



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 2, February 2026

Phytochemical-Mediated Fabrication of CuO Nanostructures Using Aloe barbadensis Miller Extract via Co-precipitation Route

Jyoti Mayekar¹, Soham Sawant², S. N. Sowjanya Reddy³, Arif Iqbal⁴, Sachin Yadav⁵, S. Radha⁶

Department of Physics, Jai Hind College, Mumbai, India^{1,2,5}

Shah and Anchor Kutchhi Engineering College, Mumbai, India³

Department of Physics, University of Mumbai, Mumbai, India^{3,4,6}

AIKTC School of Engineering & Technology, Mumbai, India⁴

ABSTRACT: The green synthesis of metal oxide nanoparticles has emerged as a sustainable alternative to conventional chemical routes due to its simplicity, eco-friendliness, and reduced use of toxic reagents. In the present study, copper oxide (CuO) nanoparticles were synthesized using Aloe barbadensis miller commonly known as aloe vera leaf extract as a natural reducing and stabilizing agent through a wet chemical co-precipitation method. The phytochemicals present in the extract, including polyphenols and flavonoids, facilitated the reduction of copper ions and controlled nucleation, yielding stable nanoparticles under mild synthesis conditions. The obtained precipitate was filtered, washed, and calcined to form phase-pure CuO nanoparticles. Structural characterization was performed using X-ray diffraction (XRD), and the diffraction pattern confirmed the formation of monoclinic CuO nanoparticles. The average crystallite size was estimated using the Debye–Scherrer equation, revealing nanoscale dimensions indicative of effective bio-mediated synthesis. The sharp diffraction peaks suggested good crystallinity, while the absence of impurity phases affirmed the purity of the synthesized product. The study highlights the role of Aloe vera bio-components in modulating nanoparticle formation, offering an efficient and reproducible green synthesis approach. This method demonstrates potential for scalable production of CuO nanoparticles for applications in catalysis, antimicrobial coatings, sensors, and environmental remediation. Overall, the work reinforces the viability of plant-mediated nanoparticle synthesis as a sustainable strategy in nanotechnology.

KEYWORDS: Copper oxide nanoparticles, Green synthesis, Aloe vera extract, Co-precipitation.

I. INTRODUCTION

Metal oxide nanoparticles (MONPs) are gaining rapid demand in the field of nanotechnology because of its tunable physicochemical properties and its application in wide range of fields such as bioimaging, biosensing, pharmaceuticals, cosmetics, electronics, photonics, pigments, etc [1]. When compared to the bulk counterpart, they exhibit properties such as quantum confinement effects, altered surface energies, interface effects, and increased surface-to-volume ratios on nanoscale [2]. A variety of MONPs such as titanium dioxide (TiO₂), silicon dioxide (SiO₂), nickel oxide (NiO), copper Oxide (CuO), magnesium oxide iron Oxide (Fe₃O₄/Fe₂O₃), zinc Oxide (ZnO), etc. can be synthesized using different methods, exhibiting different morphology such as spherical, triangular, star, nanowire, etc[3-10]. Among them, the transition metal oxide CuO is a p-type semiconductor with narrow bandgap, and as nanoparticle shows unique physical and chemical properties such as superior surface and quantum size effects, which affects their magnetic behavior, optical absorption, chemical reactivity, thermal stability, and catalytic performance significantly [11]. Thus, they are widely used in photocatalysis, gas sensing, environmental remediation, antimicrobial applications, electrochemical devices, and solar energy conversion systems [12]. CuO nanoparticles can be synthesized using various physical and chemical methods, including sol–gel, hydrothermal, solvothermal, microwave-assisted, co-precipitation, arc discharge and thermal decomposition approaches [13]. However, these conventional methods often involve toxic reagents, non-biodegradable solvents, and harsh reaction conditions such as high temperature and pressure. Therefore, to minimize the environmental hazards caused by traditional methods, green synthesis of nanoparticles using plant extracts is an eco-friendly alternative [14]. The plant extracts which are rich in bioactive compounds like flavonoids, polyphenols, alkaloids, terpenoids, and sugars are used. These phytochemicals that are present in the plant extract act as

a reducing, capping and stabilizing agent during the synthesis of nanoparticles [15]. The extract can be obtained from different parts of plants, including leaves, stems, roots, and flowers. Various plant extracts such as citrofortunella microcarpa leaves, ailanthus altissima leaf aqueous extract, caesalpinia bonducella seed extract, adiantum lunulatum whole plant extract, etc are used for green synthesis of CuO nanoparticles which are used for water pollution detection and purification, antibacterial activities, electrode surface modifier, and photocatalytic activities [16]. In this paper, we are going to use Aloe vera extract for the green synthesis of CuO nanoparticles[17]. Aloe barbadensis Miller is a perennial succulent xerophyte widely recognized for its medicinal significance. It has been traditionally used for centuries possessing immunostimulatory, anti-inflammatory, wound-healing, antimicrobial, antidiabetic, antineoplastic, hematopoietic, and antioxidant properties [18]. Besides this, aloe vera can be rich in biologically active molecules that can act as multifunctional agents during nanomaterial synthesis [19]. The phytochemical present in aloe vera such as polysaccharides notably acemannan, glycoproteins, amino acids, organic acids, vitamins such as A, C, and E, enzymes e.g., catalase, peroxidase, phenolic compounds, flavonoids, etc. act as natural reducing agents, with the potential to convert Cu^{+2} ions into CuO nanoparticles at low temperatures [20]. During the synthesis of CuO nanoparticles, the viscous, polysaccharide-rich colloidal matrix of aloe vera extract promotes even distribution of precursor ions in the reaction medium, leading to uniform nucleation and better consistency in particle size and morphology[21]. Also, the regulation of precursor concentration, availability of electron donors, buffer strength, mixing conditions, and light exposure plays a vital role in affecting the nucleation and reproducibility of the synthesis process. Even the slightest variations can lead to differences in crystallite size, morphology, and surface characteristics of the synthesized CuO nanoparticles [22]. Despite several reports on plant-mediated CuO nanoparticles synthesis, a better understanding of how the composition of Aloe vera extract governs particle characteristics remains limited. Therefore, the present study focuses on the green synthesis of CuO nanoparticles using Aloe vera extract and evaluates their physicochemical properties.

II. LITERATURE REVIEW

Chakraborty et al. (2022) comprehensively reviewed the green synthesis of copper/copper oxide nanoparticles using plant, bacterial, fungal, and algal routes, highlighting the underlying biosynthetic mechanisms and characterization techniques. They discussed how biological molecules act as reducing and stabilizing agents, offering eco-friendly alternatives to conventional physicochemical methods. The review further summarized the diverse applications of biosynthesized Cu/CuO nanoparticles in antimicrobial, anticancer, agricultural, environmental, and biomedical fields[23]. Waris et al. reviewed the green synthesis of copper oxide nanoparticles using biological sources, emphasizing eco-friendly routes and the role of plant phytochemicals as reducing and stabilizing agents. They discussed various synthesis parameters, characterization techniques, and factors influencing particle size and morphology. The review also highlighted diverse biomedical, antimicrobial, catalytic, and environmental applications of biosynthesized CuO nanoparticles[24]. Mobarak et al. comprehensively reviewed plant extract-mediated green synthesis of CuO nanoparticles, explaining fundamental nanoparticle concepts and detailed biosynthetic mechanisms. The study elaborated on the role of phytochemicals in reduction, stabilization, and morphology control of CuO NPs. Furthermore, the review emphasized their mechanistic applications in environmental remediation, particularly dye and pharmaceutical degradation, along with antimicrobial activity [25]. Saif et al. reported the green synthesis of CuO nanoparticles using *Pterospermum acerifolium* leaf extract and compared their toxicity with engineered CuO nanoparticles. The study characterized the plant-mediated nanoparticles and evaluated their stability, ion release behaviour, and accumulation in *Daphnia magna*. Results demonstrated that plant-synthesized CuO nanoparticles exhibited lower acute toxicity (higher EC50 value) than engineered counterparts, indicating comparatively safer environmental behaviour [26]. Nzilu et al. investigated the green synthesis of CuO nanoparticles using plant-based extracts as eco-friendly reducing and stabilizing agents. The study systematically characterized the synthesized nanoparticles to determine their crystalline structure, morphology, and particle size. The biosynthesized CuO NPs exhibited significant antimicrobial activity, demonstrating their effectiveness against selected pathogenic strains. The work emphasized sustainable nanomaterial development with potential biomedical and environmental applications [27]. Priya et al. reported the green synthesis of CuO nanoparticles using *Morinda citrifolia* leaf extract through a simple and environmentally benign approach. Comprehensive characterization (UV-Vis, FTIR, XRD, SEM, TEM, and DLS) confirmed the formation of spherical nanoparticles in the 20–50 nm range. The study demonstrated strong antibacterial and antifungal activities of the synthesized CuO NPs. These findings highlighted their promising potential in biomedical and pharmaceutical applications [28]. Jabeen et al. synthesized CuO nanoparticles using Aloe vera leaf extract and evaluated their structural, optical, antibacterial, molecular docking, and photocatalytic properties. Characterization confirmed well-defined morphology and favorable optical behavior. The nanoparticles exhibited

strong antibacterial activity supported by molecular docking analysis with bacterial target proteins. Additionally, they achieved efficient photocatalytic degradation of methylene blue dye under UV irradiation, indicating environmental remediation potential [29]. Ramasubbu et al. developed CuO nanoparticles using *Sesbania grandiflora* leaf extract via a green synthesis approach. Detailed characterization confirmed needle-shaped crystalline nanoparticles with notable optical features. The synthesized Sg-CuO NPs demonstrated significant anti-diabetic, antioxidant, anti-inflammatory, cytotoxic, and antimicrobial activities in vitro. The study suggested their potential applicability in therapeutic and biomedical fields[30]. H.N. Jayasimha et al. synthesized copper oxide nanoparticles (CuO NPs) via a green method using plant extract, with UV-Vis analysis showing a characteristic absorption peak around ~270–290 nm, confirming nanoparticle formation. XRD patterns revealed a monoclinic crystalline structure with an average crystallite size of approximately 20–40 nm. FTIR spectra indicated the presence of phytochemicals (–OH, –C=O functional groups) responsible for reduction and capping of nanoparticles. SEM analysis demonstrated nearly spherical and uniformly distributed particles in the nanoscale range. The biosynthesized CuO NPs exhibited significant antibacterial activity, with higher inhibition zones observed against Gram-positive bacteria compared to Gram-negative strains, highlighting their biomedical potential[31]. Moroda et al. reported the green synthesis of CuO nanoparticles using *Rosmarinus officinalis* leaf extract, where phytochemicals such as polyphenols, flavonoids, alkaloids, and tannins acted as reducing and stabilizing agents. The synthesized nanoparticles exhibited a monoclinic crystalline structure with crystallite sizes ranging from 18–26 nm and predominantly spherical aggregated morphology, confirmed by XRD, UV-Vis, FTIR, and SEM analyses. UV-Vis spectra showed maximum absorption at 351–360 nm with a red shift at higher weight fractions, while FTIR peaks ($563\text{--}565\text{ cm}^{-1}$) confirmed Cu–O bond formation. The biosynthesized CuO NPs demonstrated strong antimicrobial activity against *E. coli*, *S. aureus*, *C. albicans*, and *B. cereus*, with maximum zones of inhibition of 26, 25, 18, and 17 mm respectively, highlighting their biomedical potential[32]. Adewale et al. reported the green synthesis of metal oxide nanoparticles using *Tithonia diversifolia* leaf extract, where phytochemicals such as phenolics, flavonoids, and terpenoids acted as reducing and stabilizing agents. The synthesized nanoparticles exhibited crystalline structure with nanoscale particle size and defined morphology, confirmed by XRD, UV-Vis, FTIR, and SEM analyses. UV-Vis spectra confirmed nanoparticle formation, while FTIR peaks indicated functional groups responsible for stabilization. The biosynthesized nanoparticles demonstrated significant antibacterial and antioxidant activity, highlighting their biomedical and environmental potential [33]. Rao et al. reported the green synthesis of metal oxide nanoparticles using *Morinda citrifolia* leaf extract, where bioactive compounds such as polyphenols and flavonoids acted as reducing and capping agents. The synthesized nanoparticles exhibited crystalline structure with nanoscale dimensions and controlled morphology, confirmed by XRD, UV-Vis, FTIR, and SEM analyses. UV-Vis spectroscopy confirmed nanoparticle formation, while FTIR spectra revealed functional groups responsible for nanoparticle stabilization. The biosynthesized nanoparticles showed promising antimicrobial and catalytic properties, demonstrating their potential for biomedical and industrial applications [34]. Gebrie et al. reported the green synthesis of CuO nanoparticles using *Plumbago zeylanica* leaf extract, where phytochemicals such as flavonoids, tannins, saponins, and phenolics acted as reducing and stabilizing agents. The synthesized CuO nanoparticles exhibited a monoclinic crystalline structure with an average crystallite size of ~25 nm and spherical morphology, confirmed by XRD, UV-Vis, FTIR, SEM, and TGA analyses. UV-Vis spectra confirmed CuO nanoparticle formation with a band gap of ~3.22 eV, while FTIR peaks confirmed Cu–O bond formation. The biosynthesized CuO nanoparticles demonstrated significant antibacterial and antioxidant activity, indicating their potential biomedical and environmental applications [35]. Baral et al. described an eco-friendly synthesis of CuO nanoparticles employing *Mentha* leaf extract as a bioreducing and capping agent. Phytochemical screening confirmed the presence of flavonoids, saponins, and terpenoids, which facilitated nanoparticle formation. XRD analysis revealed a monoclinic crystalline phase with an average crystallite size of ~19 nm, while UV-Vis ($\lambda_{\text{max}} \approx 275\text{ nm}$; $E_g \approx 2.98\text{ eV}$) and FTIR studies verified CuO formation and functional group involvement. The synthesized nanoparticles exhibited pronounced antimicrobial activity against Gram-positive, Gram-negative, and fungal strains, demonstrating their potential for biomedical and antimicrobial applications [36]. Kumari et al. evaluated the toxicological behavior of CuO nanoparticles using *Daphnia magna* as an aquatic bioindicator model. Phytochemical The synthesized CuO nanoparticles were confirmed to possess a monoclinic crystalline phase with nanoscale particle dimensions through XRD and spectroscopic analyses. Morphological studies revealed relatively stable and dispersed nanostructures, while physicochemical characterization supported their structural integrity in aqueous media. Toxicity assays demonstrated concentration-dependent immobilization and oxidative stress responses in *D. magna*, underscoring the ecological risks associated with CuO nanoparticle release into aquatic environments [37]. Suresh et al. employed Gum karaya as a natural biotemplate for the controlled synthesis of CuO nanoparticles. The polysaccharide matrix facilitated reduction and stabilization, leading to the formation of monoclinic CuO confirmed by XRD analysis. SEM observations indicated morphology modulation by the polymeric scaffold, producing relatively uniform nanostructures

with reduced agglomeration. FTIR spectra verified Cu–O bond formation along with interactions between CuO and hydroxyl/carboxyl functional groups of the biopolymer. The templated nanoparticles exhibited enhanced catalytic efficiency and antimicrobial performance, demonstrating the effectiveness of natural polymers in structure-directed nanoparticle synthesis [38]. Ramesh et al. reported the green synthesis of CuO nanoparticles using leaf extract of *Gloriosa superba*, where bioactive constituents such as alkaloids and phenolics acted as reducing and capping agents. XRD patterns confirmed the formation of monoclinic CuO with nanoscale crystallite size, while UV–Vis absorption and FTIR bands substantiated optical transitions and Cu–O bonding. SEM analysis revealed predominantly spherical particles with slight aggregation. The biosynthesized nanoparticles displayed appreciable antimicrobial activity against selected pathogenic strains along with antioxidant potential, indicating their suitability for biomedical and therapeutic applications [39]. Udayabhanu et al. developed a green combustion route for synthesizing CuO nanoparticles using aqueous leaf extract of *Tinospora cordifolia* as a biofuel and reducing agent. XRD confirmed the formation of pure monoclinic CuO with a remarkably small crystallite size of approximately 6–8 nm. SEM and TEM analyses revealed sponge-like nanostructures with high surface area, favorable for catalytic applications. The nanoparticles exhibited efficient photocatalytic degradation of methylene blue under both UV and sunlight irradiation, along with strong DPPH radical scavenging and antibacterial activity against Gram-positive and Gram-negative bacteria. The study demonstrated a rapid, energy-efficient, and multifunctional synthesis strategy [40]. Keabadile et al. conducted a comparative investigation of CuO nanoparticles synthesized via green and conventional chemical routes using leaf extract of *terminalia phanerophlebia*. UV–Vis spectra (290–293 nm) confirmed nanoparticle formation, while FTIR analysis indicated characteristic Cu–O vibrations and phytochemical involvement in green synthesis. SEM imaging showed predominantly spherical, agglomerated particles for both methods, though zeta potential measurements revealed greater surface stability and higher negative charge for green-synthesized CuO. Electrochemical evaluation through cyclic voltammetry demonstrated enhanced electrocatalytic activity, suggesting their potential application in sensor fabrication and electrochemical devices [41]. Rani et al. reported the green synthesis of CuO nanoparticles using leaf extract of *hemidesmus indicus* as a natural reducing and capping agent. Phytochemical constituents such as flavonoids, phenolics, and glycosides facilitated the conversion of copper ions into stable CuO nanostructures. XRD analysis confirmed the formation of monoclinic crystalline CuO with nanoscale crystallite dimensions, while UV–Vis and FTIR spectra verified characteristic absorption peaks and Cu–O bond formation. Morphological studies revealed predominantly spherical particles with moderate aggregation. The biosynthesized nanoparticles demonstrated promising antibacterial and antioxidant activities, highlighting their suitability for biomedical and environmental applications [42]. Sivakumar et al. described an eco-friendly fabrication of CuO nanoparticles utilizing aqueous leaf extract of *adhatoda vasica*. Bioactive compounds including alkaloids and polyphenols played a significant role in reduction and stabilization processes. Structural characterization through XRD confirmed monoclinic CuO formation, while SEM analysis indicated the formation of quasi-spherical nanostructures with uniform dispersion. FTIR results showed functional group interactions responsible for capping and stabilization. The synthesized CuO nanoparticles exhibited enhanced antimicrobial efficacy against both Gram-positive and Gram-negative bacteria, suggesting their potential as alternative antimicrobial agents [43]. Shafiq et al. developed a sustainable approach for synthesizing CuO nanoparticles by recovering copper from discarded photovoltaic modules and employing fruit extract of *piper nigrum* as a green reducing agent. Nitric acid leaching enabled efficient copper recovery, which was subsequently converted into CuO nanoparticles via plant-mediated reduction. UV–Vis spectroscopy confirmed nanoparticle formation with a characteristic absorption around 294 nm, while TEM analysis revealed spherical particles ranging from ~10–60 nm with an average size near 26 nm. EDS analysis verified high copper purity with surface-bound biomolecules from the extract. The obtained nanoparticles displayed significant antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*, demonstrating a circular-economy strategy for converting electronic waste into value-added antimicrobial nanomaterials [44]. Bibi et al. reported the one-pot green synthesis of multifunctional carbon-coated CuO nanosheets using aqueous extract of *rhazya stricta*. Phytochemical screening revealed the presence of saponins, tannins, and polyphenols responsible for metal ion reduction and stabilization. UV–Vis spectra exhibited a prominent absorption peak at 294 nm, while XRD and FTIR analyses confirmed crystalline CuO formation and functional group involvement. FE-SEM imaging showed self-assembled nanosheets with an average size of ~20 nm, arranged in layered 3D cubical architectures. The synthesized CuO nanosheets demonstrated strong antibacterial activity against *Ralstonia solanacearum* and *Clavibacter michiganensis*, along with efficient photocatalytic degradation (~83%) of methylene blue under solar irradiation, indicating their dual environmental and agricultural applications [45]. Ali et al. reported the green synthesis of CuO nanoparticles using *Aegle marmelos* leaf extract, producing crystalline, non-aggregated nanoparticles (~32 nm). The biosynthesized CuO NPs showed dose-dependent antibacterial and antifungal activity, with lower MIC values for bacteria than fungi. Additionally, the nanoparticles demonstrated strong sunlight-driven

photocatalytic degradation of methylene blue and methyl orange dyes. The study highlights an eco-friendly and cost-effective approach for biomedical and environmental applications [46]. Hojat Veisi et al. reported the green fabrication of CuO nanoparticles using herbal tea extract as a natural reducing and stabilizing agent. The synthesized nanoparticles exhibited well-defined crystalline structure and enhanced visible-light photocatalytic degradation efficiency against industrial dyes. The phytochemical-rich extract contributed to improved surface activity and stability of the nanoparticles. This work emphasizes a simple, low-cost strategy utilizing commonly available plant infusions for environmental remediation [47]. Sukumar et al. described the biosynthesis of CuO nanoparticles employing *Caesalpinia bonducella* seed extract, where bioactive seed phytoconstituents facilitated nanoparticle reduction and capping. The resulting CuO NPs displayed controlled morphology and significant antimicrobial potential against pathogenic strains. The study uniquely demonstrates the effectiveness of seed-derived biomolecules, rather than leaf extracts, in stabilizing functional metal oxide nanostructures for biomedical use [48]. Aroob et al. developed a bio-mechanochemical synthesis of CuO nanoparticles using *Seriphidium oliverianum* leaf extract in a solvent-minimized grinding process. XRD confirmed monoclinic CuO with an average crystallite size of approximately 12 nm, and the nanoparticles achieved approximately 65% photocatalytic degradation of methyl green and methyl orange. The study uniquely integrates mechanochemistry with green synthesis, offering a scalable and energy-efficient approach for wastewater dye treatment [49]. Tamuly et al. synthesized flower-like hierarchical CuO nanoparticles using peel extract of *Musa balbisiana*. The nanostructures exhibited high catalytic efficiency (74–96% yield) in the aqueous reduction of aromatic nitro compounds to corresponding amines using NaBH₄. Notably, the catalyst demonstrated excellent recyclability over multiple cycles, highlighting its practical applicability in green organic synthesis [50]. Gunalan et al. reported the synthesis of monodisperse CuO nanoparticles using *aloe barbadensis* Miller extract, achieving controlled particle sizes (15–30 nm) by varying extract concentration. The nanoparticles exhibited distinct optical and photoluminescence properties, confirming their crystalline and stable nature. The study uniquely focused on morphology control and optical characterization, proposing potential applications in biomedical and cosmetic industries [51]. Prakash et al. reported the green synthesis of CuO nanoparticles using plant extract-mediated reduction, producing crystalline nanostructures with controlled morphology confirmed by XRD and electron microscopy analyses. The synthesized CuO NPs exhibited enhanced catalytic and/or antimicrobial performance attributed to high surface reactivity and nanoscale dimensions. The study uniquely emphasized morphological tuning through extract concentration and its influence on functional efficiency, highlighting the versatility of plant-assisted nanofabrication [52]. Muthu Kathija et al. reported the biosynthesis of CuO nanoparticles using *Syzygium cumini* seed extract as both reducing and capping agent. The prepared CuO NPs achieved approximately 97% photocatalytic degradation of methylene blue within 60 minutes under UV irradiation, following pseudo-first-order kinetics ($k = 0.06 \text{ min}^{-1}$). Notably, the catalyst retained approximately 95% efficiency even after five reuse cycles and remained stable over a wide pH range. The degradation pathway was elucidated via HR-MS analysis, providing mechanistic insight into dye mineralization [53]. Awwad and Amer reported the eco-friendly synthesis of CuO nanoparticles using *Ailanthus altissima* leaf extract. The spherical, well-crystalline nanoparticles exhibited significant antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*, with inhibition zones comparable to standard antibiotics at higher concentrations. The novelty of the work lies in the first-time use of *Ailanthus altissima* for CuO NP synthesis and its promising biomedical antimicrobial application [54]. Vidovix et al. reported the green synthesis of CuO nanoparticles using *punica granatum* leaf extract for methylene blue removal via adsorption. The synthesized nanoparticles demonstrated a high maximum adsorption capacity of 166.02 mg g⁻¹ at 318 K, with equilibrium data fitting the Langmuir isotherm model. Kinetic studies followed a pseudo-second-order model, and thermodynamic analysis confirmed a spontaneous and endothermic process. The study uniquely focused on adsorption mechanisms rather than photocatalysis, highlighting CuO NPs as efficient dye adsorbents [55]. Seerangaraj Vasantharaj et al. synthesized copper oxide nanoparticles (CuONPs) using *Ruellia tuberosa* leaf extract via a green approach. The nanorod-shaped CuONPs exhibited strong antibacterial activity against *Staphylococcus aureus*, *Escherichia coli*, and *Klebsiella pneumoniae*. CuO NPs incorporated into cotton fabrics demonstrated enhanced bactericidal efficiency. Additionally, the nanoparticles showed efficient photocatalytic degradation of crystal violet dye under sunlight, indicating potential applications in antimicrobial textiles and wastewater treatment [56]. Lagerstroemia indica et al. reported the green synthesis of copper oxide nanoparticles (CuO NPs) using *Lagerstroemia indica* flower extract. The synthesized nanoparticles were predominantly spherical and confirmed by UV-Vis, XRD, and FTIR analyses. The CuO NPs exhibited significant antibacterial activity against both Gram-positive and Gram-negative bacteria. The study emphasized the eco-friendly synthesis route and the potential biomedical applications of the prepared nanoparticles [57].

III. EXPERIMENTAL

Preparation of aloe vera extract

Fresh leaves of *Aloe barbadensis* Miller were washed thoroughly and the inner gel was separated. Approximately 20 g of gel was homogenized in 100 mL distilled water and heated at 60–70 °C for 30 min under continuous stirring. The mixture was filtered using muslin cloth followed by Whatman No.1 filter paper. The obtained filtrate was stored at 4 °C and used as a reducing and stabilizing agent for CuO nanoparticle synthesis.

Preparation of Copper oxide nanoparticles

An aqueous solution of 0.1 M copper nitrate trihydrate ($\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$) was prepared by dissolving the required amount in 100 mL of distilled water. 10 mL of Aloe vera extract was added slowly to the copper precursor solution under continuous magnetic stirring at 80 °C.

To facilitate precipitation, freshly prepared NaOH solution (0.2 mmol) was added dropwise to the reaction mixture until the pH reached 10. The reaction was maintained under vigorous stirring for 2 hours to ensure complete formation of the precipitate. The mixture was then allowed to settle, and the resulting precipitate was collected.

The obtained precipitate was washed 4–5 times with distilled water followed by ethanol to remove residual impurities and unreacted species. The purified product was dried, transferred to a crucible, and calcined in a muffle furnace at 600 °C for 4 hours to obtain uniformly crystalline CuO nanoparticles. The calcination step ensured phase purity and improved crystallinity of the synthesized nanoparticles.

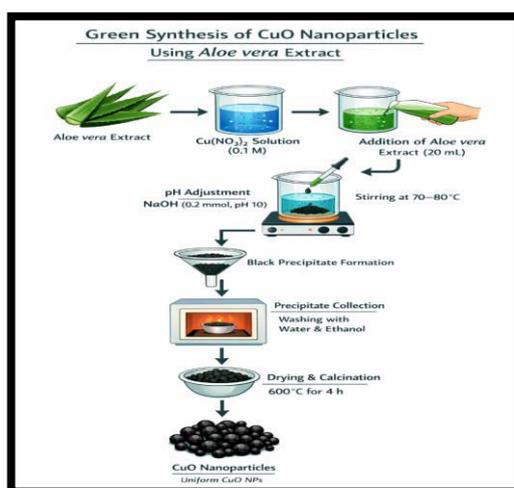


Figure 1: Schematic representation of synthesis of Copper oxide nanoparticles using aloe vera extract

IV. RESULTS AND DISCUSSIONS

X ray diffraction spectroscopy

The X-ray Diffraction (XRD) analysis confirms the formation of crystalline Copper Oxide (CuO) nanoparticles. The diffraction peaks observed at 2θ values such as 28.959°, 33.678°, 36.239°, 38.617°, 47.453°, 53.062°, 57.414°, 67.918°, and 74.66° correspond to the characteristic planes of monoclinic CuO structure.

The most intense peak is observed at 38.617° corresponding to the (111) plane, indicating preferred orientation. The calculated d-spacing values are in good agreement with standard JCPDS data for CuO. The crystallite size calculated using the Scherrer equation is approximately 24nm, indicating nanocrystalline nature of the synthesized sample. The sharp diffraction peaks confirm good crystallinity, while variation in FWHM values indicates difference in crystallite dimensions across various lattice planes.

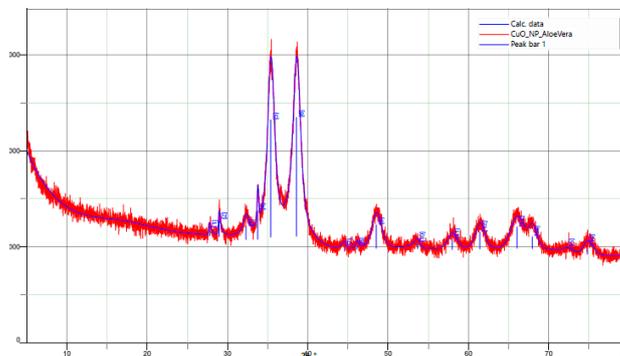


Figure 2: X ray diffraction graph of CuO Nps

Scanning electron microscopy

The surface morphology and microstructural features of the green-synthesized CuO nanoparticles were investigated using Scanning Electron Microscopy (SEM), as shown in Fig. X. The SEM micrographs reveal the formation of densely packed, irregularly shaped nanostructures with a predominantly flake-like and petal-like morphology. The nanoparticles appear to assemble into flower-like agglomerated clusters, forming a hierarchical microstructure. The individual nanoflakes exhibit sharp edges and thin layered structures, suggesting anisotropic growth during synthesis. Such morphology is typically observed in plant-mediated synthesis routes, where phytochemicals act as both reducing and capping agents, influencing directional crystal growth. The observed agglomeration may be attributed to high surface energy of nanosized CuO particles, interparticle van der Waals forces or residual phytochemical interactions from Aloe vera extract. The porous and layered architecture increases the effective surface area, which can enhance catalytic and antimicrobial performance. Furthermore, the morphology is consistent with monoclinic CuO structures reported in literature.

Although some degree of aggregation is evident, this is common in calcined metal oxide nanoparticles, especially after thermal treatment at 600 °C, which promotes crystallite fusion and growth.

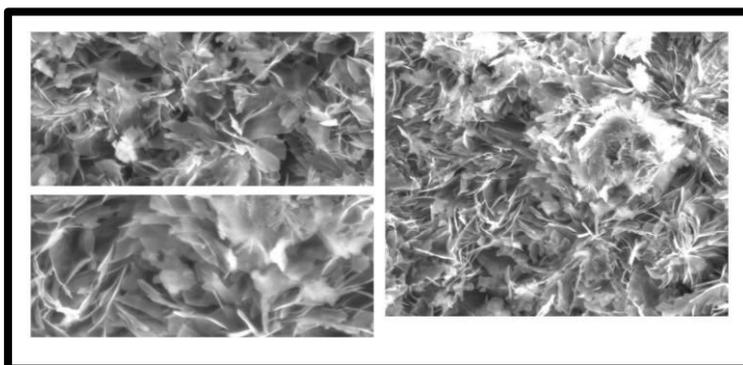


Figure 3: Scanning electron microscopic images of synthesized copper oxide nanoparticles

V. CONCLUSION

In the present study, copper oxide (CuO) nanoparticles were successfully synthesized via an eco-friendly wet chemical co-precipitation method using Aloe barbadensis Miller leaf extract as a reducing and stabilizing agent. The green synthesis approach eliminates the need for hazardous chemicals, highlighting its sustainability and environmental compatibility. X-ray diffraction (XRD) analysis confirmed the formation of phase-pure monoclinic CuO, with diffraction peaks matching standard JCPDS data. The absence of secondary phases indicates the effectiveness of the plant-mediated synthesis route. The average crystallite size calculated using the Debye–Scherrer equation was found to be in the nanometer range, confirming nanoscale crystallinity and good structural ordering after calcination at 600 °C.

Scanning Electron Microscopy (SEM) revealed the formation of flake-like and petal-like nanostructures arranged in agglomerated, flower-like assemblies. The hierarchical morphology suggests that phytochemicals present in Aloe vera play a crucial role in directing crystal growth and influencing particle assembly. Although slight agglomeration was observed, this is typical for calcined metal oxide nanoparticles and does not compromise structural integrity. Overall, the study demonstrates that Aloe vera-mediated green synthesis is a simple, cost-effective, and sustainable method for producing crystalline CuO nanoparticles with well-defined morphology. The obtained structural and morphological characteristics suggest potential applicability of the synthesized nanoparticles in catalytic, antimicrobial, and environmental remediation applications.

VI. FUTURE SCOPE

The successful green synthesis of phase-pure CuO nanoparticles using Aloe barbadensis Miller extract opens several avenues for further investigation. Future studies may focus on optimizing synthesis parameters such as extract concentration, pH, calcination temperature, and reaction time to achieve controlled particle size and morphology tailoring. Advanced characterization techniques such as TEM, BET surface area analysis, XPS, and EDX mapping can be employed to gain deeper insights into surface chemistry, elemental distribution, and porosity. Understanding the role of specific phytochemicals in directing anisotropic growth may also provide mechanistic clarity and enable morphology engineering. From an application perspective, the synthesized CuO nanoparticles can be explored in antimicrobial activity against multidrug-resistant strains, photocatalytic degradation of organic pollutants, electrochemical sensing, and energy storage devices. Surface functionalization strategies may further enhance their selectivity and efficiency for biomedical and environmental applications. Additionally, scaling up the green synthesis process while maintaining structural uniformity and reproducibility remains an important research direction toward industrial feasibility. Overall, plant-mediated nanoengineering offers a sustainable pathway for designing functional metal oxide nanomaterials with tunable physicochemical properties.

REFERENCES

- [1] Chavali, M. S., & Nikolova, M. P. (2019). Metal oxide nanoparticles and their applications in nanotechnology. *SN applied sciences*, 1(6), 607.
- [2] Zheng, H., Ou, J. Z., Strano, M. S., Kaner, R. B., Mitchell, A., & Kalantar-zadeh, K. (2011). Nanostructured tungsten oxide—properties, synthesis, and applications. *Advanced Functional Materials*, 21(12), 2175-2196.
- [3] Prasanna, S. S., Balaji, K., Pandey, S., & Rana, S. (2019). Metal oxide based nanomaterials and their polymer nanocomposites. In *Nanomaterials and polymer nanocomposites* (pp. 123-144). Elsevier.
- [4] Mayekar, J., Dhar, V., & Radha, S. (2014). Role of salt precursor in the synthesis of zinc oxide nanoparticles. *International Journal of Research in Engineering and Technology*, 3(3), 43-45.
- [5] Jyoti, M., Vijay, D., & Radha, S. (2013). To study the role of temperature and sodium hydroxide concentration in the synthesis of zinc oxide nanoparticles. *International Journal of Scientific and Research Publications*, 3(11), 2250-3153.
- [6] Mayekar, J., & Radha, S. (2021). Synthesis and characterization of zinc oxide nanoparticles and silver doped zinc oxide nanoparticles and their comparative antibacterial activity. *J Interdiscip Cycle Res*, 13, 2127-2133.
- [7] Mayekar, J. S., Dhar, V. S., & Radha, S. (2015). Synthesis and characterization of pure zinc oxide nanoparticles and nickel doped zinc oxide nanoparticles. *IJRET: Int. J. Res. Eng. Technol.*, 4(11), 104-107.
- [8] Mayekar, J. (2024). A review on the plant mediated, synthesis of zinc oxide nanoparticles. *Int j creative res thoughts*, 12, 2320-882.
- [9] Mayekar, J., Dhar, V., & Radha, S. (2014). Synthesis of copper oxide nanoparticles using simple chemical route. *International Journal of Scientific and Engineering Research*, 5, 928-930.
- [10] Mayekar, J. (2024). Study on the Synthesis and Characterization of Magnesium Oxide Nanoparticles Synthesized By Precipitation Method. *International Journal of Engineering and Science Invention*, 13(3), 10-4
- [11] Akhtar, N., Malik, S., Muhammad, F., & Ullah, Z. (2025). CuO nanoparticles: tuning properties for energy and optoelectronic applications. *Nano Select*, 6(11), e70015.
- [12] Prakruthi, R., & Deepakumari, H. N. (2024). CuO nanoparticles: green combustion synthesis, applications to antioxidant, photocatalytic and sensor studies. *RSC advances*, 14(39), 28703-28715.

- [13] Khairy, M., El-Shaarawy, M. G., & Mousa, M. A. (2021). Characterization and super-capacitive properties of nanocrystalline copper ferrite prepared via green and chemical methods. *Materials Science and Engineering: B*, 263, 114812.
- [14] Almarhoon, Z. M., Indumathi, T., & Kumar, E. R. (2022). Optimized green synthesis of ZnO nanoparticles: evaluation of structural, morphological, vibrational and optical properties. *Journal of Materials Science: Materials in Electronics*, 33(30), 23659-23672.
- [15] Tran, T. H., & Nguyen, V. T. (2014). Copper oxide nanomaterials prepared by solution methods, some properties, and potential applications: a brief review. *International scholarly research notices*, 2014(1), 856592.
- [16] Sachdeva, H., Sharma, N., Sharma, A., & Shrivastava, R. (2022). Plant-extract mediated synthesis of copper- and iron-based nanoparticles for various applications. *NanoWorld Journal*, 8(S1), S162-S167.
- [17] Aroob, S.; Taj, M.B.; Shabbir, S.; Imran, M.; Ahmad, R.H.; Habib, S.; Raheel, A.; Akhtar, M.N.; Ashfaq, M.; Sillanpää, M. In situ biogenic synthesis of CuO nanoparticles over graphene oxide: A potential nanohybrid for water treatment. *J. Environ. Chem. Eng.* 2021, 9, 105590.
- [18] Talmadge, J., Chavez, J., Jacobs, L., Munger, C., Chinnah, T., Chow, J. T., ... & Yates, K. (2004). Fractionation of Aloe vera L. inner gel, purification and molecular profiling of activity. *International immunopharmacology*, 4(14), 1757-1773.
- [19] Mensah, E. O., Adadi, P., Asase, R. V., Kelvin, O., Mozdehi, F. J., Amoah, I., & Agyei, D. (2025). Aloe vera and its byproducts as sources of valuable bioactive compounds: Extraction, biological activities, and applications in various food industries. *PharmaNutrition*, 31, 100436.
- [20] Surjushe, A., Vasani, R., & Saple, D. (2008). Aloe vera: a short review. *Indian journal of dermatology*, 53(4), 163-166.
- [21] Onfray, C., & Thiam, A. (2023). Biomass-derived carbon-based electrodes for electrochemical sensing: a review. *Micromachines*, 14(9), 1688.
- [22] Irvani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green chemistry*, 13(10), 2638-2650.
- [23] Chakraborty, N., Banerjee, J., Chakraborty, P., Banerjee, A., Chanda, S., Ray, K., ... Sarkar, J. (2022). Green synthesis of copper/copper oxide nanoparticles and their applications: a review. *Green Chemistry Letters and Reviews*, 15(1), 187–215. <https://doi.org/10.1080/17518253.2022.2025916>.
- [24] Waris, A., Din, M., Ali, A., Ali, M., Afridi, S., Baset, A., & Khan, A. U. (2021). A comprehensive review of green synthesis of copper oxide nanoparticles and their diverse biomedical applications. *Inorganic Chemistry Communications*, 123, 108369.
- [25] Mobarak, M. B., Sikder, M. F., Muntaha, K. S., Islam, S., Rabbi, S. F., & Chowdhury, F. (2025). Plant extract-mediated green-synthesized CuO nanoparticles for environmental and microbial remediation: a review covering basic understandings to mechanistic study. *Nanoscale Advances*, 7(9), 2418-2445.
- [26] Saif, S., Tahir, A., Asim, T., & Chen, Y. (2016). Plant mediated green synthesis of CuO nanoparticles: comparison of toxicity of engineered and plant mediated CuO nanoparticles towards *Daphnia magna*. *Nanomaterials*, 6(11), 205.
- [27] Nzilu, D. M., Madivoli, E. S., Makhanu, D. S., Wanakai, S. I., Kiprono, G. K., & Kareru, P. G. (2023). Green synthesis of copper oxide nanoparticles and its efficiency in degradation of rifampicin antibiotic. *Scientific Reports*, 13(1), 14030.
- [28] Priya, M., Venkatesan, R., Deepa, S., Sana, S. S., Arumugam, S., Karami, A. M., ... & Kim, S. C. (2023). Green synthesis, characterization, antibacterial, and antifungal activity of copper oxide nanoparticles derived from *Morinda citrifolia* leaf extract. *Scientific reports*, 13(1), 18838.
- [29] Jabeen, S., Siddiqui, V. U., Bala, S., Mishra, N., Mishra, A., Lawrence, R., ... & Khan, T. (2024). Biogenic synthesis of copper oxide nanoparticles from aloe vera: antibacterial activity, molecular docking, and photocatalytic dye degradation. *ACS omega*, 9(28), 30190-30204.
- [30] Ramasubbu, K., Padmanabhan, S., Al-Ghanim, K. A., Nicoletti, M., Govindarajan, M., Sachivkina, N., & Rajeswari, V. D. (2023). Green synthesis of copper oxide nanoparticles using *Sesbania grandiflora* leaf extract and their evaluation of anti-diabetic, cytotoxic, anti-microbial, and anti-inflammatory properties in an in-vitro approach. *Fermentation*, 9(4), 332.
- [31] Jayasimha, H. N., Chandrappa, K. G., Sanaulla, P. F., & Dileepkumar, V. G. *Sensors International*.
- [32] Moroda, M. D., Deressa, T. L., Tiwikrama, A. H., & Chala, T. F. (2025). Green synthesis of copper oxide nanoparticles using *Rosmarinus officinalis* leaf extract and evaluation of its antimicrobial activity. *Next Materials*, 7, 100337.

- [33] Millavithanachchi, S. S., Gunasena, M. D. K. M., Galpaya, G. D. C. P., Priyadarshana, H. V. V., Indupama, S. V. A. A., Induranga, D. K. A., ... & Koswattage, K. R. (2025). Green synthesis, optimization, and characterization of CuO nanoparticles using *Tithonia diversifolia* leaf extract. *Nanomaterials*, 15(15), 1203.
- [34] Priya, M., Venkatesan, R., Deepa, S., Sana, S. S., Arumugam, S., Karami, A. M., ... & Kim, S. C. (2023). Green synthesis, characterization, antibacterial, and antifungal activity of copper oxide nanoparticles derived from *Morinda citrifolia* leaf extract. *Scientific reports*, 13(1), 18838.
- [35] Gebrie, H. T., Assege, M. A., Meshesha, D. S., Tebeje, B. A., Moges, G. W., Wodajo, A. T., ... & Belew, A. A. (2025). Biosynthesis and characterization of copper oxide nanoparticles from *Plumbago zeylanica* leaf extract for antibacterial and antioxidant activities. *Scientific Reports*, 15(1), 30656.
- [36] Baral, J., Pokharel, N., Dhungana, S., Tiwari, L., Khadka, D., Pokhrel, M. R., & Poudel, B. R. (2025). Green synthesis of copper oxide nanoparticles using *Mentha* (mint) leaves characterization and its antimicrobial properties with phytochemicals screening. *Journal of Nepal Chemical Society*, 45(1), 111-121.
- [37] Saif, S., Tahir, A., Asim, T., & Chen, Y. (2016). Plant mediated green synthesis of CuO nanoparticles: comparison of toxicity of engineered and plant mediated CuO nanoparticles towards *Daphnia magna*. *Nanomaterials*, 6(11), 205.
- [38] Padil, V. V. T., & Černík, M. (2013). Green synthesis of copper oxide nanoparticles using gum karaya as a biotemplate and their antibacterial application. *International journal of nanomedicine*, 889-898.
- [39] Naika, H. R., Lingaraju, K., Manjunath, K., Kumar, D., Nagaraju, G., Suresh, D., & Nagabhushana, H. (2015). Green synthesis of CuO nanoparticles using *Gloriosa superba* L. extract and their antibacterial activity. *Journal of Taibah University for Science*, 9(1), 7-12.
- [40] Nethravathi, P. C., Kumar, M. P., Suresh, D., Lingaraju, K., Rajanaika, H., Nagabhushana, H., & Sharma, S. C. (2015). *Tinospora cordifolia* mediated facile green synthesis of cupric oxide nanoparticles and their photocatalytic, antioxidant and antibacterial properties. *Materials Science in Semiconductor Processing*, 33, 81-88.
- [41] Keabadile, O. P., Aremu, A. O., Elugoke, S. E., & Fayemi, O. E. (2020). Green and traditional synthesis of copper oxide nanoparticles—comparative study. *Nanomaterials*, 10(12), 2502.
- [42] K. Suganya, Dr. K. Sudharsan (2025). Plant-Mediated Green Synthesis and Evaluation of Copper Oxide Nanoparticles Utilizing *Hemidesmus indicus* Extract. *Journal of Neonatal Surgery*, 14 (23s), 540-545.
- [43] Bhavyasree, P. G., & Xavier, T. S. (2020). Green synthesis of Copper Oxide/Carbon nanocomposites using the leaf extract of *Adhatoda vasica* Nees, their characterization and antimicrobial activity. *Heliyon*, 6(2).
- [44] Shafiq, A., Jeong, U., Han, Y., Kim, Y., Lee, J., & Kim, B. S. (2024). Green synthesis of copper oxide nanoparticles from waste solar panels using *piper nigrum* fruit extract and their antibacterial activity. *Catalysts*, 14(8), 472.
- [45] Bibi, H., Iqbal, M., Wahab, H., Ozturk, M., Ke, F., & Iqbal, Z. Green synthesis of multifunctional carbon coated copper oxide nanosheets and their photocatalytic and antibacterial activities. *Sci Rep.* 2021; 11: 10781.
- [46] Ali, S. G., Haseen, U., Jalal, M., Khan, R. A., Alsalmeh, A., Ahmad, H., & Khan, H. M. (2023). Green synthesis of copper oxide nanoparticles from the leaves of *Aegle marmelos* and their antimicrobial activity and photocatalytic activities. *Molecules*, 28(22), 7499.
- [47] Veisi, H., Karmakar, B., Tamoradi, T., Hemmati, S., Hekmati, M., & Hamelian, M. (2021). Biosynthesis of CuO nanoparticles using aqueous extract of herbal tea (*Stachys Lavandulifolia*) flowers and evaluation of its catalytic activity. *Scientific Reports*, 11(1), 1983.
- [48] Sukumar, S., Rudrasenan, A., & Padmanabhan Nambiar, D. (2020). Green-synthesized rice-shaped copper oxide nanoparticles using *Caesalpinia bonducella* seed extract and their applications. *ACS omega*, 5(2), 1040-1051.
- [49] Aroob, S., Carabineiro, S. A., Taj, M. B., Bibi, I., Raheel, A., Javed, T., ... & Sillanpää, M. (2023). Green synthesis and photocatalytic dye degradation activity of CuO nanoparticles. *Catalysts*, 13(3), 502.
- [50] Tamuly, C., Saikia, I., Hazarika, M., & Das, M. R. (2014). Reduction of aromatic nitro compounds catalyzed by biogenic CuO nanoparticles. *RSC advances*, 4(95), 53229-53236.
- [51] Gunalan, S., Sivaraj, R., & Venkatesh, R. (2012). *Aloe barbadensis* Miller mediated green synthesis of mono-disperse copper oxide nanoparticles: optical properties. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 97, 1140-1144.
- [52] Prakash, S., Elavarasan, N., Venkatesan, A., Subashini, K., Sowndharya, M., & Sujatha, V. (2018). Green synthesis of copper oxide nanoparticles and its effective applications in Biginelli reaction, BTB photodegradation and antibacterial activity. *Advanced Powder Technology*, 29(12), 3315-3326.
- [53] MuthuKathija, M., Muthusamy, S., Khan, R. I., Badhusha, M. S. M., Rajalakshmi, K., Rama, V., & Xu, Y. (2024). Photocatalytic degradation of methylene blue dye using biogenic copper oxide nanoparticles and its degradation pathway analysis. *Inorganic Chemistry Communications*, 161, 111929.

Volume 15, Issue 2, February 2026**|DOI: 10.15680/IJRSET.2026.1502092|**

- [54] Awwad, A. K. L., & Amer, M. (2020). Biosynthesis of copper oxide nanoparticles using *Ailanthus altissima* leaf extract and antibacterial activity. *Chemistry International*.
- [55] Vidovix, T. B., Quesada, H. B., Januário, E. F. D., Bergamasco, R., & Vieira, A. M. S. (2019). Green synthesis of copper oxide nanoparticles using *Punica granatum* leaf extract applied to the removal of methylene blue. *Materials Letters*, 257, 126685.
- [56] Vasantharaj, S., Sathiyavimal, S., Saravanan, M., Senthilkumar, P., Gnanasekaran, K., Shanmugavel, M., ... & Pugazhendhi, A. (2019). Synthesis of ecofriendly copper oxide nanoparticles for fabrication over textile fabrics: characterization of antibacterial activity and dye degradation potential. *Journal of Photochemistry and Photobiology B: Biology*, 191, 143-149.
- [57] Geremew, A., Palmer, L., Johnson, A., Reeves, S., Brooks, N., & Carson, L. (2024). Multi-functional copper oxide nanoparticles synthesized using *Lagerstroemia indica* leaf extracts and their applications. *Heliyon*, 10(9).



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