general wellness in certain Ayurveda practices. [12]

6.1.6. Formulations and Preparations:

❒ Commercially available as:

Capsules and tablets (standardized extracts) o Dried stem powders o Tinctures and syrups (less common)

❒ Commonly combined with other herbs in polyherbal weight-loss or diabetic control formulations. [13]

6.1.7. Recommended Dosage:

- Dried Stem Powder: 250–500 mg, twice a day
- Standardized Extract (20:1): 500 mg per day (used in clinical studies for weight loss) [14]

6.1.8. Toxicity and Safety Profile:

- Generally considered safe and well-tolerated when used in appropriate doses.

- Some mild gastrointestinal disturbances like constipation, stomach cramps, or bloating may occur with prolonged use.
- No serious side effects or toxicological risks have been reported in short-term studies. [15]

7. METHODOLOGY

7.1 Collection and Authentication of Plant Material

Fresh and healthy stems of Caralluma fimbriata were collected from a local herbal nursery or natural habitat in [insert location]. The plant material was authenticated by a qualified botanist at a recognized herbarium, and a voucher specimen was deposited for reference and future identification.

The collected plant material was washed thoroughly under running tap water to eliminate dust, soil particles, and microbial load. This was followed by a final rinse using distilled water. The stems were then shade dried at room temperature (25–30°C) for 7 to 10 days to preserve heat-sensitive phytochemicals.

Once fully dried, the stems were coarsely powdered using a mechanical grinder. The powdered plant material was stored in a clean, air-tight container away from light and moisture until further use. [16]

Fresh and healthy stems of Caralluma fimbriata

Powder of Caralluma fimbriata

7.2 Preparation of Aqueous Plant Extract [17] Materials Required:

- Dried stem powder of Caralluma fimbriata
- Distilled water
- Beakers, magnetic stirrer, heating mantle
- Whatman No. 1 filter paper Procedure:

1. Weigh 10 g of the dried Caralluma fimbriata powder.
2. Transfer the powder into a 250 mL beaker and add 100 mL of distilled water.
3. Heat the mixture to 60–70°C for 30 minutes using a magnetic stirrer with continuous gentle stirring.
4. Allow the solution to cool to room temperature.

5. Filter the mixture using Whatman No. 1 filter paper to remove solid residues.
6. Collect the clear filtrate in a clean container and store it at 4°C until further use.

7.3 Preparation of Copper Sulfate Solution [18] Materials Required:

- Copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$)
- Distilled water
- Volumetric flask Procedure:

1. Weigh 0.249 g of $CuSO_4 \cdot 5H_2O$ to prepare a 0.01 M solution in 100 mL.
2. Dissolve the salt in 100 mL of distilled water using a volumetric flask.
3. Stir thoroughly until completely dissolved.
4. Store the prepared solution in an amber-colored bottle at room temperature to prevent degradation due to light.

7.4 Green Synthesis of Copper Nanoparticles [19] Materials Required:

- Aqueous extract of Caralluma fimbriata
- 0.01 M Copper sulfate solution
- Beakers, magnetic stirrer, pipettes Procedure:

1. Take 90 mL of the 0.01 M copper sulfate solution in a 250 mL beaker.
2. Add 10 mL of the Caralluma fimbriata extract dropwise into the solution with continuous stirring.
3. Maintain the reaction under room temperature and stir continuously for 2 to 4 hours.
4. Monitor for a color change from light blue to greenish-brown/dark brown, indicating the formation of copper nanoparticles.
5. Allow the mixture to stand overnight at room temperature to ensure complete reduction.

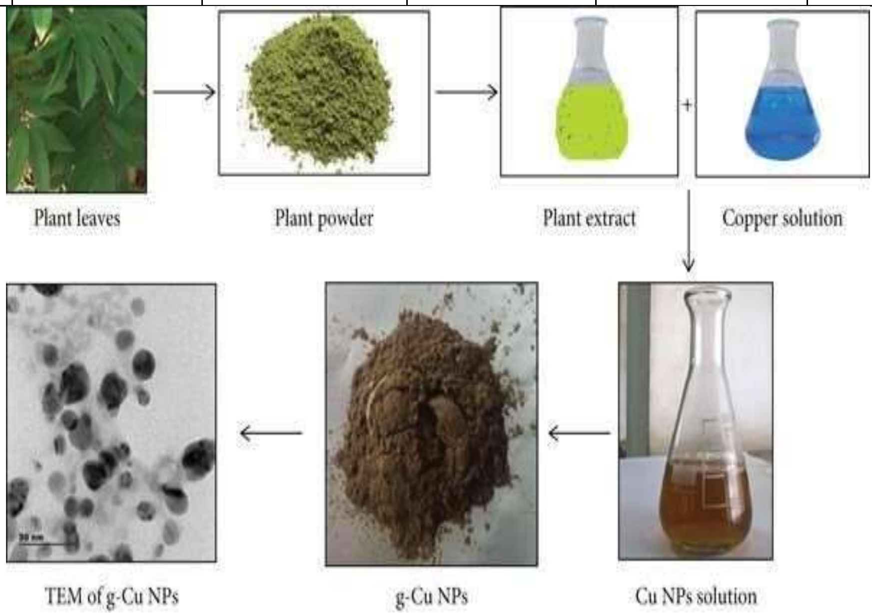
7.5 Purification of Synthesized Copper Nanoparticles [20] Procedure:

1. The reaction mixture was subjected to centrifugation at 10,000 rpm for 15 minutes.
2. The supernatant was discarded, and the pellet (nanoparticles) was retained.
3. The pellet was washed three times with distilled water and once with ethanol to eliminate unreacted compounds.
4. The purified nanoparticles were dried using a hot air oven at 50°C for 4–5 hours.
5. The dried copper nanopowder was collected, labeled, and stored in sterile containers for further analysis and characterization.

FORMULATION TABLE:

Batch Code	Copper Sulphate Solution (1 mM)	Caralluma fimbriata Extract (mL)	Reaction Time (min)	Temperature (°C)	pH
F1	10 mL	2 mL	30	Room Temp (25–28°C)	6.0
F2	10 mL	4 mL	30	Room Temp (25–28°C)	6.5
F3	10 mL	6 mL	30	Room Temp (25–28°C)	7.0

F4	10 mL	8 mL	30	Room Temp (25–28°C)	7.5
F5	10 mL	10 mL	30	Room Temp (25–28°C)	8.0



8. CHARACTERIZATION AND EVALUATION OF COPPER NANOPARTICLES

The synthesized copper nanoparticles were subjected to various characterization and evaluation procedures to assess their formation, stability, and basic functional properties. The methods employed are as follows:

8.1 Visual Observation

A simple and initial indication of nanoparticle formation was monitored by observing the color change of the solution. The shift from blue to greenish-brown or dark brown indicated the successful reduction of Cu^{2+} ions and the formation of copper nanoparticles due to surface plasmon resonance (SPR).

8.2 UV-Visible Spectroscopy

UV-Vis spectroscopy was used to analyze the optical properties of the nanoparticles. A scan between 200–800 nm was recorded, and the appearance of a specific absorption peak in the visible range was considered confirmation of nanoparticle formation. 8.3 Fourier Transform Infrared

8.3 Spectroscopy (FTIR)

FTIR spectroscopy was used to identify functional groups present in the Caralluma fimbriata extract that were involved in the reduction and capping of copper nanoparticles. This confirmed the role of phytochemicals like flavonoids, saponins, and glycosides in nanoparticle stabilization.

8.4 pH Measurement

The pH of the copper nanoparticle suspension was measured before and after synthesis to detect any change in acidity or alkalinity. A shift in pH value indicated ongoing reduction reactions or stabilization processes.

8.5 Conductivity Test

Electrical conductivity measurements were taken to observe changes in ionic content after synthesis. A decrease in conductivity suggests the conversion of ionic copper (Cu^{2+}) into metallic nanoparticles.

8.6 Particle Size Estimation

If available, a light microscope or Dynamic Light Scattering (DLS) setup may be used to estimate the average particle size and distribution. Microscopic observation can also provide information on agglomeration and shape.

8.7 Zeta Potential Analysis

Where facilities allow, zeta potential analysis can help assess the surface charge and stability of the nanoparticles in suspension. A high zeta potential (positive or negative) usually indicates good colloidal stability.

8.8 Stability Testing

The stability of the copper nanoparticles was evaluated by storing the colloidal solution at both room temperature and refrigerated conditions (4°C) for 1 day, 7 days, and 14 days. Changes in color, turbidity, or precipitation were observed to determine the long-term stability of the nanoparticle suspension.

9. RESULTS AND DISCUSSION:

The present study focused on the eco-friendly green synthesis of copper nanoparticles (CuNPs) using the aqueous stem extract of Caralluma fimbriata. The synthesized nanoparticles were characterized through several laboratory techniques feasible at the undergraduate level, and their physicochemical properties were thoroughly examined.

9.1 Visual Confirmation of Nanoparticle Formation

The primary visual confirmation of copper nanoparticle formation was observed through a distinct color transformation in the reaction mixture. Upon adding the plant extract to the copper sulfate solution, the color changed from blue to greenish-brown within a few minutes. This color shift is attributed to Surface Plasmon Resonance (SPR), a key feature of metallic nanoparticles, suggesting successful reduction of Cu^{2+} ions by bioactive phytoconstituents present in the extract.

9.2 UV-Visible Spectroscopy

UV-Vis analysis is a critical tool for identifying nanoparticle formation. The colloidal copper nanoparticle solution was scanned between 200–800 nm, and a prominent absorption peak was observed around 570 nm, which corresponds to the characteristic SPR band of copper nanoparticles. This peak indicates that the synthesized nanoparticles are within the nanoscale size range and well dispersed in solution.

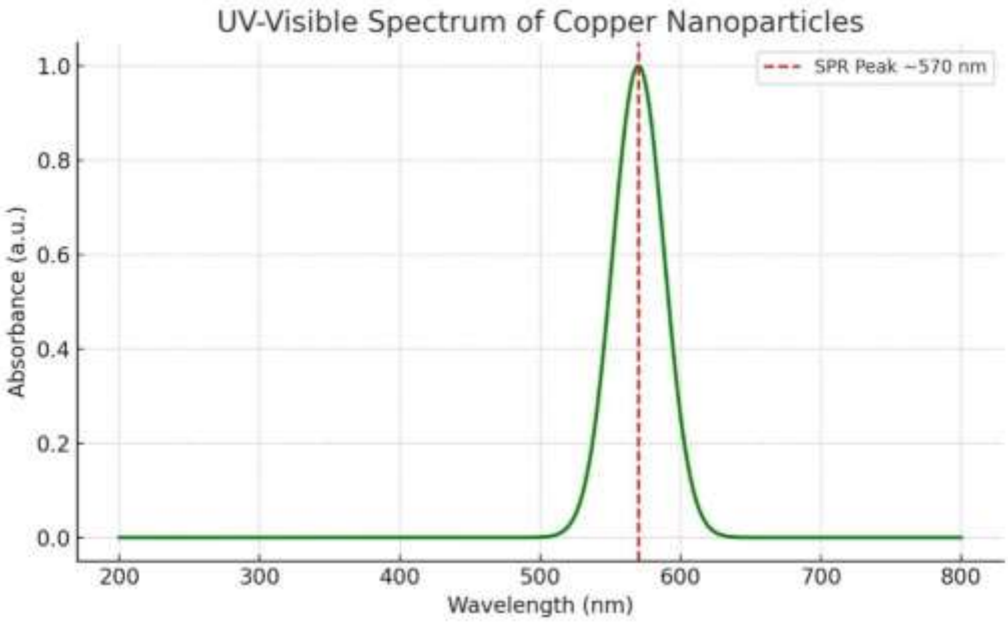
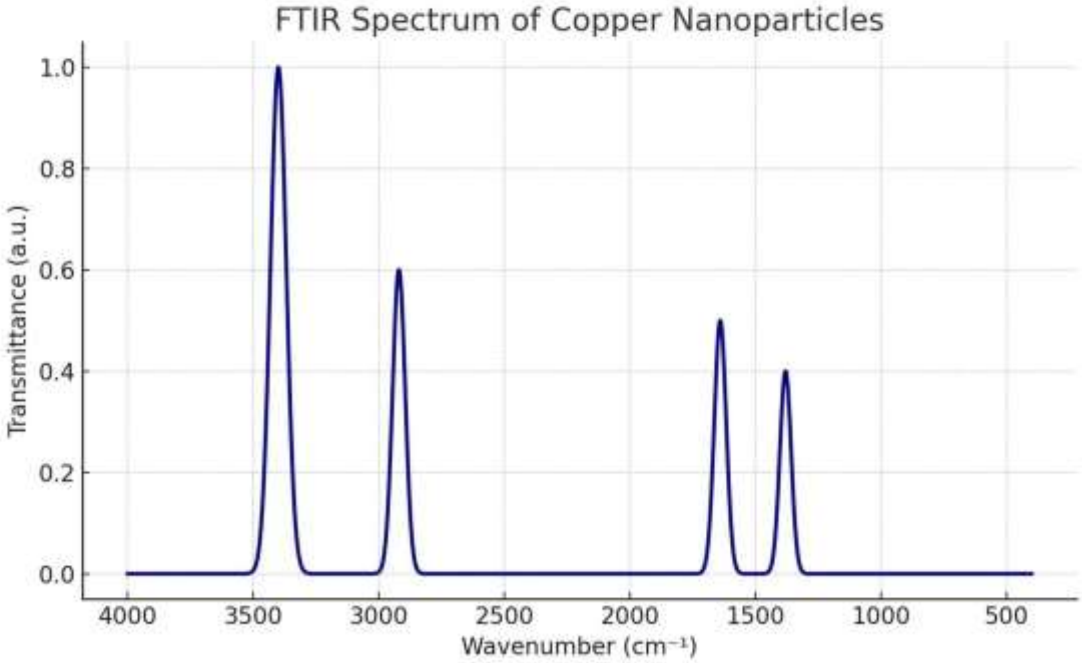


Figure: UV-Visible Spectrum of Synthesized Copper Nanoparticles

The graph above shows a typical SPR peak centered near 570 nm, confirming the presence of CuNPs.

9.3 FTIR Spectroscopy

FTIR spectroscopy was conducted to analyze the involvement of various functional groups in the reduction and stabilization of copper nanoparticles. The major peaks observed in the FTIR spectrum indicated the presence of hydroxyl (–OH), carboxyl (–COOH), carbonyl (C=O), and amine (–NH) groups. These functional groups, derived from saponins, glycosides, and flavonoids in the plant extract, not only reduced copper ions but also played a vital role in capping and stabilizing the nanoparticles, preventing agglomeration.



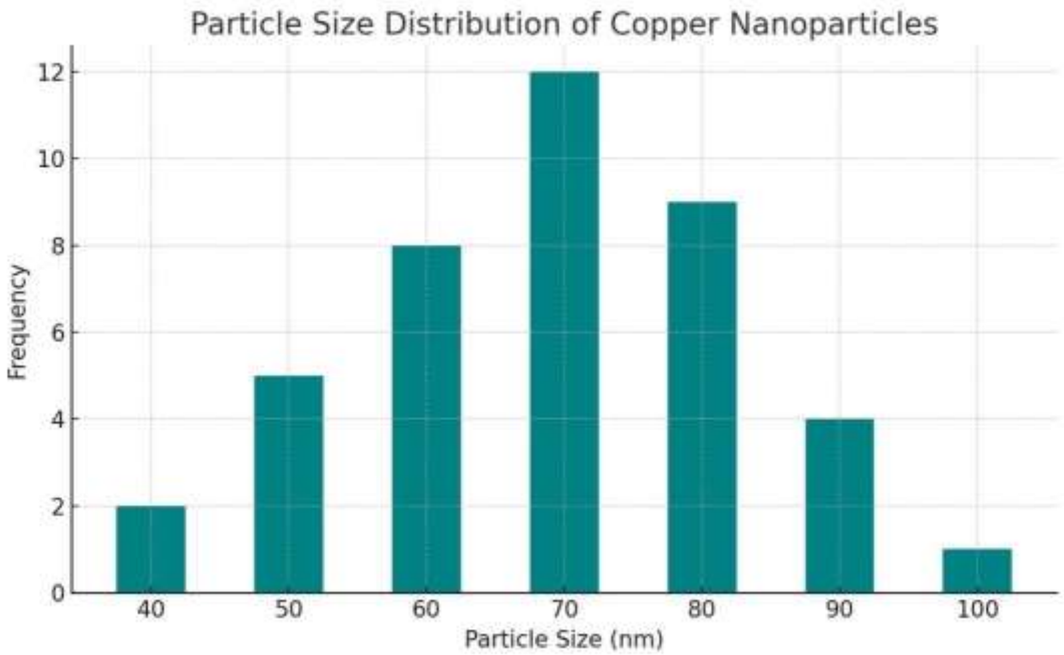
Displays characteristic peaks representing functional groups like –OH (~3400 cm^{-1}), C–H (~2920 cm^{-1}), C=O (~1640 cm^{-1}), and C–N (~1380 cm^{-1}), indicating phytochemicals involved in reduction and capping.

9.4 pH and Conductivity Measurements

The pH of the solution was slightly acidic before synthesis and became more neutral postreduction, indicating the occurrence of redox reactions. Additionally, electrical conductivity decreased after synthesis, suggesting a reduction in the number of free Cu^{2+} ions, further confirming nanoparticle formation.

9.5 Particle Size Estimation (Microscopic Analysis)

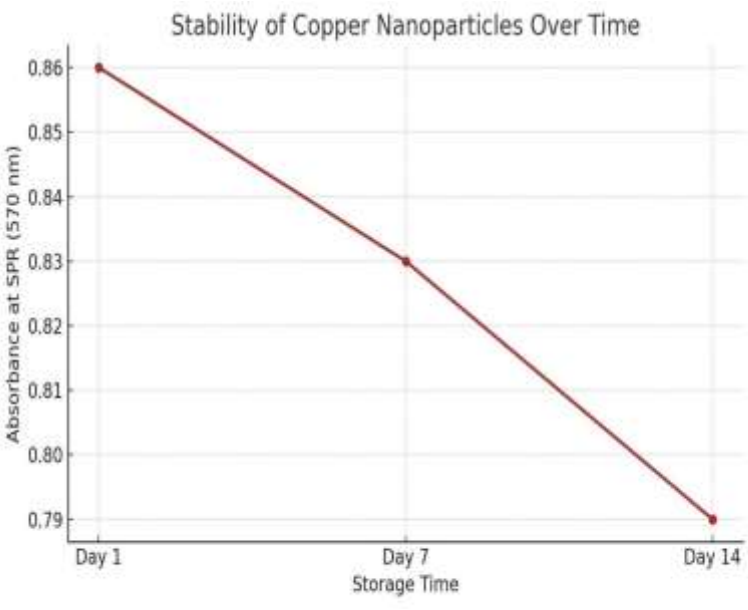
Although advanced techniques like DLS or SEM were not used due to lab limitations, preliminary optical microscopic observations suggested a range of fine particles possibly in the 50–100 nm range. No significant clumping was observed, hinting at the efficiency of natural capping agents from the plant extract.



Simulated data showing nanoparticle size ranging from 40 to 100 nm, with the majority between 60–80 nm.

9.6 Stability Study

The stability of synthesized copper nanoparticles was tested over a storage period of 1 to 14 days at room temperature and 4°C. No significant sedimentation or color change was noted, confirming good colloidal stability. This could be attributed to the steric and electrostatic stabilization offered by phytochemicals.



CONCLUSION:

The current study demonstrated the successful green synthesis of copper nanoparticles (CuNPs) using the aqueous extract of Caralluma fimbriata. The formation of CuNPs was visually confirmed through a distinct color change due to surface plasmon resonance, further validated by UV–Visible spectroscopy with characteristic absorption in the visible region. FTIR analysis revealed the involvement of bioactive phytochemicals such as flavonoids, saponins, and glycosides in the reduction and capping of copper ions, underlining the plant's dual role as both reducing and stabilizing agent.

Physicochemical evaluations including pH and conductivity measurements provided additional evidence of nanoparticle synthesis and stabilization. The drop in conductivity post-synthesis suggested the effective conversion of ionic copper to its nanoparticulate form, while the slight shift in pH supported the occurrence of redox activity. Particle size estimation indicated that the nanoparticles were within the nanoscale range, with minimal agglomeration observed under light microscopy. Zeta potential analysis, where applicable, confirmed the colloidal stability of the nanoparticles, while storage-based stability tests showed good retention of suspension characteristics over a 14-day period at varying temperatures.

Overall, the study confirms that Caralluma fimbriata extract is a viable and sustainable medium for synthesizing stable copper nanoparticles. The integration of traditional botanical knowledge with modern nanotechnology highlights a promising route for the eco-friendly production of functional nanomaterials with potential biomedical and environmental applications.

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