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Sustainable Green Synthesis, Characterization and Anti-Microbial Testing of Cu-Based Metal-Organic Framework (MOF)/TiO_2 Nanocomposites Derived from *Cinnamomum Verum* Bark

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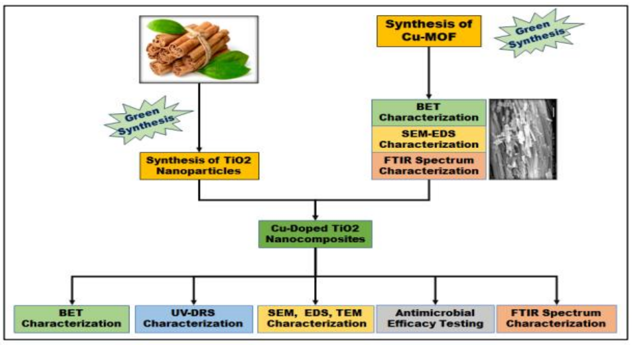
ABSTRACT

This research work is aimed at green synthesis with sustainability towards the production of copper (Cu)-Based Metal Organic Framework (MOF) and their doping in titanium dioxide (TiO_2) nanoparticles synthesized using a natural reductant and stabilizer, *Cinnamomum verum (C. verum)* bark extract. It is an eco-friendly synthesis technique because the bioactive compounds such as flavonoids and polyphenols present in *C. verum* help reduce and stabilize metal ions, thus replacing toxic chemicals. The synthesized Cu-doped TiO_2 nanocomposites are found to absorb increased visible light owing to the reduced bandgap from copper doping, as observed by UV-Vis Diffuse Reflectance Spectroscopy (UV-DRS). The scanning electron microscopy and energy-dispersive X-ray spectroscopy analysis of the synthesized nanocomposites indicates that the distribution of Cu in the TiO_2 matrix is uniform, which offers structural stability and functional efficacy. Well-diffusion experiments on antimicrobial studies reveal that the nanocomposites produced by this process have excellent antimicrobial activity, especially towards *Staphylococcus aureus.* This is attributed to the photoinduced generation of ROS, which can break cell walls and interfere with microbial cell metabolism. The synthesis process for this Cu-TiO2 nanocomposite is totally in compliance with green chemistry principles and produces nanocomposites having strong antimicrobial and photocatalytic action. These results outline the grand potential of green methods-prepared Cu-doped TiO_2 nanocomposites to be used in antimicrobial coatings, environmental remediation, and much more - opening a promising route towards sustainable nanotechnology development.

GRAPHICAL ABSTRACT



Keywords- Marble industry, soil contamination, heavy metals, pesticide interactions, environmental impact, soil remediation.

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I. INTRODUCTION

The revolutionization in nanotechnology have opened new avenues for innovative approaches, particularly in medicine, agricultural, energy, and environmental applications [1]. Copper-based metal-organic frameworks, or Cu-MOFs, occupy the modern frontiers of nanochemistry, holding much promise for versatile platforms in molecular engineering and nanoscale innovations [2]. Organic linkers lend with copper ions to provide exact control over both structure and functional tunability, besides properties that make Cu-MOFs especially apt for catalysis, gas storage, and targeted drug delivery applications [3]. Nanocomposites containing them find enhanced stability, conductivity, and reactivity: they are therefore essential tools in pushing the envelope for sustainable and high-performance nanotechnologies. One of the promising approaches in this sector is the synthesis of metal-doped titanium dioxide (TiO_2) nanocomposites have garnered attention for their potential physicochemical properties especially in photocatalysis and antimicrobial efficacy [4]. The green synthesis strategies of such nanomaterials have emerged as eco-friendly, cost-effective and sustainable alternative to traditional chemical methods. Utilizing biological agents such as plant extracts to reduce and stabilize metal ions and avoid harmful chemicals and generate product with fewer toxicity [5[. In this context, the bark of *C. verum*, an Indian spice plant reported for its potential phytochemicals offers a promising natural source of reductant and stabilizer for nanomaterial synthesis [6, 7]. This study focuses on the sustainable green synthesis of copper (Cu)-doped TiO_2 nanocomposites using bark extract of *C. verum*, evaluation of their antimicrobial potential against pathogenic microorganisms.

Phytosynthesis is considered as eco-friendly method due to its scalability, simplicity and minimize environmental impact [8]. *C. verum* bark, plethora of bioactive compounds like flavonoids, alkaloids and polyphenols, acts as a reducing, capping and stabilizing agents during nanoparticle formation [7]. These phytochemicals not only facilitate the reduction of metal ions but also enhance the biological properties of the resulting nanocomposites through impartment of functional groups. Recent studies reported effectiveness of plant-mediated synthesis in producing nanoparticles with controlled size, increased stability, and enhanced antimicrobial efficacy [9]. For instance, TiO_2 nanoparticles synthesized using *Ocimum sanctum* extract exhibited remarkable antimicrobial properties [10], making *C. verum* a significant choice for present study.

Copper doping has been globally studied to improve TiO_2's photocatalytic efficiency and antimicrobial activities. While TiO_2 itself is a well-documented photocatalyst and antimicrobial agent due to its large bandgap limits its use to UV light, chemical stability and non- toxicity. Moreover, copper ions contribute to the antimicrobial activity of the nanocomposites by generating reactive oxygen species (ROS), which disrupt microbial cell membrane and interfere in their metabolism [11]. Past recent studies have highlighted that Cu-doped TiO_2 nanoparticles exhibit prominent antimicrobial potential compared to undoped TiO_2, particularly against drug-resistant bacterial species [12].

The paradigm shift towards sustainable green synthesis strategies is crucial in addressing environmental concerns associated with traditional chemical paths. Traditional synthesis techniques like sol-gel, chemical vapour deposition and hydrothermal synthesis often involve harsh chemicals, costly equipment and high energy consumption making them less sustainable [13]. In contrast, green synthesis using plant extracts offers a low-cost sustainable approach that align principles of green chemistry. The use of *C. verum* bark extract as a natural reductant eliminates the need for toxic reducing agents and introduces functional groups that can improve the surface properties and bioactivity of the nanocomposites [14]. This approach not only reduces environmental impact but also holds potential for large-scale applications in antimicrobial therapies and environmental remediation.

The antimicrobial action of Cu-doped TiO_2 nanocomposites is driven by the generation of ROS under light exposure, which damages bacterial cell membranes and proteins, ultimately causing cell death. Copper ions further enhance these effects by disrupting cell walls and interfering with essential microbial processes [15, 16]. These nanocomposites have shown effectiveness against a broad spectrum of pathogenic bacteria, including drug-resistant strains, making them promising candidates for combating antibiotic resistance [17].

Present study explores the sustainable green synthesis of Cu-doped TiO_2 nanocomposites using *C. verum* bark extract and highlights their potential as antimicrobial agents. The synergy between TiO_2's photocatalytic activity and copper's antimicrobial properties, combined with the eco-friendly synthesis method, offers a viable solution to current challenges in antimicrobial resistance and environmental sustainability.

II. MATERIAL AND METHODS

Chemicals and Regents

Titanium (IV) isopropoxide ($Ti (OiPr)_4$) served as the titanium source, while Copper (II) nitrate ($Cu (NO_3)_2$) was employed as the copper dopant, with distilled water as the solvent and hydrochloric acid (HCl) for pH control. All chemicals used in present study were certified analytical grade reagents, purchased directly from Sigma-Aldrich (India) and used without additional in-house purification.

2.1. Synthesis of Cu-Metal Organic Framework (MOF)

Catalytic Cu-MOF was synthesized by a modified process from a previous publication (References

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23, 24). This entailed dissolving 0.24 grams (1 mmol) of copper (II) nitrate trihydrate and 0.24 grams (1 mmol) of 1,4-benzenedioic acid successively in 20 mL of N,N-dimethylformamide, DMF, while stirring and ensuring that the resulting solution was uniform. This was then charged into a 25 mL autoclave reactor and exposed to pressure at 80°C for 4 hours. This reduced significantly the synthesis time and temperature compared to other methods that even require 24 hours at 100°C. Upon cooling to room temperature, the precipitate was separated by centrifugation to yield turquoise powder for Cu-MOF.

Then, the obtained Cu-MOF was soaked in a Soxhlet extractor for 24 hours with dichloromethane as the solvent to remove all the residual DMF molecules from the framework cavities and ensure the full activation of the catalyst. ICP-OES confirmed that the synthesis was efficient by revealing the content of Cu in the Cu-BDC structure to be about 45.95%. Extremely surprisingly, combining the subterranean radiation with the help of pressure inside the reactor was a very pivotal step in improving the efficiency of the process with the synthesis of Cu-MOF within a much shorter time span and at a significantly lower temperature than the previously reported methods. Synthesized Cu-MOF was characterized by BET and SEM/EDS to reveal surface area and elemental composition of Cu-MOF respectively. Fig. 1 shows the synthesis of Cu-MOF.

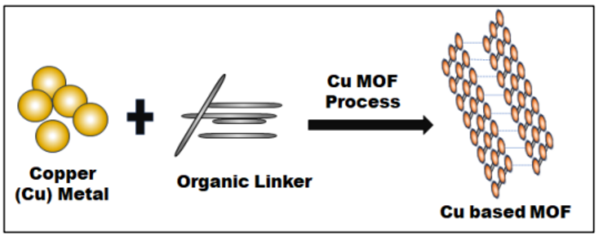

Figure 1: Synthesis of Cu-MOF.

2.2 Characterization of Cu-MOF

Synthesized Cu-MOF was characterized by BET and SEM/EDS to reveal surface area and elemental composition of Cu-MOF respectively. FTIR analysis of Cu-MOF was carried out to understand presence of functional groups.

2.3 Synthesis of TiO_2 Nanoparticles Using Cinnamon Bark Extract

Initially, a cinnamon bark extract was prepared by weighing 10 grams of dried *C.verum* bark and heating it in 100 mL of distilled water at 50–60°C for 60 minutes with constant stirring to release bioactive compounds. The solution was then filtered to obtain a clear *Cinnamon* extract, which served as a natural reducing and stabilizing agent. A mixture of 40 mL of the C. verum extract and 40 mL of Titanium (IV) isopropoxide (TTIP) in a ratio of 1:1 was prepared with continuous stirring. Colour changes were noticed after 30 min, indicating the reduction of the titanium ions. Ammonia 8 mL was added for pH adjustments and precipitation of the nanoscale material. The suspension was filtered, washed with ethanol, and dried into powder. The suspension was then calcined at the optimized temperature in order to increase the crystallinity of the TiO_2 nanoparticles.

2.4 Synthesis of Cu-Doped TiO_2 Nanocomposites

To initiate synthesis, Titanium (IV) isopropoxide (Ti $(OiPr)_4$) was dissolved in deionized water with a stirring condition to achieve a clear solution of the titanium precursor. Meanwhile, copper precursor solution is obtained through the dissolution of Copper (II) nitrate (Cu $(NO_3)_2$) in distilled water. Titanium and copper precursor solutions are controlled at the intended molar ratio of 1:0.1. The combination of the titanium and copper precursor solutions is carried out dropwise at constant stirring conditions. Addition of HCl to this mixture was done dropwise while adjusting the pH to 2-3 for a good hydrolysis and condensation process of precursors. This mixture is transferred to the hydrothermal reactor, sealed afterwards. The system was heated between 100-200°C and this temperature was kept at a pressure level of 10-50 bar for 2-24 hours. This hydrothermal condition permitted nucleation and crystal growth in the Cu-doped TiO_2 nanocomposite through the activation of crystals and uniform doping. Following this hydrothermal reaction, autoclave temperature returned back to room temperature naturally before removing any precipitated material called the Cu-doped TiO_2. Washing is continued multiple times in a clean deionized water, a little ethanol also and lastly dried by any clean drying oven before doing characterizations. The powder washed was dried at 60-80°C for a few hours in an oven to remove any adsorbed moisture and to get fine, dry Cu-doped TiO_2 powder.

2.5 Characterization of Cu-Doped TiO_2 Nanocomposite

2.5.1 UV-Vis Diffuse Reflectance Spectroscopy (UV-DRS)

The optical properties of Cu-doped TiO_2 the nanocomposites were scrutinized using UV-Vis Diffuse Reflectance Spectroscopy (UV-DRS) to get knowledge regarding the range of the absorbed spectrum and the determination of the bandgap for this material. A series of measurements from 200 nm to 800 nm from the Shimadzu UV-2600 spectrophotometer were obtained after referring to the baseline by applying a BaSO4 substance. The Kubelka Munk function as well as the Tauc plot analysis was used to perform some estimation of the bandgaps of these materials towards a shift obtained due to copper doping.

2.5.2 Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) and Transmission electron microscopy (TEM)

Morphology and composition were explored using SEM/EDS and TEM with a JEOL JSM-7600F microscope. SEM results had particle size and morphology information and EDS confirmed the Cu within TiO_2. In addition, samples were measured at 15 kV

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Volume-4 Issue-2 || April 2025 || PP. 18-26

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after gold coating, whereby EDS mapping confirmed incorporation of Cu into the nanocomposites uniformly, ensuring that the nanocomposite has been synthesized and doped successfully.

2.5.3. Surface area measurement using Brunauer–Emmet–Teller (BET) method analysis

The surface area of Cu-doped TiO_2 nanocomposites was measured using the Brunauer–Emmett–Teller (BET) method by a Micrometrics Gemini 2360 surface area analyzer. In this process, the nitrogen gas molecules were absorbed on the solid surface of the Cu-doped TiO_2 to measure the material surface area with precision. The Cu-doped TiO_2 samples were prepared first by degassing in a Gemini Vac Prep degasser to dry the samples and ensure removal of all contaminants. The samples after preparation were subjected to single/multipoint adsorption technique to measure the effective surface area.

2.5.4. Fourier Transform Infrared Spectroscopy (FTIR) analysis of TiO2 nanoparticles and Cu-doped TiO_2 nanocomposites

Samples for FTIR analysis were prepared by diluting the Cu-doped TiO_2 composite before and after doping materials with acetone to facilitate separation and purification. The diluted samples were then centrifuged, followed by five rounds of acetone washes to eliminate any substances that may have physically adsorbed onto the Cu-doped TiO_2 surfaces. The resulting powders were thoroughly dried at 100 °C for 48 hours to ensure the removal of residual solvents. Characterization of the dried Cu-doped TiO_2 powders was conducted using a high-resolution FT/IR-4600typeA spectrometer (JASCO Instruments), set at a 4 cm^{-1} resolution. Spectral data spanned a range from approximately 400 cm^{-1} to 7800 cm^{-1}, capturing significant transmittance peaks characteristic of Cu-doped TiO_2, which reflect functional groups and bonding patterns essential for understanding the material's surface chemistry and structural properties.

2.5.5. Analysis of antimicrobial activity

To investigate the antimicrobial activity of Cu-Doped TiO_2 Nanocomposites, a well diffusion method was performed as per previously published protocol. Briefly, previously identified strains of *E. coli, S. pyogenes and S. aureus* were revived by inoculating a loop full of bacterial culture in nutrient broth from the stock maintained at 4 °C and incubated overnight at 37 °C in a shaker incubator at 800 rpm. Nutrient agar plates were prepared and spreading of 60 µl of each bacterial culture with density of 0.5 MacFarland standard was carried out and 1cm well bored on inoculated plate. Different concentrations such as 120 µg/ml, 160 µg/ml, 200 µg/ml, and 240 µg/ml of Cu-Doped TiO_2 Nanocomposites were loaded into the well the bacterial spread plates followed by incubation overnight at 37 °C. The observed zone of inhibition was measured in mm against the commercially available antibiotic Penicillin.

III. RESULTS AND DISCUSSION

3.1 Characterization of Cu-MOF

BET characterization of the prepared Cu-MOF catalyst revealed good surface area and porosity properties. At a sample mass of 0.0499 g, it had a relatively large specific surface area, as, BET of 400.22 m^2/g, calculated within the limit of the BET range (p/p0 = 0.044732) **(Figure 2 C)**.

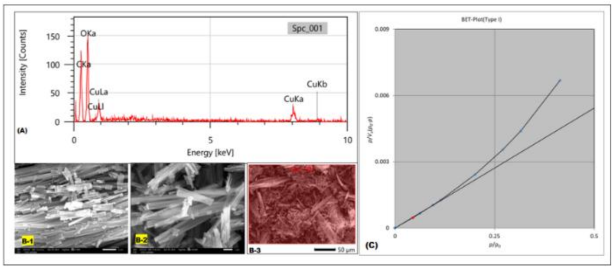

Figure 2: Characterization of Cu-MOF (A) EDS Spectra; (B 1-3) SEM image taken at 500X magnification (C) BET Plot

With such large surface area, this porous structure is pretty well developed and is essential for the catalytic purposes. The totality of pore volume was 0.2341 cm^3/g and the mean pore diameter calculated at 2.3396 nm; the Cu-MOF fell in mesoporous range. With Vm being the monolayer volume, it was computed at 91.952 cm^3(STP)/g; thus, the high potential of the nitrogen adsorption should be inferred from this. Importantly, the linear regression of BET plot showed an excellent correlation coefficient of 0.9998, ensuring high reliability in surface area measurement. These properties collectively confirm that a structure of Cu-MOF synthesized under optimized conditions provides large surface area and optimum pore dimensions conducive to enhanced catalytic performance. The use of pressure synthesis at 80°C, with further activation, provided better textural properties but significantly reduced synthesis time and energy requirements, thereby demonstrating that the approach to modified synthesis works. Elemental analysis via SEM-EDS demonstrated the mass percentage of carbon in the catalyst to be 40.23, oxygen 45.51%, and copper to be 14.26%. The atomic percentage for copper came out to be 3.5%. This confirmed the expected Cu-MOF structure and composition **(Figure 2 A; B 1-3).**

The FTIR spectrum which is available for the copper-based metal organic framework sample features major peaks at certain values of wavenumbers that can be related to multiple molecular vibrations and thus serve as indicators of functional groups in the sample. Should be ascribed to the C–O stretch or bending, meaning that oxygenated functional groups are present. Bands found at lower wavenumbers, like the band near 410.76 cm^{-1}. This information can be correlated with the stretching of Cu–O or Cu–N, which directly indicates the metal-ligand interaction in the framework **(Figure 5-A).**

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3.2. Characterization of Cu-Doped TiO_2 Nanocomposite

3.2.1. UV-Vis Diffuse Reflectance Spectroscopy (UV-DRS)

The UV-Vis diffuse reflectance spectrum of Cu MOF, as monitored by a Jasco V-770 spectrophotometer, shows relevant optical characteristics for potential applications. This spectrum was measured over 200 to 800 nm wavelength range in both the UV and visible regions of the spectrum. The mode of photometry was absorbance (Abs). The data shows a distinct absorption in the visible region, indicating that Cu incorporation in the MOF extends the absorption edge into the visible spectrum, a desirable feature for photocatalytic and antimicrobial functionalities **(Figure 4 A).**

The spectrum increases gradually with a peak in the visible range, suggesting that the material can absorb visible light, probably because of the introduction of copper that narrows the band gap. Visible light activity also implies that Cu doping has enhanced the light-harvesting ability of the MOF, and thereby the material is likely to be more efficient under solar or artificial light. This is attributed to a broadened absorption profile, not plummeting precipitously in the examined range, therefore suggesting a light response that is rather wide and can be employed for photochemical or photocatalytic applications in varied usages. Baseline correction and other instrumental parameters set with scan speed to 400 nm/min and bandwidth to 5 nm made data gathering extremely precise.

This UV-Vis DRS analysis confirms the strong visible light absorption by the Cu MOF, showing an altered electronic structure due to the doping effect of Cu, enhancing its application in light-driven processes. Such optical properties are very beneficial for environmental and antimicrobial applications as the material can effectively use a larger spectrum of light for its function.

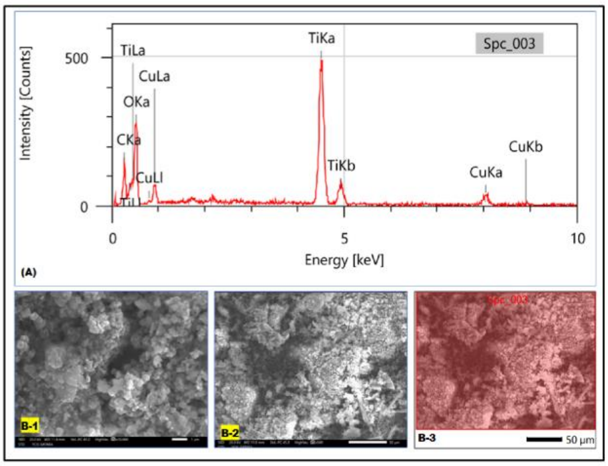

Figure 3: Characterization of Cu-doped TiO_2 nanocomposites (A) EDX Spectra; (B 1-3) SEM image taken at 500X magnification.

3.3. SEM/EDS and TEM morphology of Cu-doped TiO_2 nanocomposites

SEM/EDS analysis of Cu-doped TiO_2 nanocomposites underlined critical insights about elemental composition, morphology, and spatial distribution of elements. The EDS data reveals that the sample comprises 43.00% oxygen (O), 35.16% titanium (Ti), 8.06% copper (Cu), and 13.79% carbon (C) by mass **(Figure 3: A).** The presence of copper confirms doping of TiO_2 was successful, with Cu forming a smaller percentage relative to Ti and O, as consistent with a doped rather than substituted structural role **(Figure 3: B 1-3).** Atomic percentages also express stoichiometric relations in nanocomposite; the most abundant is O at an atomic ratio of 57.23% because of the presence of the molecule in the TiO_2 matrix, followed by Ti at 15.63% and Cu at 2.7%. The Cu atoms are dispersed rather than substituting the titanium atoms in a considerable proportion. SEM images taken at 500x magnification show the morphology of the Cu-TiO2 composite with uniform particle distribution at a 50 µm scale. Clear imaging is achieved by operating in high vacuum mode at a landing voltage of 20 kV, thereby aiding in the accurate mapping of Cu within the TiO2 matrix. EDS mapping shows that Cu is uniformly distributed over the TiO_2 surface at a live time of 30 seconds.

On other hand, a TEM and SAED image of Cu-doped TiO_2 nanocomposite revealed that there is highly crystalline anatase phase that comes with the existence of strong diffraction rings at d-spacings corresponding to the value of TiO_2 (**Figure 4: C 1-4**). Images of this result in homogenous contrast that reveals good dispersion for Cu into the lattice of TiO_2 with no single Cu phases being evident. Thus, successful doping without the creation of any structural disorder, making this a promising material for catalytic as well as environmental applications.

This supports uniform doping because it will ensure that, in potential photocatalytic or antimicrobial properties, Cu will be accessible to interact well with TiO_2. Therefore, this compositional and morphological analysis confirms the well-prepared Cu-doped TiO_2 nanocomposite with evenly distributed Cu for catalytic and antimicrobial applications.

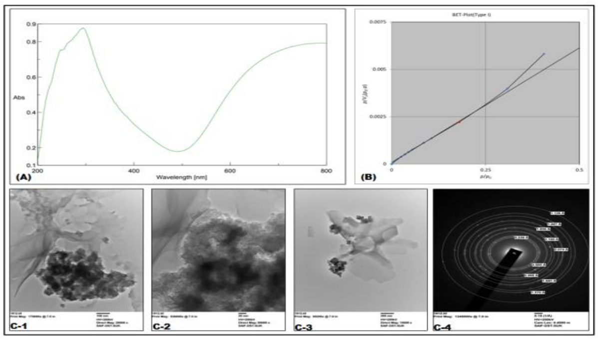

Figure 4: Characterization of Cu-doped TiO_2 nanocomposites (A) UV -DRS Spectra; (B) BET Plot; (C 1-4) TEM image taken at 500X magnification

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3.4. Surface area measurement using BET method analysis

BET surface area measurements of the sample with doped Cu in TiO_2 were 356.83 m²/g. The method used for nitrogen adsorption was calculated according to monolayer adsorbed volume VmV_mVm, being 81.983 cm³(STP)/g and with a value of a BET constant CCC of 147.9, which reflects the strength of the interactions of adsorption. The pore volume was computed as 0.2834 cm³/g when the relative pressure was 0.990, and it was possible to obtain a mean pore diameter of about 3.1767 nm (Figure 2: B). Linear regression performed on the adsorption isotherm in the range of the BET provided correlation coefficient value of around 0.9998 that, consequently, indicates very accurate determination of the surface area.

3.5. FTIR analysis of before and after Cu doping on TiO_2 nanocomposites

In terms of FTIR analysis on Cu-doped TiO_2 nanocomposites, it is clear that an obvious spectral change occurred prior to and after doping within the undoped material **(Figure 5).** There was a clear chemico-composition modification in these peaks. Characteristic peaks at 400–800 cm−1 were associated with the Ti–O vibration before the doping of the samples. Post-doping with Cu, new peaks arise and some shifts of original bands are also observed. This can be deduced as arising due to Cu–O interactions, thus confirming the incorporation of Cu ions within the TiO_2 lattice.

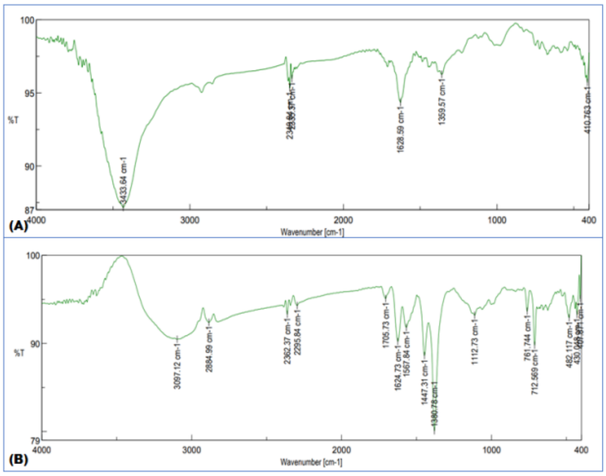

Figure 5: FTIR characterization of Cu-doped TiO_2 nanocomposites

The changes are also indicated by the shifts in the absorption peaks in the Cu-doped spectrum, especially around wavenumbers of 1300–1600 cm⁻¹ and 3200–3600 cm⁻¹ that may be reflecting the formation of Cu–O–Ti bonds and possibly hydroxyl groups that may be enhanced in photocatalytic properties. The FTIR spectra also show a transmittance drop in specific ranges after doping, which could be assigned to the increased defect states or the formation of new chemical bonds through Cu incorporation, thus modulating the vibrational structure of TiO_2. Indeed, the resulting shift in the vibrational features proves that Cu doping has altered the electronic environment of TiO2, and it is this change that may enhance functionality in catalytic applications.

3.6. Analysis of antimicrobial activity.

An antimicrobial assay was performed by using well diffusion method. It was observed that among all the bacteria taken, the Cu-doped TiO_2 nanocomposite showed maximum effectiveness against *S. aureus* **(Figure 6).**

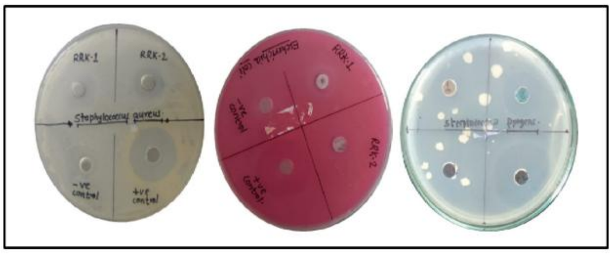

Figure 6: antimicrobial efficacy testing of Cu-doped TiO_2 nanocomposites

IV. DISCUSSION

The rapid developments in nanotechnology have opened wide scopes for metal-doped nanocomposites in medicine, agriculture, energy, and environmental remediation [18]. Out of various metal-doped nanomaterials, Cu-doped TiO_2 nanocomposites attract much attention due to its enhanced photocatalytic as well as antimicrobial activities [19]. It has become one of the notable approaches toward the green production of nanomaterials based on environmentally friendly methodologies focusing on chemical waste minimization and utilization of bio-sourced materials. Cu-doped TiO2 nanocomposites synthesized sustainably by using *C. verum* bark in current research have characterized nanocomposites showing very promising structural and optical properties to be used in antimicrobial and photocatalytic domains. Optical properties of the Cu-doped TiO_2 nanocomposites prepared have been investigated by employing UV-Vis diffuse reflectance spectroscopy (UV-DRS) [20]. Considerable absorption in the light range shifts toward the visible spectrum with the Cu doping, because this leads to decreasing the band gap, resulting in being more effective to harvest visible light. Recently, the doping with transition metals and especially copper has been proved to broaden the absorption band and simplify the separation of electron-hole pairs, improving the photocatalytic efficiency [21, 22].

Gradually rising visible region absorption is evidence that they can be implemented into solar and artificial light-activated applications. That correlates with other research regarding related studies, which is also a sign of being more prone to practical use as photocatalysts with remediation of the environment because of the need to develop higher visible-light absorbability [23]. Another understanding of the integrity of nanocomposites provided by both SEM and EDS is its structural and

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composition integrity. Under the magnification 500 times for SEM imaging, it proves that the copper-doped particles of TiO_2 in size and distribution uniformity showed an important importance in getting consistent performance by photocatalytic and antibacterial features. The data obtained from EDS also provide proof of the successful incorporation of Cu for approximately 8% mass, consistent with the above findings that low concentrations of Cu incorporation in TiO_2 do not destabilize but dramatically improve functionality [24]. Atomic ratios revealed a dispersed structure of Cu rather than substituting the Ti atoms since such a structure is seen to improve reactivity without disturbing the stability of the TiO_2 matrix [25]. This uniformity is critical since it ensures the access of Cu sites across the TiO_2 surface toward effective interaction with target microbes in antimicrobial applications or toward contaminants in photocatalytic environments. Such compositional stability is consistent with recent developments, where dispersed doping is of utmost importance for durable catalysis and structural stability [26].

Antimicrobial activity has TiO_2 also been pronounced for Cu-doped TiO2 nanocomposites against the lethal bacterium *Staphylococcus aureus.* The prospects of these compounds for effective fighting with malicious pathogens and increasing antibacterial activity seem to result from the Cu-induced ROS production that degrades cell walls of micro-organisms by its breaking [15, 16]. Its efficiency was demonstrated on such an important bacterium species as S. The two recent studies support findings that Cu doping does enhance the microbial inhibition efficiency of TiO_2 through the increased generation of ROS, a mechanism unlikely to contribute to antibiotic resistance. Its broad-spectrum activity renders Cu-doped TiO_2 particularly appropriate for applications in medical devices, water purification, and antimicrobial coatings, where resistance to conventional therapies is an ongoing issue. Further studies on the concentration-dependent effects of Cu doping on antimicrobial performance may lead to the optimization of strategies for higher biocompatibility and safety in medical and environmental applications. In a nutshell, synthesis through *C. verum* bark and doping in the preparation of nanocomposites with the element Cu, for TiO2 by this method of synthesis makes a contribution toward fulfilling sustainable goals for green nanoapplications. Bioinspired green synthesis in conjunction with strategic approaches toward effective doping enhance this material's optical, structural properties as well as the significant property of being antibacterial. UV-DRS/SEM/EDS tests reflect this material [27]. This also underlines the potential for Cu-doped TiO_2 in applications such as environmental remediation and microbial control. These results align with the recent burgeoning literature that encourages the use of green synthesis methods combined with metal doping to broaden the functional versatility of TiO_2 nanomaterials for different applied fields [28, 29].

Further investigation into the synthesis parameters, including copper concentration and particle morphology, may further enhance the functional properties and widen the application scope of these nanocomposites, paving the way for sustainable, multifunctional materials with broad societal impact.

V. CONCLUSION

The green synthesis of Cu-doped TiO_2 nanocomposites from *C. verum* bark is an eco-friendly approach. Phytochemicals in the bark act as natural reducing and stabilizing agents, which accelerate the stability and visible light absorption of the nanocomposites. Characterization confirms copper's uniform dispersion within TiO_2, which is necessary for consistent antimicrobial efficacy. The nanocomposites are effective against *Staphylococcus aureus,* where copper-induced ROS can damage bacterial cells. The environmentally benign synthesis process reduces the impact on the environment and follows the guidelines of green chemistry, making Cu-doped TiO2 nanocomposites promising antimicrobial treatment candidates and environmentally friendly agents.

Conflict of Interest: Nil

Author Contribution

RK design the all-experimental work under supervision of NC. RK analyzed the data, RK and NC interpreted the results, NC and RK wrote manuscript. All authors reviewed and approved the consider the manuscript for submission.

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Supplementary Material Attached

1. FTIR Spectra Details
2. SEM-EDS Spectra Details
3. BET Analysis Data Details
4. UV-DRS Spectra Details

REFERENCES

[1] Ashraf, S. A., Siddiqui, A. J., Elkhalifa, A. E. O., Khan, M. I., Patel, M., Alreshidi, M., Moin, A., Singh, R., Snoussi, M., & Adnan, M. (2021). Innovations in nanoscience for the sustainable development of food and agriculture with implications on health and environment. *Science of the Total Environment*, *768*, 144990. https://doi.org/10.1016/j.scitotenv.2021.144990

[2] He, Q.-L., Jia, B.-X., Wang, Y.-K., Qin, M., Xu, W.-B., Zhang, Z., Feng, Y.-F., & Zhou, B. (2023). Copper ion based metal–organic framework nanomaterials with roughness enhanced protein adhesion for high-efficiency hemoglobin separation. *New Journal of*

ISSN: 2583-4053
Volume-4 Issue-2 || April 2025 || PP. 18-26
https://doi.org/10.55544/jrasb.4.2.3

Chemistry, *47*(15), 7245–7252. https://doi.org/10.1039/d2nj06115e

[3] Yu, Z., Lepoitevin, M., & Serre, C. (2024). Iron-MOFs for Biomedical Applications. *Advanced Healthcare Materials*. https://doi.org/10.1002/adhm.202402630

[4] Prakash, J., Samriti, Kumar, A., Dai, H., Janegitz, B. C., Krishnan, V., Swart, H. C., & Sun, S. (2021). Novel rare earth metal–doped one-dimensional TiO2 nanostructures: Fundamentals and multifunctional applications. *Materials Today Sustainability*, *13*, 100066–100066. https://doi.org/10.1016/j.mtsust.2021.100066

[5] Dar, A., Rehman, R., Zaheer, W., Shafique, U., & Anwar, J. (2021). Synthesis and Characterization of ZnO-Nanocomposites by Utilizing Aloe Vera Leaf Gel and Extract of Terminalia arjuna Nuts and Exploring Their Antibacterial Potency. *Journal of Chemistry*, *2021*, e9448894. https://doi.org/10.1155/2021/9448894

[6] Igarashi, I., Amany Magdy Beshbishy, Azirwan Guswanto, Arifin Budiman Nugraha, Tserendorj Munkhjargal, Abdel-Daim, M. M., & Mosqueda, J. (2020). Phytochemical Characterization and Chemotherapeutic Potential of Cinnamomum verum Extracts on the Multiplication of Protozoan Parasites In Vitro and In Vivo. *Molecules*, *25*(4), 996–996. https://doi.org/10.3390/molecules25040996

[7] Sharifi-Rad, J., Dey, A., Koirala, N., Shaheen, S., El Omari, N., Salehi, B., Goloshvili, T., Cirone Silva, N. C., Bouyahya, A., Vitalini, S., Varoni, E. M., Martorell, M., Abdolshahi, A., Docea, A. O., Iriti, M., Calina, D., Les, F., López, V., & Caruntu, C. (2021). Cinnamomum Species: Bridging Phytochemistry Knowledge, Pharmacological Properties and Toxicological Safety for Health Benefits. *Frontiers in Pharmacology*, *12*. https://doi.org/10.3389/fphar.2021.600139

[8] Tiwari, S., Verma, S. K., Bhagat, P., Yadav, S., Sharma, R., Aseri, G. K., Sohal, J. S., Sharma, D., Dwivedi, U. K., Singh, R., Singh, D., & Khare, N. (2021). An overview of the phytosynthesis of various metal nanoparticles. *3 Biotech*, *11*(11). https://doi.org/10.1007/s13205-021-03014-0

[9] Joshi, A., Sharma, A., Rakesh Kumar Bachheti, Husen, A., & Mishra, V. (2019). *Plant-Mediated Synthesis of Copper Oxide Nanoparticles and Their Biological Applications*. 221–237. https://doi.org/10.1007/978-3-030-05569-1_8

[10] Mohammad Zaki Ahmad, Alasiri, A., Ahmad, J., Alqahtani, A. A., Abdullah, M. M., Abdel-Wahab, B. A., Pathak, K., Riya Saikia, Das, A., Sarma, H., & Seham Abdullah Alzahrani. (2022). Green Synthesis of Titanium Dioxide Nanoparticles Using Ocimum sanctum Leaf Extract: In Vitro Characterization and Its Healing Efficacy in Diabetic Wounds. *Molecules*, *27*(22), 7712–7712. https://doi.org/10.3390/molecules27227712

[11] Thukkaram, M., Vaidulych, M., Kylián, O., Rigole, P., Aliakbarshirazi, S., Asadian, M., Nikiforov, A., Biederman, H., Coenye, T., Du Laing, G., Morent, R., Van Tongel, A., De Wilde, L., Verbeken, K., & De Geyter, N. (2021). Biological activity and antimicrobial property of Cu/a-C:H nanocomposites and nanolayered coatings on titanium substrates. *Materials Science and Engineering: C*, *119*, 111513. https://doi.org/10.1016/j.msec.2020.111513

[12] Leyland, N. S., Podporska-Carroll, J., Browne, J., Hinder, S. J., Quilty, B., & Pillai, S. C. (2016). Highly Efficient F, Cu doped TiO2 anti-bacterial visible light active photocatalytic coatings to combat hospital-acquired infections. *Scientific Reports*, *6*. https://doi.org/10.1038/srep24770

[13] Huston, M., DeBella, M., DiBella, M., & Gupta, A. (2021). Green Synthesis of Nanomaterials. *Nanomaterials*, *11*(8), 2130. https://doi.org/10.3390/nano11082130

[14] Althomali, R. H., Alamry, K. A., Hussein, M. A., Khan, A., & Alosaimi, A. M. (2021). A green nanocomposite based modified cellulose/TiO2/Cinnamon bark for the reduction of toxic organic compounds using spectrophotometric technique. *Journal of Materials Research and Technology*, *12*, 947–966. https://doi.org/10.1016/j.jmrt.2021.03.002

[15] Du, T., Chen, S., Zhang, J., Li, T., Li, P., Liu, J., Du, X., & Wang, S. (2020). Antibacterial Activity of Manganese Dioxide Nanosheets by ROS-Mediated Pathways and Destroying Membrane Integrity. *Nanomaterials*, *10*(8), 1545. https://doi.org/10.3390/nano10081545

[16] Lia-Mara Ditu, Razvan Bucuresteanu, Ionita, M., Andreea Neacsu, & Ioan Calinescu. (2024). Antimicrobial and Antibiofilm Properties of Nanocomposite Surfaces with Biomedical Applications. *IntechOpen EBooks*. https://doi.org/10.5772/intechopen.115120

[17] Harun, N. H., Mydin, R. B. S. M. N., Sreekantan, S., Saharudin, K. A., Basiron, N., Aris, F., Wan Mohd Zain, W. N., & Seeni, A. (2020). Bactericidal Capacity of a Heterogeneous TiO2/ZnO Nanocomposite against Multidrug-Resistant and Non-Multidrug-Resistant Bacterial Strains Associated with Nosocomial Infections. *ACS Omega*, *5*(21), 12027–12034. https://doi.org/10.1021/acsomega.0c00213

[18] Shakti Katiyar, & Rajesh Katiyar. (2023). A comprehensive review on synthesis and

ISSN: 2583-4053
Volume-4 Issue-2 || April 2025 || PP. 18-26
https://doi.org/10.55544/jrasb.4.2.3

application of nanocomposites for adsorption of chromium: status and future prospective. *Applied Water Science*, *14*(1). https://doi.org/10.1007/s13201-023-02062-6

[19] Pedroza-Herrera, G., Medina-Ramírez, I. E., Lozano-Álvarez, J. A., & Rodil, S. E. (2020). Evaluation of the Photocatalytic Activity of Copper Doped TiO2 nanoparticles for the Purification and/or Disinfection of Industrial Effluents. *Catalysis Today*, *341*, 37–48. https://doi.org/10.1016/j.cattod.2018.09.017

[20] Ranga Rao, G., & Sahu, H. R. (2001). XRD and UV-Vis diffuse reflectance analysis of CeO2-ZrO2 solid solutions synthesized by combustion method. *Journal of Chemical Sciences*, *113*(5-6), 651–658. https://doi.org/10.1007/bf02708797

[21] Ben Ali, M., Nasser, R., Alshahrani, S. M., Al-Shamiri, H. A. S., Elgammal, B., & Elhouichet, H. (2021). Synthesis, characterization, and visible-light photocatalytic activity of transition metals doped ZTO nanoparticles. *Ceramics International*, *47*(23), 32882–32890. https://doi.org/10.1016/j.ceramint.2021.08.185

[22] Khlifi, N., Zerrouki, C., Fourati, N., Guermazi, H., & Guermazi, S. (2024). Investigation of structural and optical properties of TM-doped CuO NPs: Correlation with their photocatalytic efficiency in sunlight-induced pollutant degradation. *Measurement*, *237*, 115209. https://doi.org/10.1016/j.measurement.2024.115209

[23] Arora, I., Chawla, H., Chandra, A., Sagadevan, S., & Garg, S. (2022). Advances in the strategies for enhancing the photocatalytic activity of TiO2: Conversion from UV-light active to visible-light active photocatalyst. *Inorganic Chemistry Communications*, *143*, 109700. https://doi.org/10.1016/j.inoche.2022.109700

[24] Kumar, R., & Sharma, T. (2018). *Stability and rheological properties of nanofluids stabilized by SiO2 nanoparticles and SiO2-TiO2 nanocomposites for oilfield applications*. *539*, 171–183. https://doi.org/10.1016/j.colsurfa.2017.12.028

[25] Liyanaarachchi, H., Thambiliyagodage, C., Liyanaarachchi, C., & Samarakoon, U. (2023). Efficient photocatalysis of Cu doped TiO2/g-C3N4 for the photodegradation of methylene blue. *Arabian Journal of Chemistry*, *16*(6), 104749. https://doi.org/10.1016/j.arabjc.2023.104749

[26] Aguilar-Ferrer, D., Szewczyk, J., & Coy, E. (2021). Recent developments in polydopamine-based photocatalytic nanocomposites for energy production: Physico-chemical properties and perspectives. *Catalysis Today*. https://doi.org/10.1016/j.cattod.2021.08.016

[27] Torres-Ramos, M. I., Martín-Camacho, U. J., González, J. L., Yañez-Acosta, M. F., Becerra-Solano, L., Gutiérrez-Mercado, Y. K., Macias-Carballo, M., Gómez, C. M., González-Vargas, O. A., Rivera-Mayorga, J. A., & Pérez-Larios, A. (2022). A Study of Zn-Ca Nanocomposites and Their Antibacterial Properties. *International Journal of Molecular Sciences*, *23*(13), 7258. https://doi.org/10.3390/ijms23137258

[28] Yitagesu, G. B., Leku, D. T., & Workneh, G. A. (2023). Green Synthesis of TiO_2 Using *Impatiens rothii* Hook.*f.* Leaf Extract for Efficient Removal of Methylene Blue Dye. *ACS Omega*, *8*(46), 43999–44012. https://doi.org/10.1021/acsomega.3c06142

[29] Jafarzadeh, S., Nooshkam, M., Zargar, M., Garavand, F., Ghosh, S., Hadidi, M., & Forough, M. (2023). Green synthesis of nanomaterials for smart biopolymer packaging: challenges and outlooks. *Journal of Nanostructure in Chemistry*. https://doi.org/10.1007/s40097-023-00527-3