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Plant-Mediated Green Synthesis and Evaluation of Copper Oxide Nanoparticles Utilizing Hemidesmus indicus Extract

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ABSTRACT

The green synthesis of nanoparticles has attracted significant interest in the modern world because of the increasing need for safe, sustainable, econimical and eco-friendly methods to produce a diverse range of materials, including metal and metal oxide nanoparticles, as well as hybrid and bioinspired materials. In this study, we conducted a green synthesis of copper oxide nanoparticles utilizing *Hemidesmus indicus* extract as both a stabilizing and reducing agent. The synthesized nanoparticles that were produced were analyzed using Ultraviolet-Visible spectroscopy, Fourier Transform Infrared spectroscopy, X-Ray Diffraction spectroscopy, and Field Emission Scanning Electron Microscope methods. The UV-Vis spectra indicated a peak absorption at 274 nm associated with the copper oxide nanoparticles. The FT-IR spectra show a faint peak at 523 cm^{-1}, which is associated with the vibration of CuO, thereby confirming the formation of CuO nanoparticles. XRD verified the crystalline structure of the nanoparticles. The SEM survey indicates that the nanoparticles obtained have an irregular shape.

Keywords: *Green synthesis, Copper oxide nanoparticles, Characterization, Hemidesmus indicus.*

1. INTRODUCTION

Nanotechnology is emerging as a crucial field with significant potential for various applications, due to the unique properties of nanoparticles. These nanoscale materials possess improved optical, magnetic, catalytic, and electrical properties when compared to their larger counterparts [1]. Consequently, there is an increased focus on developing sustainable and efficient techniques for synthesizing NPs. Conventional techniques for producing nanoparticles typically require hazardous substances, elevated temperatures, and energy-consuming procedures, raising environmental issues and possible harmful effects [2]. To tackle these challenges, green synthesis has emerged as a highly regarded alternative. Also referred to as environmentally friendly or sustainable synthesis, green synthesis utilizes natural resources, biomolecules, or eco-friendly materials to synthesis nanoparticles [3]. It provides numerous benefits compared to traditional methods, such as lower energy usage, limited reliance on harmful chemicals, biodegradability, and the possibility of mass production. It provides numerous benefits compared to traditional methods, such as lower energy usage, limited reliance on harmful chemicals, biodegradability, and the possibility of mass production [4].

Metal oxide NPs have attracted attention due to their usefulness in diverse areas such as catalysis, electronics, medicine, and environmental science. This interest stems from their remarkable reactivity, optical characteristics, pore size, high surface-to-volume ratio, elevated surface reactivity, and compatibility with biological systems [5]. There are several techniques for synthesizing nanoparticles, primarily utilizing chemical processes such as the precipitation method, microwave synthesis, electrochemical methods, spray pyrolysis and etc [6]. However, all these chemical synthesis methods come with several drawbacks, such as high energy consumption, the need for expensive and hazardous chemicals, and the generation of toxic by-products, which ultimately lead to environmental pollution. As a result of this challenge, numerous researchers have been motivated to create green chemistry and bioprocesses [7]. Consequently, the green fabrication of nanoparticles has recently attracted interest due to its environmentally friendly nature and biocompatibility, making it suitable for various applications. The use of plant extracts for the synthesis of nanoparticles is a developing field of study that significantly contributes to nanomaterials. This approach is economical, eco-friendly, and may offer benefits compared to traditional chemical and physical methods. Additionally, it reduces the time needed for the synthesis process and enhances the potential for large-scale production [8].

Copper nanoparticles are particularly notable due to their affordability and high production efficiency, which makes them suitable for use in environmental and biomedical fields. Researchers are highly interested in copper oxide nanomaterials due to their unique properties, which make them useful for a range of applications including pigmentation, supercapacitors, optics, cancer treatment, and more [9]. Conventional techniques for producing metal oxide nanoparticles, like CuO nanoparticles, typically use hazardous chemicals and extreme physical conditions, resulting in toxic byproducts and environmental contamination. To tackle these issues, scientists have explored plant-mediated synthesis as an environmentally friendly and sustainable method for producing CuO nanoparticles [10]. Phytochemicals derived from Hemidesmus indicus plants have shown the presence of several compounds, including tannins, cardiac glycosides, alkaloids, polyphenols, and flavonoids. The secondary metabolites found in *Hemidesmus indicus* act as both capping and reducing agents, aiding in the stabilization of NPs. When metal salts are combined with *Hemidesmus indicus* extract, the metal salts are converted into metal oxide nanoparticles [11].

This report focuses on the environmentally friendly synthesis of copper oxide nanoparticles (CuO NPs) using the *Hemidesmus indicus* plant. It presents the novel approach of utilizing *Hemidesmus indicus* extract for the production of copper oxide nanoparticles. The extract serves as both a stabilizing and reducing agent. The resulting nanoparticles were characterized through various techniques, including UV-Vis spectroscopy, Fourier transform infrared (FT-IR) spectroscopy, X-ray diffraction (XRD), and field emission scanning electron microscopy (FE-SEM).

2. MATERIALS AND METHODS

Materials

All chemicals used were of analytical grade and were utilized as received. Copper sulphate pentahydrate ($CuSO_4.5H_2O$) and sodium hydroxide (NaOH) were obtained from SRL Chemicals.

Preparation of leaf extract

The *Hemidesmus indicus* was carefully rinsed with distilled water to eliminate any contaminants and dust, and then allowed to dry in the shade. To prepare an aqueous extract of the plant, approximately 10 grams of the dried leaves were placed in a 250 mL beaker. After adding 100 mL of double distilled water, the mixture was heated to 70 ℃ for approximately 30 minutes. Once it cooled, it was filtered using Whatman filter paper no.1, and the resulting filtrate was utilized as the plant extract for the next step in synthesizing the nanoparticles.

CuO nanoparticles synthesis

To produce CuO nanoparticles, 0.1 M of copper sulphate pentahydrate was dissolved in 100 mL of distilled water and stirred for 20 minutes. After that, 20 mL of *Hemidesmus indicus* plant extract was added, and the mixture was stirred and heated to 70°C for 4 hours. The pH of the reaction mixture was kept at 8 using a NaOH solution. The solution color changed from green to dark brown. The final reaction mixture was centrifuged at 8000 rpm for 15 minutes. The precipitate was rinsed with distilled water and ethanol, and then dried in an oven at approximately 80 ℃ for 5 hours. The dried nanoparticles were stored in airtight containers.

Characterization

The absorption spectra of the green-synthesized CuO NPs were measured using a JAZ Ocean Optics spectroscopy from the USA. Furthermore, FT-IR spectroscopy was utilized for analysis with a Perkin Elmer Spectrum 2 instrument from the United States. The crystal structure of the synthesized nanoparticles was examined with a Rigaku Smart Lab X-ray diffractometer from Japan. The structure and makeup of the green-synthesized nanoparticles were examined using a High-Resolution Scanning Electron Microscope, ZEISS SIGMA 300, from Germany.

3. RESULT AND DISCUSSION

XRD analysis

Figure 1. shows the XRD spectra collected for two theta angles between 10 and 80 degrees. XRD was used to analyze the crystalline structures and phases of the nanoparticles. The Scherrer formula was used to determine the particle size. Figure 2 displays the XRD pattern of CuO nanoparticles synthesized using *Hemidesmus indicus* extract. It displays four intensity peaks within the 2q range, corresponding to angles of 29.31°, 36.61°, 42.54°, and 60.69°. As per JCPDS card number 00-005-0667, the observed peaks correspond to the (110), (111), (200), and (220) crystallographic planes [12]. The existence of these broad peaks indicates that the granules show some degree of crystallinity. The broadening of the XRD peaks suggests that the particles are small and that there is a varied distribution of their sizes [13].

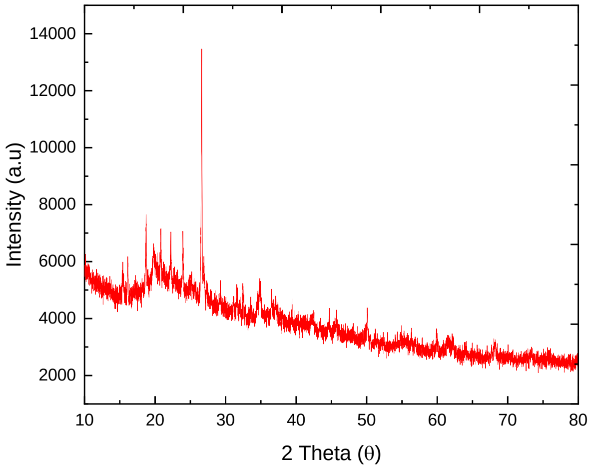

Figure 1. XRD diffraction pattern for CuO NPs.

FT-IR analysis

Figure 2 shows the FT-IR spectra of copper oxide and nickel oxide nanoparticles obtained from the extract of *Hemidesmus indicus*. The produced nanoparticles exhibited absorption bands ranging from 4000 to 400 cm^{-1}. The complex spectral lines show peaks at 3258, 1622, 1023, and 523 cm^{-1}. The wide absorption band at 3258 cm^{-1} is associated with -OH stretching vibrations. The peaks observed at 1622 cm^{-1} are associated with the stretching vibrations of the C=O carbonyl group. A peak at 1023 cm^{-1} indicates C-O stretching [14]. Additionally, the peak at 523 cm^{-1} confirms the existence of CuO nanoparticles [15].

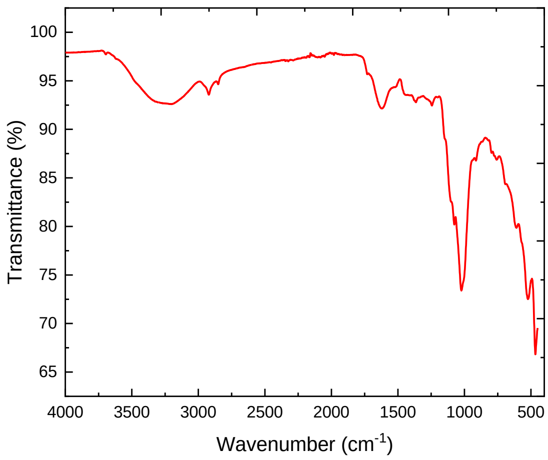

Figure 2. FT-IR spectroscopy for CuO NPs

UV-VIS analysis

Figure 3 illustrates the spectral absorption analysis of CuO nanoparticles. The optical band gap of the CuO nanoparticles was examined using UV-Visible spectroscopy. A unique peak was observed at 274 nm, which could be attributed to surface plasmon resonance (SPR), and this finding was disclosed. The surface plasmon resonance (SPR) at 274 nm suggests the formation of copper oxide nanoparticles. This SPR is caused by the oscillation of surface electrons within the nanoparticles [16]. According to Mie's theory, the number of surface plasmon resonance bands is primarily influenced by the shape of the nanoparticles that are formed. The energy of the band gap can be determined using the following equations (1) [17].

$Eg = h\nu g = hc/\lambda g$ (1)

In this context, E stands for the energy gap of the material, h refers to Planck's constant, c indicates the speed of light, and λ represents the wavelength. The synthesized CuO nanoparticles exhibit their most intense and well-defined absorption peak at 274 nm. The band gap energy determined from the UV-visible absorption spectrum is 4.52 eV.

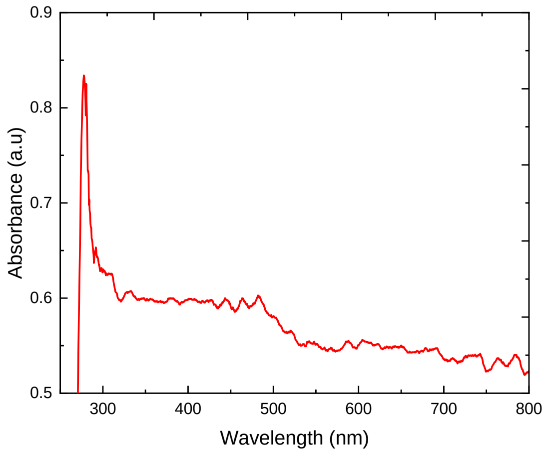

Figure 3. Uv-visible spectroscopy for CuO NPs.

FE-SEM analysis

FE-SEM was performed to examine the surface structure of the synthesized nanoparticles FE-SEM was used to examine the dimensions and morphology of the CdS nanoparticles synthesized from *Hemidesmus indicus* extract. Figures 4(a), (b), and (c) display FE-SEM images of CuO nanoparticles (NPs) captured at various magnifications. The FE-SEM images reveal that the CuO nanoparticles exhibit well-defined, irregular shapes. It is evident that as the particle sizes increase, they tend to cluster together and display a rounded, agglomerated look [18]. The irregular shape of the particles indicates that the CuO nanoparticles may not have developed and been encapsulated consistently throughout the synthesis process. This clustering could be a result of the secondary metabolites found in the *Hemidesmus indicus* extract.

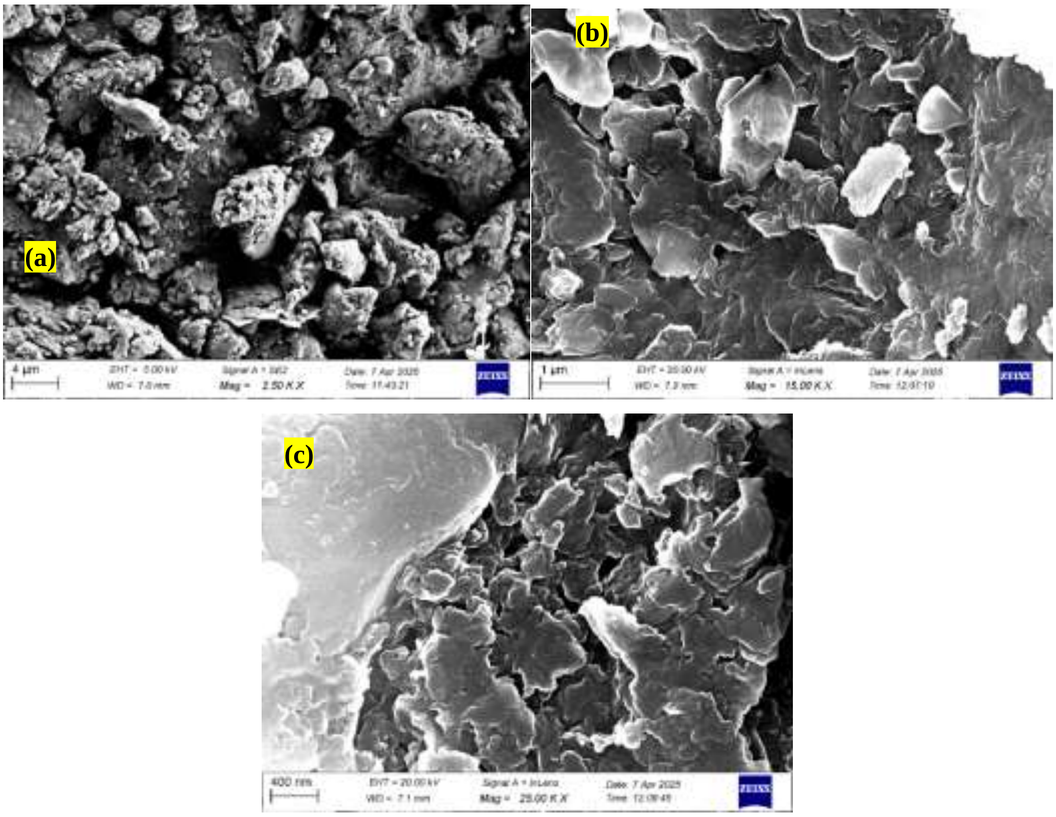

Figure 4. FE-SEM images for CuO NPs.

4. CONCLUSION

In this study, we have produced CuO nanoparticles using an extract from *Hemidesmus indicus*. The phytoconstituents found in *Hemidesmus indicus* demonstrated the ability to reduce and stabilize during the synthesis of CuO nanoparticles. The bio-synthesized CuO nanoparticles were characterized using UV-Vis, FTIR, XRD, and FE-SEM techniques. The findings indicated that the nanoparticles have a crystalline structure and an irregular shape. The FTIR analysis revealed the presence of phytoconstituents in the biosynthesized CuO nanoparticles. The synthesis method employed is environmentally friendly and practical due to its simplicity, effectiveness, affordability, and sustainability when compared to alternative approaches. As a result, it is believed that creating nanoparticles using a cost-effective and eco-friendly green approach could lead to valuable applications in combining nanoparticles with bacterial systems. This integration can greatly improve bioremediation by accelerating the breakdown of pollutants, boosting microbial resilience in harmful environments, and facilitating more precise and effective strategies for environmental cleanup.

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