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Research Article

Biogenic Synthesis of Copper Oxide Nanoparticles Using *E. coli* for Photocatalytic Degradation of Synthetic Textile Dyes

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Abstract

The uncontrolled discharge of synthetic dyes from the textile industries poses a major threat to freshwater ecosystems, human health and the environment. Conventional dye removal methods often fall short due to inefficiency, high cost, or environmental toxicity. The present study explores an eco-friendly approach to dye degradation through the green synthesis of copper oxide (CuO) nanoparticles using Escherichia coli. The biosynthesized CuO nanoparticles were characterized using UV-Vis spectroscopy, SEM, and FTIR, confirming their nanoscale size, spherical morphology, and functional surface chemistry with Cu–O bonding. Their photocatalytic performance was evaluated against two model textile dyes: Reactive Red and Methylene Blue, representing anionic and cationic dye classes, respectively. Results revealed dose- and time-dependent degradation, with the first 7 hours under sunlight and the remaining period in an incubator at 37 °C. For Reactive Red, 5 ml of CuO NPs achieved 22.33% degradation after 7 hours of sunlight exposure and 25.05% by the end of 24 hours. For Methylene Blue, 5 ml of CuO NPs achieved 10.85% degradation after 7 hours in sunlight and 14.32% after 24 hours. Reactive Red dye was consistently degraded more efficiently than Methylene Blue, likely due to its azo structure interacting more effectively with CuO catalytic sites. The study demonstrates that biologically synthesized CuO nanoparticles offer a cost-effective, sustainable, and efficient solution for dye-laden wastewater remediation. These findings highlight the potential of microbially mediated nanotechnology for real-world environmental applications and contribute to the growing shift toward green chemistry in pollutant treatment systems.

Keywords: Reactive red, methylene blue, biosynthesis, copper oxide nanoparticles, dye degradation, nanotechnology

1. Introduction

The textile industry stands amongst the leading contributors to global water pollution [1]. From the cultivation of raw fabrics to the final stages of garment production, the industry consumes millions of tons of freshwater and discharges heavily contaminated effluents into the aquatic bodies. These effluents often contain toxic chemicals, heavy metals, and synthetic dyes, which not only alter the physicochemical properties of aquatic ecosystems but also pose severe threats to aquatic life and human health. Historically, textiles were dyed using natural colourants extracted from natural sources, such as plants (indigo, madder and turmeric) insects (cochineal insects), animals (cuttlefish, octopus) and minerals [2]; However, following the industrial revolution, there was a paradigm shift towards the use of synthetic dyes, which now dominate the market due to their

vibrant hues, broad colour range, superior binding properties and cost effectiveness [3]. As of today, natural dyes account for less than 1% of global synthetic dye consumption [4], highlighting a near-complete dependence on synthetic alternatives. Chemical dyes offer a wide range of more intense colours than natural ones. Colourants include both pigments and dyes [5]. Pigments are inorganic salts or oxides like lead, chromium, cadmium or oxides of iron, etc.. In contrast, dyes are organic molecules like azo dyes, vinyl sulfone dyes, perylene dyes and coumarin dyes. These are persistent, and so, the colour would not fade after a few washes like natural ones. Hence, chemical dyes are non-biodegradable and are toxic to the environment. To address the growing challenge of textile wastewater management, various treatment strategies have been explored, including adsorption, coagulation, flocculation, membrane filtration, advanced oxidation, and electrochemical degradation [4]. Despite the wide array of dye removal technologies, the mentioned conventional methods suffer from high operational costs, limited reusability, and the generation of secondary pollutants. Moreover, they often fail to achieve complete mineralization of complex synthetic dyes, necessitating more sustainable and advanced alternatives [7]. Among these, nanotechnology is a tool that has lately emerged as a promising frontier due to its ability to offer efficient, cost-effective and eco-friendly and sustainable solutions for pollutant removal. Nanomaterials are those that have at least one dimension in the 1-100 nm range, possessing unique optical, electrical, and catalytic properties compared to their bulk counterparts. According to researchers, the nanoparticles have huge potential to transform almost every aspect of present-day life [8]. Researchers suggest that nanotechnology is the most suitable for today's world because of its economic capacity, development potential, and most importantly, its ability to lessen the demand on finite resources while diminishing environmental pressures. [9]. They have a high surface area-to-volume ratio and unique properties distinct from their bulk counterparts that make them highly effective in various environmental applications. Several studies suggest their successful application in pollutant sensing, degradation and adsorption of toxic compounds. Recent research highlights the growing application of nanoparticles (NPs) in water purification, especially for the degradation of synthetic textile dyes and other organic pollutants [10]. One of the most studied approaches is photocatalysis, in which nanoparticles serve as catalysts that harness light energy (usually UV or visible) to oxidize complex organic molecules into simpler, non-toxic compounds such as water and carbon dioxide [11]. This technique offers the dual advantage of minimal chemical use and complete pollutant mineralization. Among various synthesis methods (chemical, physical and biological), the biological (green) synthesis route has grabbed attention due to its environmentally sustainable, safe, and cost-efficient nature. Green synthesis method avoids hazardous reagents and harsh conditions, relying instead on naturally occurring reducing agents, such as extracts from plants, or enzymes from bacteria, fungi or algae [12]. There has been an increasing interest in producing new functional nanomaterials through biological agents. These biological systems can reduce metal salts into nanoparticles through enzymatic mechanisms, simultaneously acting as both reducing and stabilizing (capping) agents. Synthesizing nanoparticles through microorganisms makes them cheap and effective. They are also a sustainable choice when compared to chemically synthesized particles, as they use harsh chemicals such as in the chemical vapour deposition method, where toxic gaseous thin film is deposited on the substrate and are often left out as by-products. Methods, including the use of high energy, such as in the thermal decomposition process, etc., are also harmful to the environment [13]. In bacterial synthesis, metal salts are reduced into nanoparticles either intracellularly or extracellularly, facilitated by enzymes like nitrate reductases or other bioactive metabolites. In the present paper, *Escherichia coli* is being used for synthesizing copper oxide nanoparticles (CuO NPs). *E. coli* is commonly found in human intestines and is a Gram-negative and non-toxic bacterium that grows rapidly and has potential for large-scale production. Copper (Cu) and its oxides are among the most versatile metals used in nanotechnology due to their high redox potential, catalytic efficiency, antimicrobial properties and relative abundance [14].

Among the wide spectrum of dyes released into the environment Methylene Blue (MB) and Reactive Red (RR) represent two major classes: cationic and azo-based anionic dyes, respectively. Methylene Blue is widely used in the textile, paper and pharmaceutical industries. Although not considered highly toxic in low concentrations, Methylene Blue can cause significant health problems at elevated levels, including methemoglobinemia, gastrointestinal irritation and cyanosis [15, 16]. The major concern with textile effluent is that it persists in water and resists natural degradation, making its removal from effluents imperative. On the other hand, Reactive Red, particularly those in the azo class, are highly water-soluble synthetic dyes used in cotton and wool dyeing. These dyes are of special concern due to their azo bonds (-N=N-), which can degrade into aromatic amines, known carcinogens and mutagens [17]. Reactive Red dyes have a strong affinity for cellulose, which makes their removal from water through conventional methods highly inefficient. Moreover, they are resistant to microbial degradation under natural conditions, leading to long-term environmental persistence. In the present study, Methylene Blue and Reactive Red were chosen as representative dyes to evaluate the catalytic degradation efficiency of biologically synthesized CuO nanoparticles. Their contrasting structures and charge profiles help elucidate the breadth of nanoparticles' potential in removing diverse pollutants from textile wastewater. In environmental remediation, CuO nanoparticles are particularly favoured for dye degradation applications. Copper oxide nanoparticles are one of the widely used metal nanoparticles in wastewater treatment plants, as they are highly reactive and possess superior catalytic properties[18]. Their narrow bandgap (~1.2-1.9 eV) enables absorption of visible light making them excellent photocatalysts under solar irradiation. Moreover, their low cost and high reusability make them a viable alternative to more expensive nanoparticles [19]. These advantages position CuO NPs as an ideal material for sustainable and scalable dye degradation technologies in industrial wastewater management. This study, therefore, focuses on the biological synthesis of copper oxide nanoparticles with the help of *E. coli* and evaluates the dye removal performance against Reactive Red and Methylene Blue, providing a comprehensive understanding of their possible applications in real-world wastewater treatment scenarios.

2. Materials and methods

2.1. Forming strain culture

The *Escherichia coli* (MTCC 443) strain was purchased, and a culture was prepared using *E. coli* by inoculating the strain into Lysogeny broth (LB) at 37℃ in an incubator for 24 hours. The culture was then centrifuged at 10000 rpm for 10 minutes in the Eltek Research Centrifuge (TC 4100) D. The supernatant was used for further synthesis of nanoparticles.

2.2. Nanoparticle synthesis

To synthesize the copper oxide nanoparticle, 20 mL of the supernatant was mixed with 10 mL of 0.05N $CuSO_4$ solution and was incubated for 48 hours at 37℃. The solution was again centrifuged, and the clear supernatant with blackish particles at the bottom of the flask. The pallets were obtained and were further used for characterization and assessing the dye degradation potential of the nanoparticles.

2.3. Characterization

To confirm the synthesis of CuO nanoparticles and to assess their stabilization, various characterization techniques were used. The synthesized particles were taken for further analysis by a UV-Vis spectrophotometer, SEM and FT-IR analysis.

2.4. Dye degradation potential

Reactive Red (RR) and Methylene Blue (MB) dyes were purchased from the local market of Sanganer, Jaipur, Rajasthan and were tested to determine how effective dye degradation is against copper oxide nanoparticles. The following method was used to determine the degradation potential of nanoparticles against both dyes. For this, a 50ppm dye solution was prepared, and 30 ml of this solution was added to 7 different flasks. Then the prepared nanoparticle solution was added at different concentrations as 0.5ml, 1ml, 2ml, 3ml, 4ml, 5ml, to the known dye concentration solution, and one was without nanoparticles and was used as a blank. These solutions were tested at different time intervals in bright sunlight at 0^{th} hour, 2^{nd} hour, 3^{rd} hour, 4^{th} hour, and 7^{th} hour, then these solutions were kept in an incubator at 37℃ without light and tested at 24^{th} hour. To assess the

degradation of dyes at various time intervals, a UV-Vis Spectrophotometer was used. Reactive Red dye degradation was determined at 540 nm, whereas degradation of Methylene Blue dye was studied at 664 nm.

3. Results and discussion

The greenish colour of the metal solution with *E. coli* was changed to a blackish colour after 48 hours of incubation. A visible colour change was observed. Once the incubated mix of supernatant and metal solution was centrifuged to collect the indicated nanoparticles, the blackish particles settled down, leaving clear supernatant, confirming the synthesis of CuO nanoparticles.

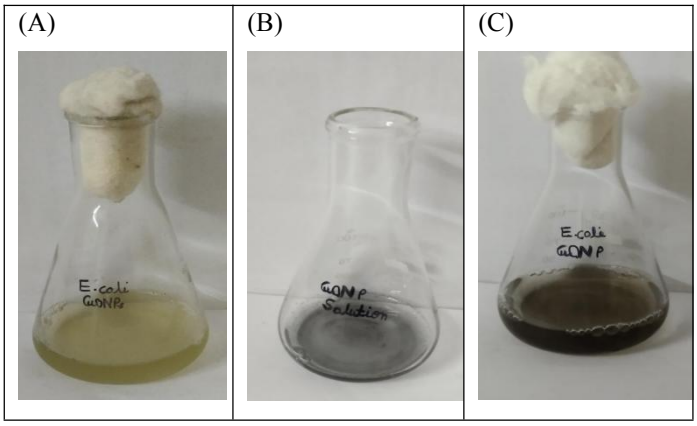

Figure 1. (A) An initial greenish colour was observed when $CuSO_4$ was mixed with LB broth containing *E. coli*. (B) Flask after 48 hours of incubation of $CuSO_4$ solution with *E.coli.* (C) After centrifugation, blackish particles were observed as pellets, and the supernatant appeared clear.

3.1. Characterization

The separated supernatant containing the synthesized nanoparticles was subjected to a series of characterization techniques, including UV-Vis spectroscopy, Scanning Electron Microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy, to confirm their formation, morphology and functional groups.

3.1.1. Ultraviolet-Visible spectrometry study

The ultraviolet-visible region of the electromagnetic spectrum was used as a characterization tool to study nanoparticle formation. The pellets obtained after centrifugation of the incubated $CuSO_4$ solution and *E. coli* mixture were carefully re-dispersed in distilled water and analyzed using UV-Visible spectroscopy (UV mini-1240). A fine peak was observed at 270nm.

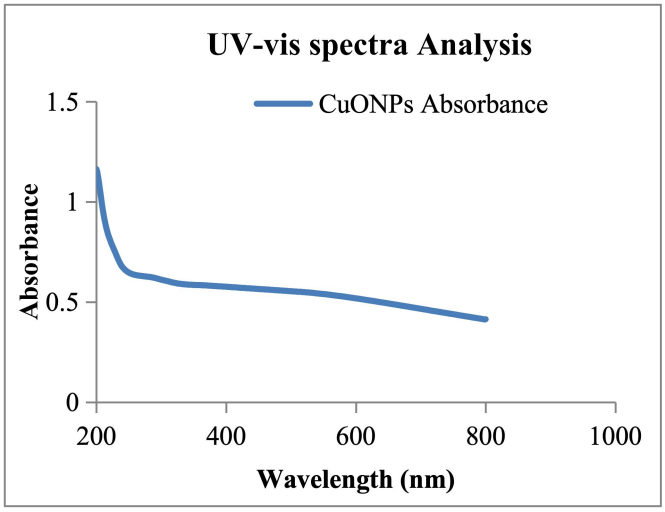

Figure 2. UV-Vis absorption spectrum of biologically synthesized CuO nanoparticles, showing a fine peak at 270nm.

3.1.2. Scanning Eelectron Microscopy (SEM) analysis

The size and surface morphology of synthesized copper nanoparticles were examined using Field Emission Scanning Electron Microscopy (FE-SEM 450, FEI). The SEM micrographs demonstrated spherical morphology of nanoparticles with varying sizes. The size of the smallest particle was approximately 19.3nm, while the average particle size ranged from 19.3nm to 98nm. The SEM analysis provided clear evidence of nanoparticle formation and supported the findings obtained from UV-Vis spectroscopy.

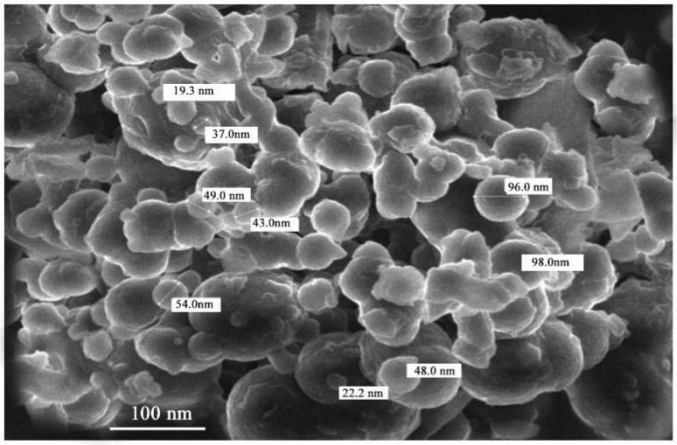

Figure 3. SEM Micrograph of biologically synthesized CuO nanoparticles reveals well-dispersed and predominantly spherical morphology. The observed particle sizes, ranging from 19.3 nm to 98 nm, confirm nanoscale synthesis.

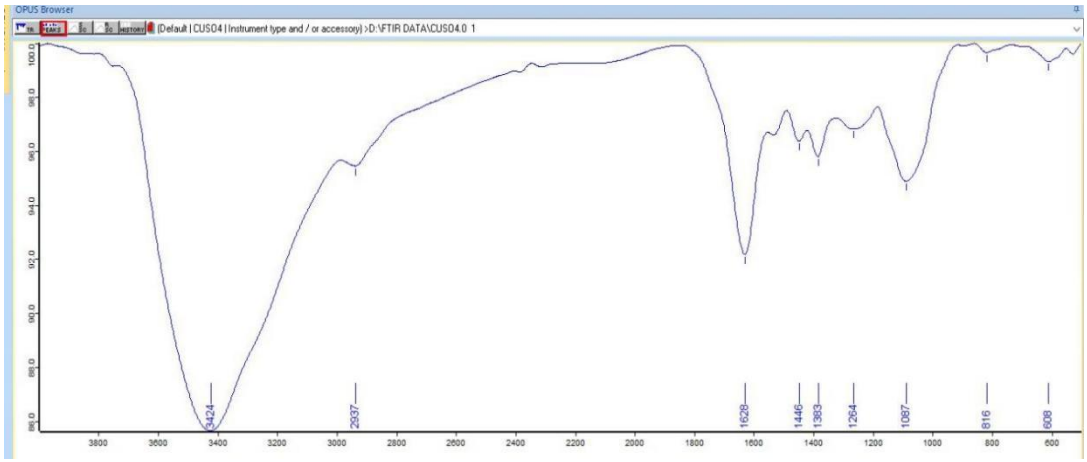

Figure 4. FTIR spectrum of biologically synthesized CuO nanoparticles, exhibiting various absorption bands.

Figure 5. Erlenmeyer flasks containing 50 ppm Reactive Red dye solution immediately after the addition of varying volumes of biologically synthesized CuO nanoparticles (0.5 ml to 5 ml). The first flask is without nanoparticles. All flasks appear uniformly pink, indicating that no immediate decolourization has taken place at the onset of the reaction.

Figure 6. The same set of flasks as Figure 5, when kept in sunlight for up to 7 hours. A progressive reduction in pink colour intensity is observed with the increasing volumes of CuO nanoparticles, indicating dose-dependent degradation of the dye. The control flask remains unchanged, which confirms that the observed decolourization is due to the photocatalytic activity of CuO nanoparticles.

Figure 7. Same set of flasks as Figure 5, after 24 hours (without sunlight) of incubation at 37℃. A reduction is again observed in pink colour intensity with respect to Figure 6 with the increasing volumes of CuO nanoparticles, indicating dose-dependent degradation of the dye even without sunlight. The control flask remains unchanged, which confirms that the observed decolourization is due to CuO nanoparticles.

3.1.3 Fourier Transform Infrared (FTIR) spectral analysis

FTIR Spectrum 2 (Perkin Elmer) was used to confirm the formation and stabilization of biologically synthesized CuO NPs The FTIR spectrum depicts the band absorption at 3424 cm^{-1}, which is due to O-H stretching vibration, typically from hydroxyl groups in water or phenolic compounds, suggesting the involvement of alcohols or polyphenols (from biological agents) in capping or stabilizing the nanoparticles. Absorption at 2937 cm^{-1} suggests C-H stretching of $-CH_2$ groups, indicating the presence of organic molecules, likely from biomolecules or reducing agents used in synthesis. The presence of band absorption at 1628 cm^{-1} is due to C=O stretching of amide or carboxyl groups, which can interact with the nanoparticle surface and contribute to stabilization. Corresponding to C-O stretching vibrations depicted at 1264 cm^{-1} and 1087 cm^{-1} are likely from alcohols or phenolic groups, which contribute in reducing and stabilizing metal ions. The band absorption at 816 cm^{-1} and 608 cm^{-1} are low-frequency bands attributed to Cu-O stretching vibrations, providing confirmed evidence for the synthesis of copper oxide (CuO) nanoparticles. The presence of functional groups like hydroxyl, carbonyl and amine groups indicates the involvement of biological molecules in reducing Cu^{2+} ions and the subsequent stabilization of the CuO nanoparticles. The prominent Cu-O bands below 700 cm^{-1} confirm the successful formation of CuO NPs.

3.2 Reactive Red Dye Degradation Potential

The change in the absorption spectra of Reactive Red with time after the photocatalytic degradation for up to 7 hours is shown in Figure 6, and overall degradation with and without light up to 24 hours is shown in Figure *7* . The Figure *8* graph shows a decrease in the concentration of the dye with increasing nanoparticle concentration in the dye solution over time.

The decolourization and dye degradation efficiency have been calculated by following equation 1.

$$E\% = [(C_0 - C_e)/C_0)] * 100 \qquad \text{Equation (1)}$$

where C_0 is the initial dye absorbance obtained without the interference of nanoparticles. And C_e is the final dye absorbance with nanoparticle interaction with the dye. The table 1 suggest degradation efficiency at different concentrations of nanoparticles at different time intervals. In the equation (1), E% represents the percentage of dye degradation.

After 24 hours, the degradation percentage of the dye with 5 mL of nanoparticles was 25.05%.

Table 1. Decolourization Efficiency (%) of Reactive Red Dye by varying concentrations of CuO nanoparticles over time.

CuO NP Conc. (ml)	E% at 2 hr	E% at 3 hr	E% at 4 hr	E% at 7 hr	E% at 24 hr
0	1.83%	-0.66%	2.93%	3.60%	3.74%
0.5	7.75%	10.91%	14.08%	21.55%	25.64%
1	6.83%	11.12%	13.38%	21.52%	25.45%
2	6.39%	10.50%	13.73%	22.04%	25.27%
3	5.58%	9.67%	13.55%	22.63%	24.64%
4	6.58%	8.55%	13.39%	21.87%	24.22%
5	7.54%	9.20%	14.49%	22.33%	25.05%

Note: CuO NP Conc. (ml)-Copper oxide nanoparticle, E%- Decolourization efficiency, hr-Hour(s)

The data reveal a clear and consistent increase in decolourization efficiency (E%) of Reactive Red dye with increasing CuO nanoparticle concentration and incubation time. In the control group (0ml CuO NPs), the dye showed minimal degradation when kept in sunlight with only ~1.8% to 3.6% reduction in 7 hours, whereas, after incubation without light, degradation efficiency was observed at 3.7% (similar to degradation efficiency at 7 hours) even after 24 hours. The addition of CuO nanoparticles resulted in a marked increase in dye removal with respect to time. The efficiency improves progressively from 2 hours to 7 hours in sunlight, while slight progress can be seen from 7 hours to 24 hours without sunlight. For example, at 5 ml CuO NPs, the decolourization efficiency increased from 7.54% at the 2nd hour to a maximum of 22.33% at the 7th hour, while 25.05% degradation efficiency was observed at 24 hours. Similar trends were observed across all tested concentrations (0.5-5 ml), with the highest degradation consistently recorded at the 5 ml level. Notably, the increase in degradation was more pronounced between 2-7 hours, indicating optimal photocatalytic activity at that point and plateaued slightly by 24 hours, which shows CuO holds dye degradation capacity even without the presence of sunlight. These observations affirm that biologically synthesized CuO nanoparticles are effective photocatalysts for Reactive Red dye degradation, and that both concentration and contact time are critical parameters influencing removal efficiency. The results strongly support the potential application of CuO nanoparticles in dye-contaminated wastewater treatment, especially for persistent azo dyes like Reactive Red.

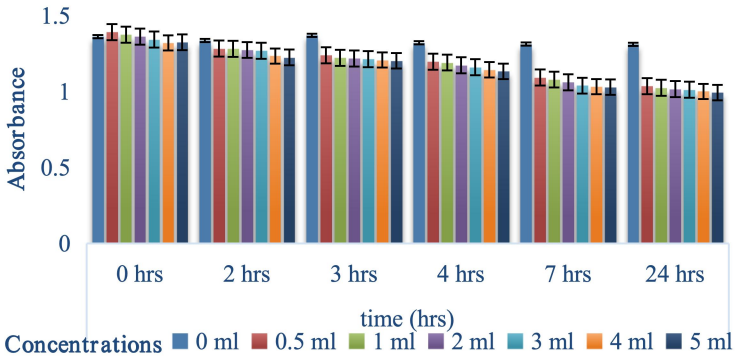

Figure 8. Variation in UV-Vis absorbance with time for the 50ppm Reactive Red dye solution at different concentrations of CuO nanoparticles, demonstrating their dye degradation potential.

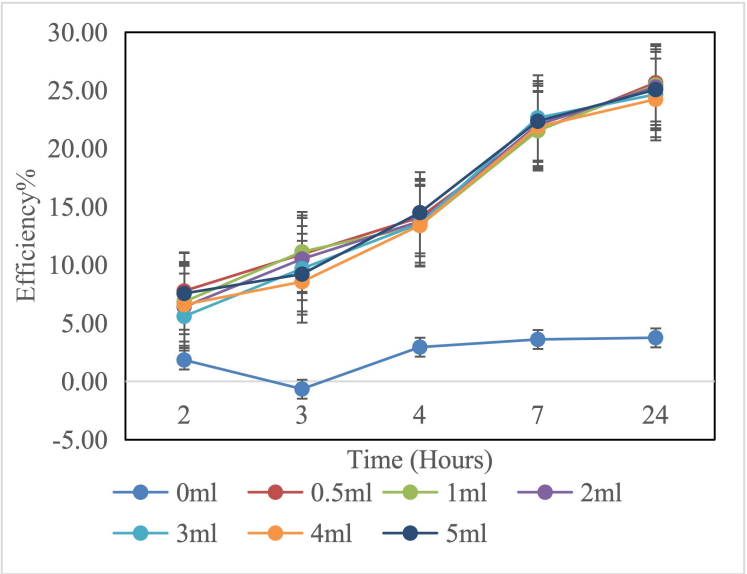

Figure 9. A line graph showing the Dye degradation efficiency of the 50 ppm Reactive Red dye solution at different concentrations of CuO nanoparticles, illustrating that higher concentrations enhance the rate and extent of degradation with time.

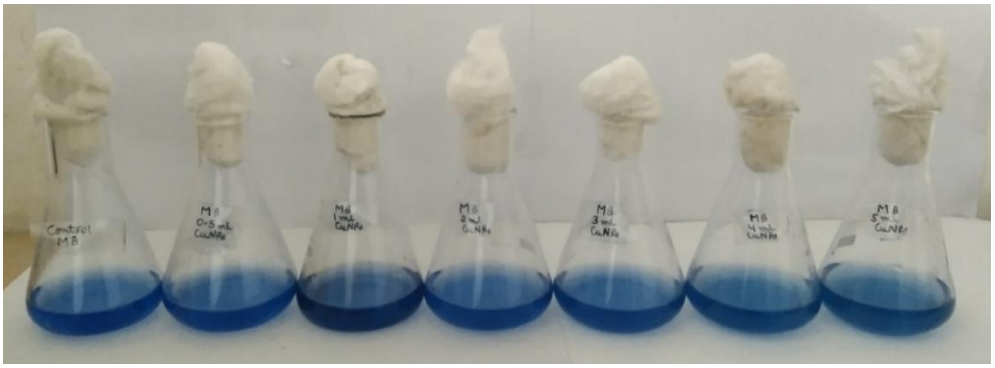

Figure 10. The image displays a set of Erlenmeyer flasks containing 50 ppm of methylene blue dye. The control flask (leftmost) contains dye only, while the remaining flasks were supplemented with increasing volumes of CuO nanoparticles (0.5 ml to 5 ml). At this initial time point, all flasks retain their deep blue colour, indicating that the nanoparticles have not yet significantly altered the dye concentration.

Figure 11: The same set of flasks as Figure 10, was kept in sunlight for up to 7 hours. A gradual reduction in Methylene Blue colour intensity is observed with the increasing volumes of CuO nanoparticles, indicating dose-dependent degradation of the dye.

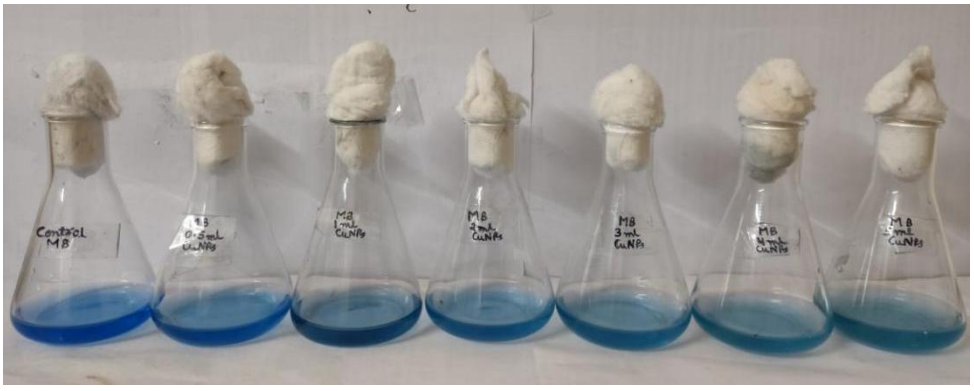

Figure 12. This image shows the same set of flasks after 24 hours, which, after 7 hours, was kept for incubation at 37℃ with no sunlight with CuO nanoparticles. A visible decline in colour intensity is noted as the nanoparticle volume increases, suggesting enhanced photocatalytic degradation of methylene blue. The control flask remains unchanged, confirming the role of CuO nanoparticles in the breakdown of the dye.

3.3. Methylene blue dye degradation potential

The change in the absorption spectra of Methylene Blue with time during the photocatalytic degradation in sunlight (up to 7 hours) is shown in Figure 11 and in an incubator at 37℃ with no light (up till 24 hours) in the aqueous medium is shown in Figure 12. A steady decrease in dye concentration

was observed as the concentration of nanoparticles in the dye solution increased over time, both with and without sunlight. Up to 1.59% of degradation was noted in the dye solution without nanoparticles, when it was kept in sunlight for up to 7 hours; however, 2.42% degradation efficiency was observed after 24 hours when it was kept in incubation at 37℃. When kept in 7 hours of sunlight, the dye solution with 5mL of nanoparticle solution showed a degradation efficiency of 10.85% and after 24 hours, a 15.53% degradation was observed. A similar observation was made across all other concentrations (0.5ml-5ml).

The results demonstrate a time- and dose-dependent increase in decolourization efficiency (E%) of Methylene Blue dye when treated with biologically synthesized CuO nanoparticles. At all times, the control sample (0ml) showed minimal or negligible dye degradation, confirming that CuO nanoparticles are the active agent responsible for the observed decolourization. As the nanoparticle concentration 0.5 ml to 5 ml, the efficiency also improved consistently across all time intervals. After just 2 hours, the degradation efficiency was modest (3.05%). Still, it gradually increased over time, reaching over 10.85% at 7 hours in broad daylight, and exhibited a slight degradation of 14.32% after 24 hours (without light in incubation at 37℃) at a 5 ml concentration. This trend was observed across all concentrations, with maximum dye removal achieved at 7 hours, indicating the effectiveness of CuO nanoparticles as a catalyst. The maximum degradation efficiency was noted in the dye solution with 5ml of nanoparticle concentration, emphasizing the importance of nanoparticle loading. Overall, these results validate the photocatalytic potential of CuO nanoparticles in degrading Methylene Blue dye and suggest that both prolonged light exposure time and higher nanoparticle concentrations enhance degradation performance. CuO nanoparticles even continued to degrade the dye without sunlight as well. This trend highlights the potential application of CuO nanoparticles in wastewater treatment, particularly for persistent synthetic dyes like Methylene Blue.

Table 2. Decolorization Efficiency (%) of Methylene Blue Dye by varying concentrations of CuO nanoparticles over time.

CuO NP Conc. (ml)	E% @ 2 hr	E% @ 3 hr	E% @ 4 hr	E% @ 7 hr	E% @ 24 hr
0	0.67%	0.33%	1.09%	1.59%	2.42%
0.5	2.43%	4.27%	5.36%	8.45%	11.71%
1	2.60%	4.36%	6.38%	8.56%	12.24%
2	2.86%	4.55%	6.90%	8.50%	12.45%
3	2.62%	4.57%	6.77%	8.88%	12.69%
4	2.46%	4.93%	6.63%	9.69%	12.99%
5	3.05%	5.34%	7.29%	10.85%	14.32%

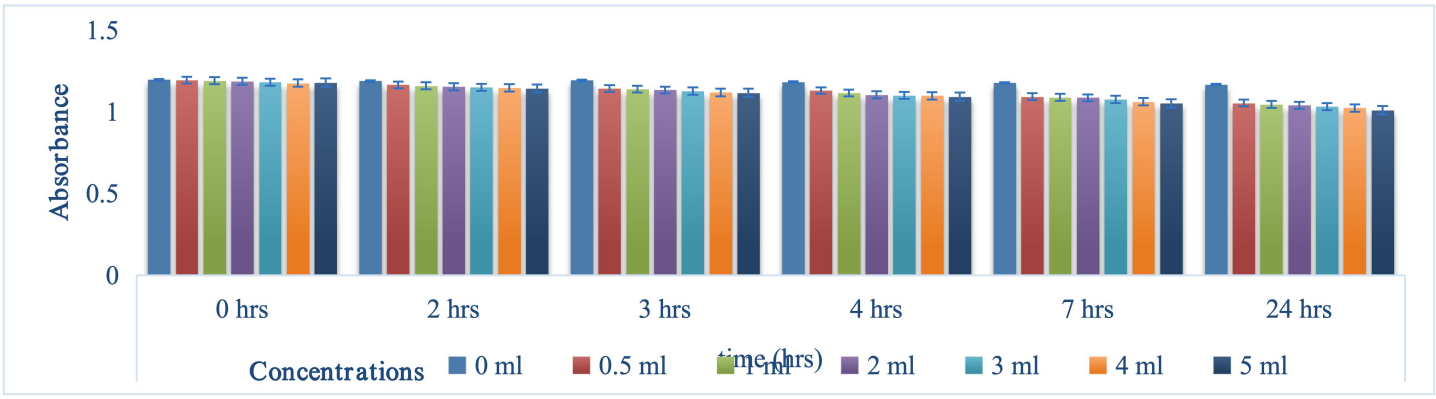

Figure 13. Variation in UV-Vis absorbance with time for the 50ppm Methylene Blue dye solution at different concentrations of CuO nanoparticles, depicting their dye degradation potential.

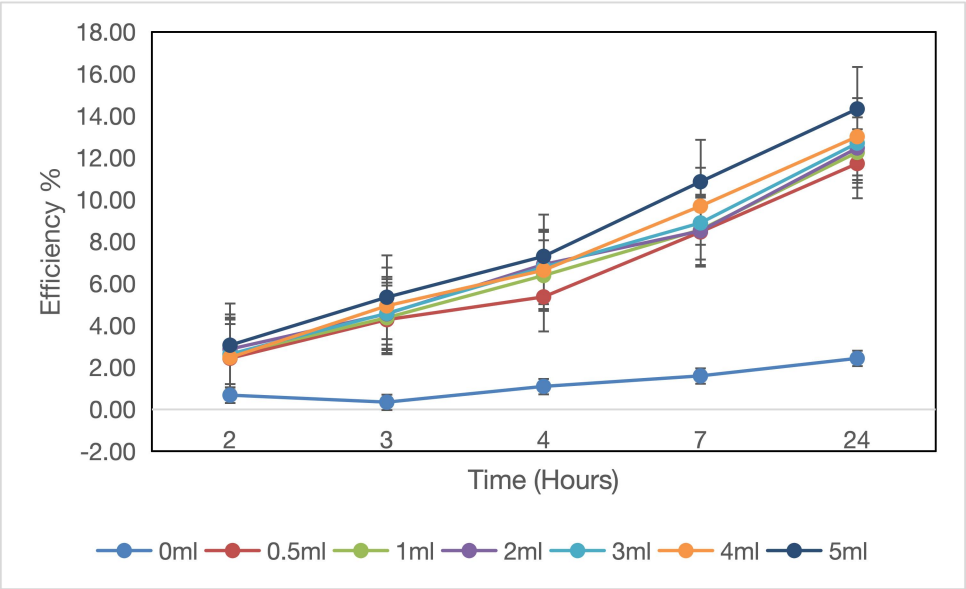

Figure 14. A line graph showing Dye degradation efficiency (%) of the 50 ppm Methylene Blue dye solution at different concentrations of CuO nanoparticles, demonstrating that higher concentrations enhance the rate and extent of degradation of the dye with time.

4. Conclusion

In response to the urgent need for sustainable solutions to combat water pollution from the textile industry, this study successfully demonstrates the biosynthesis of copper oxide (CuO) nanoparticles using *Escherichia coli*, a commonly available, non-pathogenic bacterium. The biological synthesis approach not only eliminates the need for toxic reagents and energy-intensive conditions but also offers a scalable, eco-friendly route to nanoparticle production. The successful formation of CuO nanoparticles was confirmed through UV-Vis spectroscopy (showing a distinct peak at 270 nm), SEM imaging (revealing well-dispersed, spherical particles in the 19–98 nm range), and FTIR analysis, which confirmed the presence of Cu–O bonds and surface functional groups from biological capping agents. The photocatalytic efficiency of these nanoparticles was evaluated against two structurally and chemically distinct textile dyes—Reactive Red and Methylene Blue—both widely used as model pollutants in wastewater studies. The dye degradation experiments revealed that CuO nanoparticles exhibit dose- and time-dependent photocatalytic activity under sunlight as well as in the absence of light. The results demonstrated a clear time- and dose-dependent increase in decolourization efficiency in both dyes. The highest dye degradation efficiency was observed in Reactive Red dye solution containing 5 ml of biosynthesized CuO nanoparticle solution, the dye removal rate was 22.33% in sunlight and after incubation for 24 hours, it was 25.05%. In Methylene Blue solution with a 5 ml concentration of biosynthesized CuO nanoparticles the dye degradation efficiency was 10.85% after 7 hours of sunlight exposure and up to 14.32% after 24 hours of incubation. Hence, CuO nanoparticles were able to degrade dyes in the presence of sunlight; however, even in the absence of light, a slower yet noticeable degradation of the dyes was observed. This property is beneficial, as it suggests the potential applicability of these nanoparticles for on-site wastewater treatment under both light and dark conditions. Overall, biosynthesized CuO nanoparticles showed better degradation efficiency with Reactive Red dye than Methylene Blue dye. The superior degradation of Reactive Red may be attributed to its azo structure, which interacts more effectively with the catalytic sites of CuO. Control samples showed negligible change, reaffirming that the observed activity was due to the catalytic action of CuO nanoparticles. Altogether, the study not only validates the photocatalytic effectiveness of *E. coli*-mediated biosynthesis of CuO NPs but also reinforces their applicability in the treatment of dye-laden industrial effluents. The work highlights the importance of biogenic nanomaterials in

developing low-cost, environmentally friendly wastewater treatment technologies, with promising implications for broader industrial adoption and enhanced environmental health. Future research can expand upon this foundation by exploring other dye classes, optimizing synthesis conditions, and scaling up for real-world applications.

Authors Contribution

Ms. Rajita Patni performed experiments and collected literature related to nanoparticle synthesis. Dr Pankaj Kumar Jain compile the data, and Dr Prama Esther Soloman and Dr Chhagan Lal describe the applications of nanoparticles in textile dye degradation. All the authors read and approved the final manuscript for submission.

Conflicts of Interest

There are no conflicts of interest reported by the writers.

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Data Availability statement

The data presented in this study are available on request from the corresponding author.

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