

Biogenic Synthesis of Cu–Zn Nanoparticles Using *Adiantum capillus-veneris* Leaf Extract: A Spectroscopic and XRD Study

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Abstract— The present study describes an eco-friendly and economical approach for the synthesis of Cu–Zn bimetallic nanomaterials using *Adiantum capillus-veneris* leaf extract as a natural reducing and stabilizing agent. An aqueous leaf extract was prepared and used for the bioreduction of copper sulfate and zinc nitrate under mild reaction conditions. The formation of nanoparticles was visually indicated by a change in colour from green to dark brown. The synthesized Cu–Zn nanomaterials were characterized by UV–Visible spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and X-ray diffraction (XRD). UV–Visible analysis showed a strong absorption band at approximately 210–220 nm, confirming nanoparticle formation and optical activity. FTIR analysis indicated the involvement of hydroxyl, carbonyl/amide, C–H, and C–O functional groups of plant-derived biomolecules in the reduction and stabilization of the nanoparticles. XRD analysis revealed a crystalline, polycrystalline structure with diffraction features attributed to copper oxide and zinc oxide phases. The average crystallite size was estimated to be approximately 12.5 nm using the Scherrer equation. The study demonstrates the potential of *A. capillus-veneris* leaf extract as a sustainable biological resource for the synthesis of nanoscale Cu–Zn materials and provides a simple alternative to conventional nanoparticle synthesis methods. The synthesized materials may have potential applications in catalytic, biomedical, and environmental fields

Keywords— *Adiantum capillus-veneris*, Green synthesis; Cu–Zn nanoparticles, Bimetallic nanoparticles.

I. INTRODUCTION

The ability to manipulate matter at the nanoscale (1–100 nm), where materials exhibit distinct optical, catalytic, electrical, and biological capabilities, has made nanotechnology one of the most revolutionary areas of contemporary science. High surface-to-volume ratios and quantum confinement effects cause these properties to be very different from their bulk counterparts¹. Bimetallic nanoparticles (BMNPs) like Cu–Zn have drawn a lot of interest among different nanomaterials because of their improved functional performance, synergistic catalytic activity, and increased physicochemical stability when compared to monometallic systems². Traditionally, physical and chemical techniques like laser ablation, sol-gel procedures, chemical reduction, and thermal degradation have been used to create nanoparticles.



However, these methods frequently result in dangerous byproducts for the environment, significant energy usage, and poisonous compounds³. Green synthesis, also known as biogenic synthesis, has become a viable, economical, and ecological solution to these constraints. This method reduces metal ions into nanoparticles under mild conditions by using biological entities like plants, microbes, and enzymes⁴. These phytoconstituents make it an excellent candidate for nanoparticle synthesis. The plant extract acts as a natural nanofactory, facilitating rapid reduction of metal ions and stabilization of formed nanoparticles. Studies have demonstrated successful synthesis of various nanoparticles using *Adiantum capillus-veneris*, confirming its strong reducing capability and capping efficiency⁵. Bimetallic nanoparticles consist of two different metals combined at the nanoscale, forming alloys, core–shell, or hetero structured systems. Compared to single-metal nanoparticles, BMNPs exhibit: Enhanced catalytic efficiency, Improved thermal and chemical stability, Tunable electronic and optical properties, Synergistic effects between constituent metals⁶. *Adiantum Capillus-Veneria*, also known as "Hansraj" in India, is apteridophyte that grows extensively in temperate and tropical climates. It is sometimes referred to as the Evergreen or Himalayan maidenhair fern⁷. Pteridophytes are an essential part of many plant communities, particularly those found in temperate and tropical locations, and they greatly contribute to the diversity of plants on Earth. Traditional remedies have used them to cure headaches, fever, and colds⁸.

The about 200 species of ferns in the genus *Adiantum* are categorized by some sources under the Adiantaceae family, while others place them under the Pteridaceae family. They can be found everywhere on Earth, from hot tropical regions to frigid temperate zones⁹. Among its several secondary metabolites, *Adiantum Capillus-Veneria* has shown antibacterial, anti-inflammatory, analgesic, hypoglycemic, antioxidant, antiproliferative, neuroprotective, and anticholesterolemic properties¹⁰⁻¹¹. *Adiantum Capillus: Veneria* is native to China and the Himalayas. Due to the coriander-like serration on top of its leaves, Shaar-el-Dioscorides, who flourished in the early 100s A.C., coined the epithet "Adiavrvro" to refer to *Adiantum Capillus-Veneris*. Theophrastus describes how hair oils were made using "Black" and "White" *Adiantum*. This fern is commonly referred as by Arabs as coriander of the well or Kuzburatel birthday. *Adiantum Capillus-Veneris* has been used medicinally for a very long time¹². Asthma, edema, hepatitis, snakebite, spiderbite, spleen, urinary insufficiency, and increased perspiration are all treated with it in Egypt. Additionally, it is useful for a variety of chronic cancer types. Alcoholism, bronchitis, bronchial difficulties, cough, dandruff, detoxification, diabetes, excessive mucus, the flu, and menstrual problems are all treated with it in Europe. In Iraq, it is used to treat respiratory difficulties, decreasing secretions, urinary insufficiency and raising perspiration, While Mexico, it is used to birth control, bladder problem, blood cleansing, constipation, kidney stones, liver function, respiratory distress¹³. In India, it is used to treat boils, bronchitis, cold, diabetes, eczema, fever, skin ailments¹⁴.

Due to its rich phytochemical makeup, which includes polyphenols, antioxidants, and flavonoids, *Adiantum capillus-veneris*, often known as maidenhair fern, has been extensively investigated among therapeutic plants¹⁵⁻¹⁷. It is very effective for the creation and stability of nanoparticles because of these chemicals. Its capacity to create a variety of nanomaterials, including Cu–ZnO nanocomposites and selenium nanoparticles with important biological activity, has been shown in recent research¹⁹. Because of their synergistic benefits, which include increased catalytic efficiency, greater antibacterial activity, and improved thermal stability, bimetallic nanoparticles like Cu–Zn are particularly interesting²⁰. When copper is combined with zinc or nickel, their electronic structure is altered and their redox characteristics are improved, which makes them appropriate for use in biomedicine, environmental remediation, and catalysis. Therefore, the green synthesis of Cu–Zn nanoparticles using *Adiantum capillus-veneris* provides an economical, environmentally benign, and scalable method for creating sophisticated nanomaterials with a variety of uses²¹.

Chemical study revealed that *Adiantum Capillus-veneris* contains triterpenoids, flavonoids, aoleananes, polysaccharides, phenylpropanoids, carotenoids, and alicyclics. Triterpenoid epoxide (adiantoxide), 21-hydroxy adiantone, fern-9(11)-en-12-one, isoadiantone, hydroxyhopane, isoglaucanone, isoadiantol, hydroxyadiantone, olean-12-en-3-one, olean-18-en-3-one, fern-9(11)-ene, ferna-7, 9(11)-diene, neohop-12-ene, hop-22(29)-ene, filic-3-ene, and *Adiantum capillus-veneris* leaves. Numerous flavonoids, including populnin, rutin, quercetin-3-Oglucoside, quercetin, quercitrone, nicotiflorin, isoquercitrin, astragalin, procyanidin, populnin, kaempferol-3-sulfate, and prodelfphinidin, have been shown to be present in the leaves of *Adiantum Capillus veneris*²⁰⁻²¹. The percentages of water extractable matter (24.00%), ethanol extractable matter (11.44%), and moisture in leaves were as follows. A soxhlet extraction of *Adiantum capillus-veneris* revealed the phenolics and terpenoids contained (2.73%), alkaloids (0.53%), waxes and lipids (0.20%), fiber (67.23%) and quaternary, and oxides (26.33%). Ten trace elements—magnesium, calcium, potassium, manganese, iron, cobalt, sodium, nickel, copper, and zinc—were examined in leaf extracts. The amounts of Ca and K were significant, as noted by Akabori and Hasagava (1969). Studying the hydrolytic products of the saponin to obtain a triterpenoid hydroxy hopanoneaglycon and the components of sugar, xylose, galactose, and rhamnose, is necessary because one of the components of the *Adiantum capillus-veneris* plant is a saponin glycoside. Nonetheless, protein, steroids, and alicyclic acids are present in *Adiantum capillus-veneris*²². The plant's medicinal properties are attributed to a range of bioactive phytochemicals, including alkaloids, flavonoids, lignins, tannins, and phenolic compounds. By serving as both stabilizing and reducing agents, these phytoconstituents are also essential to the environmentally friendly synthesis of nanoparticles. These characteristics make *Adiantum Capillus-Veneris* extract ideal for the creation of metal nanoparticles like Cu–Zn nanoparticles²³.

II. EXPERIMENTAL METHODS

Collection of Plant: Fresh a Plants of *Adiantum C.V* (Maiden hair fern), were collected from Bilanpura Garden, Achalpur City [Lat 21.2573717⁰, Long 77.5101653⁰ Achalpur City 44806, Dist. Amravati, Maharashtra State].

Preparation of the Adiantum C.V leaf extract:

The plant leaves were properly cleaned three times using double-distilled water. The leaves were cleaned and then shade-dried. Using a grinder, the dried plant material was subsequently reduced to a fine powder.

After that, 5 grams of plant powder were combined with 100 milliliters of distilled water and brought to a boil at 70 degrees Celsius for 20 minutes. After allowing the solution to cool, Whatmann No. 1 filter paper was used to filter it. For later usage, keep the extract at 4 °C.



Fig. Adiantum Capillus -Veneria Plant Extract (Maidenhair fern)

Preparation of Cu-Zn solutions:

Make aqueous solutions of metal precursors, such as a 0.1 M solution of zinc nitrate and a 0.1 M solution of copper sulfate. Combine the two metal salt solutions in the appropriate ratio (for example, a 1:1 ratio of copper sulfate to zinc nitrate), then boil them over a heated magnetic plate at 80°C for ten minutes while stirring constantly.

Preparation of Cu-Zn Bimetallic NPs using Adiantum Capillus -Veneria plant Extract:

Fill the burette with 60 ml of Cu-Zn solution and put it drop by drop into a conical flask after 30 ml of filtered plant extracts of *Adiantum Capillus-Veneria* were kept on a magnetic stirrer at 40 °C for an hour. After an hour, the plant extract's green hue changes to a dark brown hue, signifying the beginning of nanoparticle formation.

To guaranty full reduction of zinc and copper ions into Zn-Cu nanoparticles, the reaction mixtures were left to run for two to three hours. The mixture was centrifuged at 8000–1000 rpm for 10–15 minutes after the reaction was finished in order to separate the produced nanoparticle. To get rid of contaminants and interacting elements, the precipitate was repeatedly cleaned with distilled water and then ethanol. The purified Zn-Cu nanoparticles were then stored in an airtight container for additional characterization and analysis after being dried at 80°C in a hot air oven.

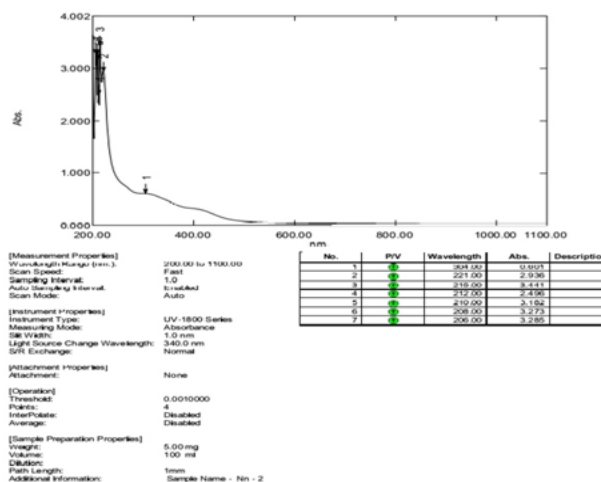
III. RESULT AND DISCUSSION

U.V Spectra of Bimetallic Cu-Zn Nanoparticle:

U.V Spectroscopy of Cu- Zn Nanoparticles The UV-Visible spectrum of the biosynthesized Cu- Zn nanoparticles using *Adiantum capillus-veneris* extract exhibits distinct absorption features confirming nanoparticle formation and optical activity.

The spectrum shows a strong and sharp absorption peak in the UV region around ~210–220 nm, with the maximum absorbance reaching above 3.0, indicating intense electronic transitions. This peak can be attributed to surface plasmon resonance (SPR) and interbond transitions associated with Cu- Zn bimetallic nanoparticles. A secondary, broader and less intense band appears near ~330–350 nm, suggesting the presence of particle size distribution and possible aggregation effects. The gradual decrease in absorbance toward the visible region (400–800 nm) indicates minimal light absorption, confirming that the synthesized nanoparticles are predominantly active in the UV region. The high absorbance intensity and sharp peak profile suggest the formation of small-sized, well-dispersed nanoparticles, stabilized by phytochemicals such as flavonoids, phenolics, and terpenoids present in *Adiantum capillus-veneris*, which act as both reducing and capping agents. Overall, the spectral pattern confirms successful green synthesis of Cu- Zn nanoparticles with stable optical properties and potential applications in catalysis, biomedical, and environmental fields

Data Set: Sample Name - Nn - 2 - RawData

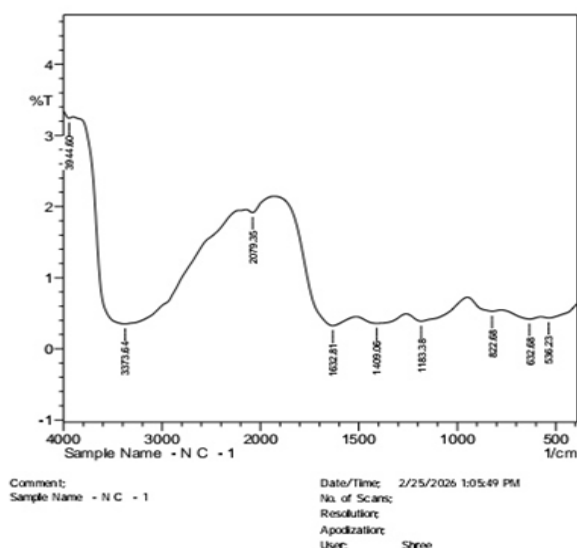


FT IR spectra of Bimetallic Cu-Zn Nanoparticles:

The FTIR spectrum of Cu–Zn nanoparticles synthesized using *Adiantum capillus-veneris* plant extract shows several characteristic absorption peaks that indicate the involvement of various functional groups in the reduction and stabilization process. A broad and intense peak observed around ~3200–3400 cm⁻¹ can be attributed to O–H stretching vibrations of hydroxyl groups present in phenolic compounds and flavonoids, suggesting their role in nanoparticle formation. The peak near ~2900 cm⁻¹ corresponds to C–H stretching vibrations of aliphatic compounds.

A distinct absorption band around $\sim 1600\text{--}1650\text{ cm}^{-1}$ is assigned to C=O stretching or amide I vibrations, indicating the presence of proteins or polyphenolic compounds acting as capping agents. The peak observed near $\sim 1400\text{--}1450\text{ cm}^{-1}$ may be due to C–H bending or O–H deformation, further confirming the presence of organic biomolecules from the plant extract. Additionally, peaks in the region $\sim 1000\text{--}1100\text{ cm}^{-1}$ are associated with C–O stretching vibrations of alcohols, ethers, or esters.

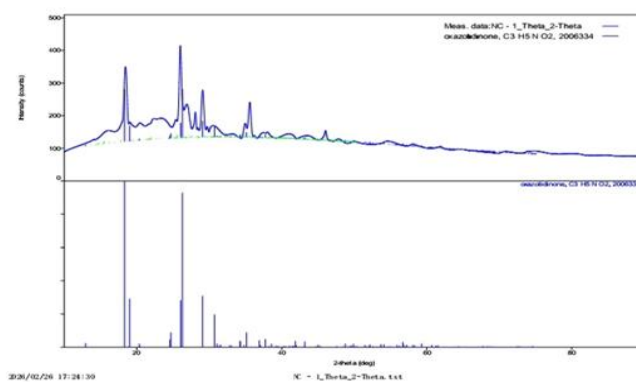
Importantly, the low-frequency peaks observed below $\sim 700\text{ cm}^{-1}$ are characteristic of metal–oxygen (Cu–O and Zn–O) vibrations, confirming the formation of Cu–Zn nanoparticles. These findings indicate that the phytochemicals present in *Adiantum capillus-veneris* not only facilitate the reduction of metal ions but also stabilize the nanoparticles by binding to their surface. Overall, the FTIR spectrum confirms the successful green synthesis and capping of Cu–Zn nanoparticles by plant-derived biomolecules.



XRD Spectra of Bimetallic Cu-Zn Nanoparticles:

The X-ray diffraction (XRD) pattern of Cu–Zn nanoparticles synthesized using *Adiantum capillus-veneris* extract reveals the formation of a well-defined crystalline structure. The diffraction peaks observed at 2θ values of approximately 15.9° , 20.2° , 23.4° , 26.0° , 28.0° , 29.1° , 30.5° , 35.6° , 41.0° , 43.0° , 48.0° , 54.7° , 58.2° , and 61.7° indicate the presence of multiple crystallographic planes, confirming the polycrystalline nature of the nanoparticles. The prominent peaks in the range of $30^\circ\text{--}45^\circ$ are attributed to copper oxide (CuO/Cu₂O) phases, while peaks around $31^\circ\text{--}36^\circ$ and $56^\circ\text{--}63^\circ$ correspond to zinc oxide (ZnO) with a hexagonal wurtzite structure.

The coexistence of these peaks suggests the successful formation of Cu–Zn mixed oxide nanocomposites. Additionally, the broadening of diffraction peaks, as indicated by the full width at half maximum (FWHM) values, confirms the nanoscale size of the crystallites. The crystallite size 12.5 nm , estimated using the Scherrer equation, falls within the nanometer range, indicating the formation of fine nanoparticles. The variation in peak intensities reflects differences in crystallographic orientation and phase composition, with higher intensity peaks indicating good crystallinity. Overall, the XRD results confirm that *Adiantum capillus-veneris* extract effectively facilitates the green synthesis of crystalline Cu–Zn nanoparticles, acting as both a reducing and stabilizing agent.



IV. CONCLUSION

The present study demonstrates a simple, rapid, economical, and environmentally friendly approach for the green synthesis of Cu–Zn nanomaterials using *Adiantum capillus-veneris* leaf extract. The phytochemicals present in the plant extract effectively facilitated the reduction and stabilization of the metal ions under mild reaction conditions, as indicated by the characteristic colour change during nanoparticle formation. The successful formation of the synthesized nanomaterials was supported by UV–Visible, FTIR, and XRD analyses. The UV–Visible spectrum showed a strong absorption band in the UV region, while FTIR analysis indicated the involvement of hydroxyl, carbonyl/amide, and C–O containing biomolecules in the reduction and stabilization process. XRD analysis confirmed the crystalline nature of the synthesized material and indicated the presence of copper oxide and zinc oxide phases, with an estimated crystallite size of approximately 12.5 nm . Overall, the findings establish *Adiantum capillus-veneris* as a promising biological resource for the sustainable synthesis of Cu–Zn nanomaterials.

The developed method avoids the use of harsh chemical reducing agents and provides a comparatively simple and eco-friendly route for nanoparticle preparation. The synthesized materials could be explored further for potential applications in catalysis, biomedical research, and environmental remediation. Future studies involving detailed morphological, elemental, and biological investigations would help to further establish their structure–property relationships and practical applications.

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