

Eco-friendly Synthesis of CuO Nanoparticles Using Ascorbic Acid and Evaluation of Their Antioxidant and Photocatalytic Activities

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INTRODUCTION & AIM

Nanotechnology has advanced rapidly in recent years, revolutionizing various scientific fields, industries, and research areas through the development and application of metal and metal oxide nanoparticles. Among these nanomaterials, copper oxide nanoparticles (CuO NPs) have gained significant attention due to their p-type semiconducting properties, narrow band gap, and high surface area [1]. These characteristics provide CuO NPs with excellent thermal stability, chemical resistance, and catalytic performance [2]. As a result, they are widely applied in photocatalysis, environmental remediation, sensing, and biomedical fields, due to their strong antimicrobial, antioxidant, and multifunctional activities [3]. The use of green synthesis methods, such as employing biological extracts or benign chemicals like ascorbic acid, provides an environmentally friendly alternative to conventional physical and chemical approaches for nanoparticle synthesis, which often involve toxic reagents and harsh conditions [4]. The proliferation of diverse pollutants, especially organic dyes from industrial sources, into ecosystems poses severe environmental and health risks, necessitating effective remediation strategies [5]. In this context, photocatalysis using metal oxide nanoparticles, such as CuO NPs, has emerged as a promising approach for the efficient degradation of organic dyes in wastewater. This study, therefore, focuses on the eco-friendly synthesis of CuO nanoparticles using ascorbic acid, a natural reducing agent. Furthermore, the antioxidant capacity of the synthesized CuO NPs was evaluated based on their ability to scavenge the stable DPPH free radical. Moreover, photocatalytic efficacy was assessed in degrading methylene blue dye under various experimental conditions.

METHOD

Synthesis of Copper Oxide Nanoparticles

Copper (II) acetate monohydrate (1 g) was dissolved in 50 mL of distilled water under magnetic stirring, followed by the dropwise addition of ascorbic acid. The mixture, which changed color from sky blue to dark brown, was heated at 60 °C for 1 h and then cooled to room temperature. The product was collected by centrifugation, washed with distilled water, and dried for 24h. Finally, calcination at 400 °C for 4 h yielded well-crystallized and thermally stable copper oxide nanoparticles.

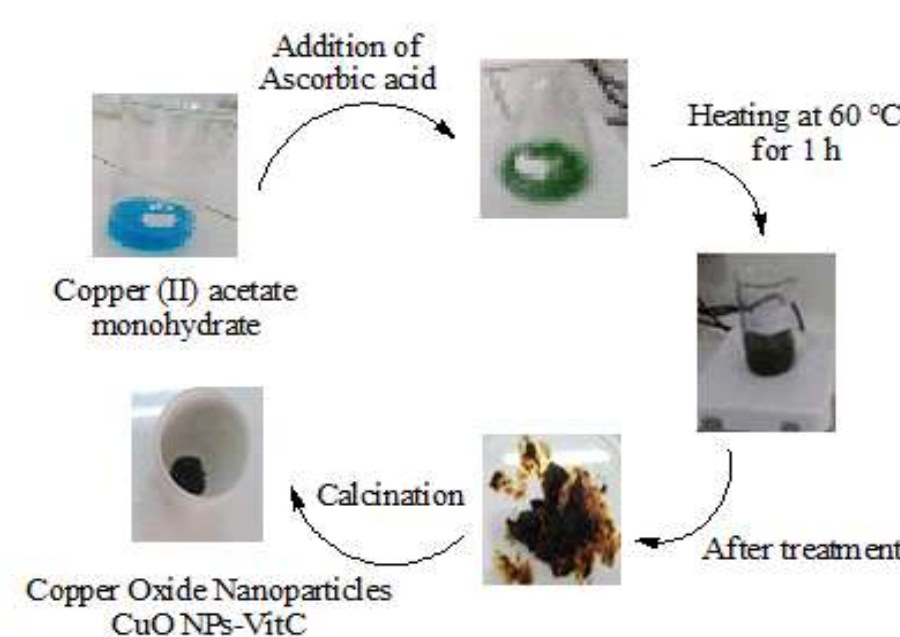


Figure 1. Synthesis protocol of copper oxide nanoparticles (CuO NPs)

Characterization Techniques

The crystalline structure of the biosynthesized nanoparticles was examined by X-ray powder diffraction (XRD). The surface functional groups were characterized by Fourier Transform Infrared Spectroscopy (FTIR). The optical behavior of the nanoparticles was investigated using UV–Visible spectroscopy.

Determination of Antioxidant activity

The antioxidant potential of the biosynthesized nanoparticles (CuO NPs) was evaluated using the DPPH free radical scavenging assay. Methanolic solutions of the samples at various concentrations (0.0078–0.5 mg/mL) were reacted with the DPPH reagent and incubated for 30 minutes at room temperature in the dark. The change in absorbance was measured at 517 nm. Ascorbic acid was used as the standard, and the percentage of inhibition (IP %) was calculated using the following equation:

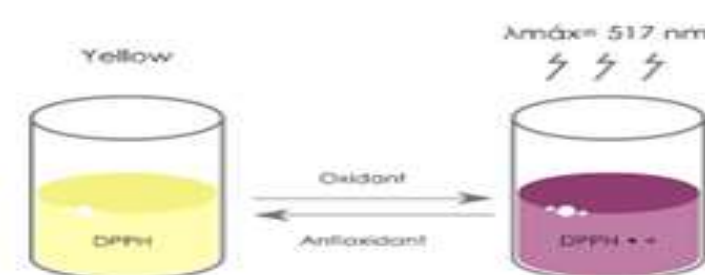


Figure 2. Color change of DPPH during the antioxidant reaction

$$\% \text{ IP} = ((A_{\text{control}} - A_{\text{sample}}) / A_{\text{control}}) \times 100$$

Where A_{control} is the absorbance of the blank control and A_{sample} is the absorbance of the test sample.

IC_{50} values were obtained from linear regression analysis of the inhibition curves.

Photocatalytic activity

The photocatalytic performance of the copper oxide nanoparticles was assessed using methylene blue (0.5 mg/100 mL) as a model pollutant. A 20 mg portion of CuO nanoparticles was dispersed in the dye solution and stirred in the dark for 30 minutes to establish adsorption–desorption equilibrium. The suspension was subsequently exposed to sunlight under continuous stirring for 2.5 hours, and the absorbance at 665 nm was recorded at regular intervals to evaluate the photocatalytic degradation efficiency.

The percentage of methylene blue (MB) degradation was calculated using the following equation:

$$\text{Degradation (\%)} = ((A_0 - A_t) / A_0) \times 100$$

Where: A_0 is the initial absorbance of the MB solution before illumination, and A_t is the absorbance at time t during irradiation.

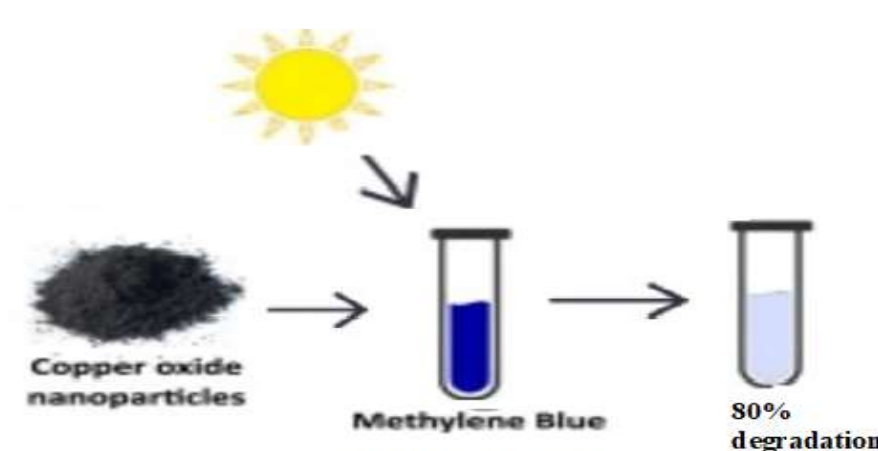


Figure 3. Photodegradation of Methylene Blue under Light in the Presence of Copper Oxide Nanoparticles.

RESULTS & DISCUSSION

The formation of CuO NPs has been confirmed by using powder X-Ray diffraction (XRD), UV-Vis spectroscopy and Fourier Transform Infrared (FTIR) spectroscopy.

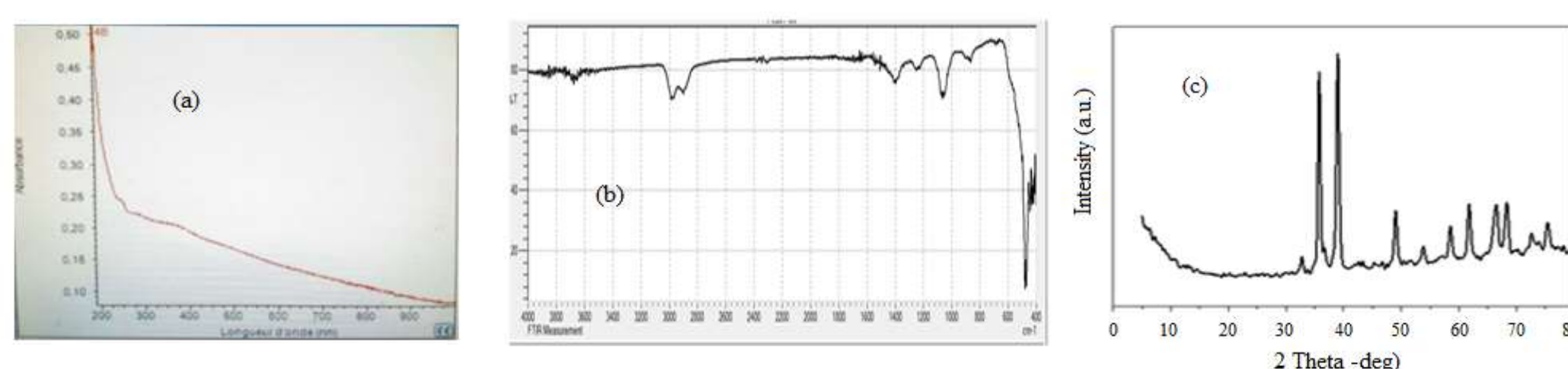


Figure 4. UV-Visible spectrum (a), FTIR spectrum (b) and XRD patterns (c) of CuO NPs

The UV spectrum showed a distinct absorption band at 274 nm, characteristic of copper oxide, indicating the formation of CuO nanoparticles. The FTIR spectrum further confirmed this with characteristic bands at $\sim 3000 \text{ cm}^{-1}$ (alcoholic and phenolic groups), $\sim 1400 \text{ cm}^{-1}$ (aromatic C=C stretching), and $530\text{--}550 \text{ cm}^{-1}$ (Cu–O vibrations), validating the successful synthesis of CuO nanoparticles.

Finally, X-ray diffraction (XRD) analysis revealed characteristic peaks at $2\theta \approx 32.5^\circ, 35.5^\circ, 38.7^\circ, 48.7^\circ, 53.5^\circ, 58.3^\circ, 61.5^\circ,$ and 66.2° , corresponding to the crystallographic planes (110), (002), (111), (202), (020), (202), and (113) of CuO. These observations confirm a well-defined and homogeneous crystalline structure, thereby establishing the presence of CuO nanoparticles.

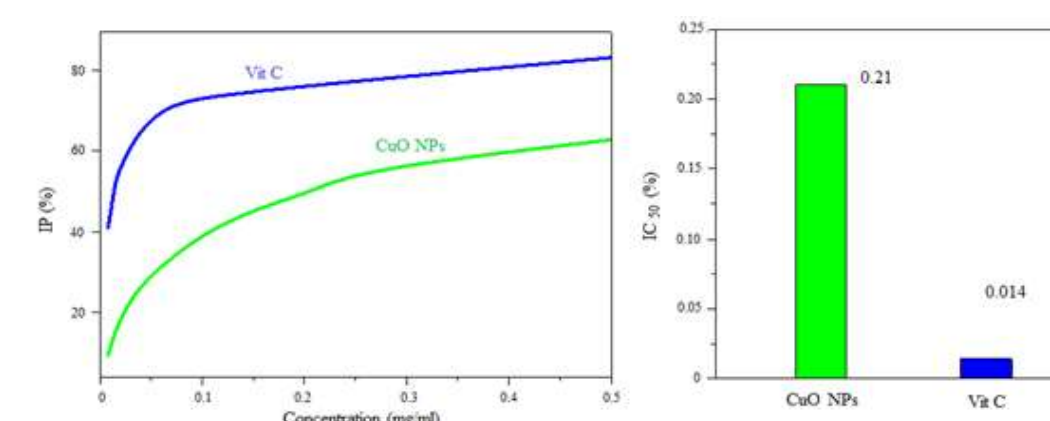


Figure 5. DPPH radical scavenging activity of CuO NPs and standard ascorbic acid (IP% and IC_{50})

The antioxidant activity of the synthesized CuO nanoparticles was evaluated using the DPPH free radical scavenging assay. The CuO NPs showed a significant antioxidant effect with an IC_{50} value of 0.21 mg/mL, compared to 0.014 mg/mL for pure ascorbic acid. Although the activity is lower than that of the standard, the results clearly demonstrate that CuO nanoparticles possess a remarkable ability to scavenge free radicals, confirming their potential as antioxidant agents.

Table 1. Results of the photocatalytic degradation of Methylene Blue using synthesized CuO nanoparticles

Time (min),	0	5	15	30	60	90	120	150
Methylene Blue degradation (%)	19.6	31.2	43.8	56.6	64.5	74.7	79.8	81.3

The photocatalytic activity of CuO nanoparticles synthesized using ascorbic acid was evaluated through the degradation of methylene blue (MB) under solar irradiation. Approximately 80% of MB was degraded within 120 minutes, indicating efficient photocatalytic performance. This activity can be attributed to the small crystallite size and high surface area of CuO NPs, which enhance light absorption and provide numerous active sites for the generation of reactive oxygen species. In addition, ascorbic acid may improve the purity and surface stability of the nanoparticles, facilitating electron–hole separation and enhancing photocatalytic efficiency.

CONCLUSION

Copper oxide nanoparticles were successfully synthesized using ascorbic acid as a green reducing agent. The obtained nanoparticles exhibited remarkable antioxidant activity with an IC_{50} value of 0.21 mg/mL, demonstrating effective free radical scavenging ability. They also showed strong photocatalytic performance, achieving about 80% degradation of methylene blue within 120 minutes under solar light. These results confirm the efficiency of ascorbic acid-assisted CuO NPs and their potential for eco-friendly environmental applications.

FUTURE WORK / REFERENCES

Our further investigations will focus on optimizing the synthesis parameters to control the morphology, particle size, and surface properties of CuO nanoparticles, which strongly influence their photocatalytic and antioxidant performances. Additionally, the photocatalytic studies will be extended to other organic pollutants.

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