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GREEN SYNTHESIS OF COPPER NANOPARTICLES FROM AN EXTRACT OF CINNAMON BARK: SPECTROSCOPIC CHARACTERIZATION, OPTICAL PROPERTIES, ANTIMICROBIAL, AND ANTIOXIDANT ACTIVITIES

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ABSTRACT

Nanobiotechnology is increasing at a very fast rate due to its various industrial applications in the textile, biomedical, food, pharmaceutical, and paint industries. The green synthesis of copper nanoparticles using an aqueous extract of cinnamon zeylanicum has been documented in our present research work. The green synthesis of Cu NPs is a very simple, fast, efficient, eco-friendly, and cost-effective method. In this work, we use an aqueous environment for the green synthesis of copper nanoparticle(Cu NPs). The aqueous environment plays a very important role in decreasing reaction time, reducing the minimum possibilities of side reactions, and proper conversion of precursors into good quality CuNPs in very less time. The existence of flavonoids, tannins, glycosides, and alkaloids was confirmed by the phytochemical analysis of the plant extract, and the presence of these chemicals can be used as reducing, stabilizing, and capping agents. The Cu NPs were characterized by structural, vibrational, and electronic spectroscopic techniques. Powdered X-ray diffraction studies confirm the formation of well-defined equispaced crystalline CUNPs. The average particle and crystalline size of CuNPs were found to be 66.16 ±1 nm and 77.54±1 nm respectively. The Surface plasmon resonance peaks were found at 233.67 and 252.2 nm, measured using UV-Visible spectroscopy, and the calculated band gap was found to be 3.5 e V at 288nm, indicating the semiconductor behavior of the CZ-CUNPs. The effective results of pharmacological activities of CuNPs due to the presence of flavonoids, tannins, glycosides, and alkaloids in the CZ bark extract. The green synthesis of CZ-CUNPs from an aqueous extract of cinnamon zeylanicum bark in the proper stoichiometric ratio is an excellent method for synthesizing highly effective bioactive agents which can be considered good drug candidates for various biomedical applications in the future for mankind.

Keywords: Copper Nanoparticles, Green Synthesis, Structural, Morphological, Pharmacological Characterizations and Antimicrobial activity

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INTRODUCTION

In material science, green synthesis of metallic nanoparticles from plant parts has gained very much attention nowadays because green synthesis is a reliable, sustainable, cost-effective, and eco-friendly protocol for synthesizing a wide range of nanoparticles. Green synthesis of metallic nanoparticles from plant parts is regarded as an important tool for reducing the toxic effects of chemicals that are used in classical chemical methods. According to the principles of green chemistry, there are several methods for the synthesis of nanoparticles. In the green approach, non-toxic and eco-friendly chemicals have been used for the synthesis of nanomaterials Nanoparticles have been synthesized from various sources of plants, animals and microorganisms.[1-3] Copper nanoparticles derived from plant sources have numerous applications as catalysts, for photocatalytic activity, antimicrobial activity, DNA binding, biosensors, reducing organ toxicity, antioxidant agents, etc.[4-10] As per the latest literature survey, copper nanoparticles have been synthesized from several plant extracts such as aloe Vera, *Magnolia kobo*, *Terminalia arjuna*, *Bifurcaria bifurcate* and *Jatropha curcas*, *Tabernaeontana.*[11-16]. In our research work, we use the aqueous extract of cinnamon bark for the synthesis of Cu NP's. Medicinally, cinnamon bark is used for treating gastrointestinal upset, diarrhea, and gas. It is also used for stimulating appetite, treating infections caused by bacteria and parasitic worms, provide relief in menstrual cramps, the common cold, and flu. In industrial applications, cinnamon oil is used in small amounts in toothpaste, mouthwashes, gargles, lotions, ointments, soaps, detergents, and other pharmaceutical and cosmetic products. It also contains a

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chemical that might work like insulin to lower blood sugar. The green synthesis of metallic nanoparticles from plant extracts has more advantages over the classical as well as microbial synthesis methods because both processes are highly expensive due to the cost of microorganisms isolation and their culture maintenance as well as the high cost of chemicals.[17-19] Metallic nanoparticles nanoparticles have been synthesized using biological sources and have been reported in potential pharmacological applications like anticancer, antioxidant, antimicrobial, photocatalytic activity, etc.[20-26] However, the multifunctional activity of green synthesized copper nanoparticles is not reported in any of the previous research. Therefore, we focused on the multifunctional, multi-pharmacological activities of Cu NP's. Cu, Ag, Au, and Fe nanoparticles derived from plant extracts play a very important role in the formulation of nanomedicines due to the size and morphology of metallic nanoparticles.[9] The active site of an effective anticancer drug can bind to the DNA of a cancer cell and reduce its activity.[27-29] The metallic nanoparticles can be bound to DNA molecules via intercalative, electrostatic, or groove-binding interactions. Recently, our research group synthesized Co S NP's from an aqueous extract of leaves of the harsingar plant and examined their pharmacological activities. In the present research work, we have reported the synthesis of CuNPs from an aqueous extract of cinnamon bark.

EXPERIMENTAL

Materials and Methods

All required chemicals were purchased from Sigma –Aldrich and Merck. All chemicals were used without purification. Triple distilled water was used for all chemical reactions, spectroscopic and pharmacological analysis of samples.

Plant Materials

The bark of cinnamon zeylanicum was collected from the medicinal garden, School of Pharmacy, ITM University, Gwalior (M.P.) India in February 2018 (Fig.-1).

Fig.-1: (a) *Cinnamomum verum*, from Koehler's Medicinal-Plants (1887), (b) Close-up View of Raw Cinnamon Bark

The authentication of the plant species was done by subject experts, and a voucher specimen (ITM/3/CZ/18) was deposited in the Department of Chemistry, School of Sciences, ITM University, Gwalior (M.P.).

Preparation of Plant Extract

An aqueous extract of cinnamon bark was used for the green synthesis of Cu NP's. In Ayurveda bark of cinnamon has been used as a medicine to treat diabetes, cancers, etc. To remove debris and related dust bark of cinnamon was washed with distilled water and cut into very small pieces before being dried in the presence of sunlight.10 g of bark pieces was immersed in 100ml distilled water and the bark pieces were incubated at 40^0C for 2 hours to prepare for extraction. Furthermore, the extract of cinnamon bark was kept at room temperature for cooling, filtered using Whatman filter paper no.41, and used for the synthesis of Cu NP's.

Phytochemical Analysis of Plant Extract

The standard protocol for qualitative phytochemical analysis was used to identify the major phytochemicals in the aqueous extract of cinnamon bark, as shown in Table-1.

Fig.-2: Preparation of Plant Extract

Table-1: Phytochemical Analysis of Cinnamon Bark Extract

S. No.	Phytochemical test	Result
1	Flavonoids	+
2	Saponins	+
3	Cardiac Glycosides	+
4	Tannins	+
5	Terpenoids	+
6	Alkaloids	+
7	Phenolic group	_
8	Steroids	_
9	Phytosterol	-
10	Anthocyanine	_
11	Anthraquinone	_

Fig.-3: Phytochemical Analysis of Cinnamon Bark Extract

Biosynthesis of Copper Nanoparticles

In an Erlenmeyer flask, 100 ml of copper sulfate (3Mm) was stirred for 5 minutes, and then 50 ml aqueous extract of cinnamon bark powder was added to the copper sulfate solution and continued to stir for another 24 hours at room temperature. During the reaction, the color of the solution mixture turned from dark brown to black brown, indicating the formation of Cu NP's, and this was also confirmed by UV-Vis spectroscopic measurements. After completion of the reaction, the final reaction mixture was centrifuged at 10,000 -11,000 rpm and Cu NP's were separated from the mixture. Finally, the solution was decanted out and the back brown Cu NP's were collected.

Characterization of CZ-Cu NP's

All required chemicals and solvents were purchased from Sigma-Aldrich and Merck Pvt Ltd. All solvents were used without further purification. Green synthesized Cu NP's were collected and characterized by various structural, morphological, and vibrational spectroscopic techniques like UV-Vis, FT-IR, XRD, TEM, and SEM. The structure and particle size of copper nanoparticles were characterized by a Bruker axis D_8 using Cu Kα radiations (λ=1.540A^0). UV –Visible absorption spectra of copper nanoparticles were recorded on a Perkin Elmer UV-Vis Lamda 25 UV-Visible spectrophotometer in PC Ray research Centre, ITM University, Gwalior (M.P.) using a 1 cm path length cuvette and used dichloromethane solvent for dissolution of CZ-Cu NP's. The IR spectra were recorded on a Perkin Elmer FT-IR spectrophotometer (KBr pellets) in PC Ray research Centre, ITM University, Gwalior (M.P.) with the wavelength range 400-4000cm^{-}1. The fine structure of the prepared sample of nanoparticles was analyzed by HR Scanning Electronic microscopy (HRSEM) by TECHAI G 2F20 operated at 300 Kv using a drop of suspension of sample in ethanol on a carbon-coated copper grid. Energy dispersive X–ray spectroscopy (EDX) OF CZ-Cu NP'S was carried out on a Sigma ZEISS, Field Emission Scanning Electron Microscope. The optical and in-vitro anti-oxidant activities of samples were investigated using a UV-Visible spectrophotometer.

In-vitro Anti-Oxidant Activities of Cu NP's

The free radical scavenging activity (RSA) of copper nanoparticles at concentrations 200, 400, 600, 800, and 1000 μg/ml was carried out in the presence of a freshly prepared solution of stable free radical DPPH

(0.04% w/v) following Hataro's method using ascorbic acid as standard. All the test analysis was performed on three triplicates and results are averaged. The results in percentage are expressed as the ratio of absorption decrease of DPPH in the presence of test compounds and absorption of DPPH in the absence of test compounds at 517 nm by UV Visible spectrophotometer. The percentage scavenging activity of the DPPH free radical was measured using the following equation-

$$\%\text{RSA} = \frac{A_C - A_S}{A_C} \times 100$$

Where, A_C = Absorbance of control.
A_S = Absorbance of the test sample

Anti-Bacterial Activities of Cu NP's

The *in vitro* antibacterial effect of biosynthesized copper nanoparticles was evaluated against one species of Gram-positive bacteria (*Staphylococcus aureus (MTCC 737)* and two Gram-negative bacteria (*Escherichia coli (MTCC 1687), Enterococcus faecalis* (MTCC -439) by the disc diffusion method using nutrient agar medium. The bacteria were sub-cultured in the agar medium and were incubated for 24 h at 37 °C. The discs having a diameter of 5 mm, were then soaked in the test solutions (Sterile filter paper discs, what man No. 1.0) with the equivalent amount of Cu NPs dissolved in sterile dimethyl sulphoxide (DMSO) at concentrations of 10 mg/mL and were placed in Petri dishes on an appropriate medium previously seeded with microbial organisms and stored in an incubator for 24 hrs. The inhibition zone around each disc was measured and the results were recorded in the form of inhibition zones (diameter, mm). To clarify any effect of DMSO on the biological screening, separate studies were carried out using DMSO as negative control and it showed no activity against any bacterial strains. Streptomycin antibiotic was used as a positive control in antibacterial analysis.

RESULTS AND DISCUSSION

This research work reports the green synthesis of copper nanoparticles from an aqueous extract of cinnamon bark which was free from any contaminations of impurities and requires continuous stirring of the reaction mixture which contains 100 ml copper sulfate solution (3Mm) and 50 ml aqueous extract of cinnamon bark extract in a ratio of 1:4 v/v with continuous stirring of 24 hours at room temperature. During the continuous stirring of the reaction mixture, the color of the solution changed from dark brown to black brown, indicating the formation of copper nanoparticles, and this was also verified using UV-Visible spectroscopy. The electronic spectra of Cu NP's arise due to the excitation of the SPR (surface plasmon resonance phenomenon). The aqueous extract of cinnamon bark contains flavonoids, saponins, cardiac glycosides, Tannins, Terpenoids, alkaloids and phenolic phytochemicals that act as capping and stabilizing agents for the green synthesis of Cu NP's, and these phytochemicals may also be responsible for the reduction of Cu^{2+} to Cu^0.The aggregation of Cu NP's was not observed3 months after the green synthesis of copper nanoparticles. The possible mechanism for the biosynthesis of Cu NP's is shown in Fig.-5. In the UV-Visible spectrum, Cu NP's showed absorption peaks at 233.67 and 252.55 nm, but no peaks appeared for copper sulfate or the extract of cinnamon bark.

Optical Properties

UV-Visible Spectroscopic Analysis

Nano-sized metallic nanoparticles exhibit unique optical properties having an exponential decay. UV-Visible absorbance spectroscopy has proved to be a very useful technique for studying nanoparticles because the peak positions and shapes are sensitive to particle size. The surface plasmon peak of Cu NP's has been reported to appear at 252.5 nm which confirms the formation of copper nanoparticles. A blue shift from 233.67 nm to 252.5 nm was observed with the increase in the amount of aqueous extract of cinnamon bark. This blue shift can be explained on the basis of an increased nucleation rate due to a greater amount of Cu^{2+} ions reduced and the generation of copper nanoparticles in the reaction mixture at the time of stirring. The black-brown color of copper nanoparticles was observed when the stoichiometric amount of cinnamon extract and copper sulfate solutions are mixed. As a result of proper stirring a large number of copper nanoparticles were formed within a short time.

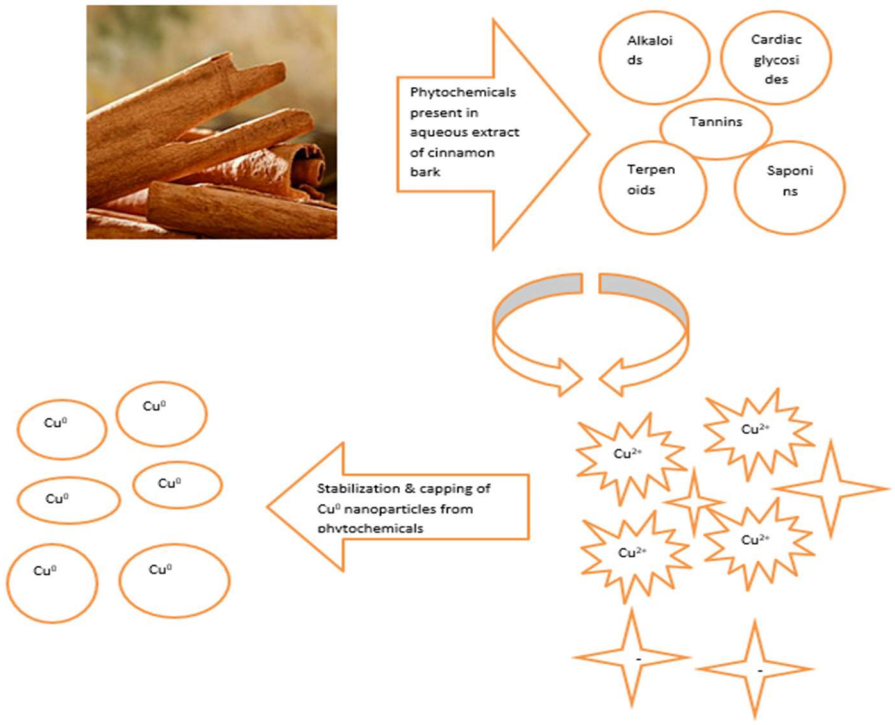

Fig.-5: Possible Mechanism of the Biosynthesis of Cu NP'S

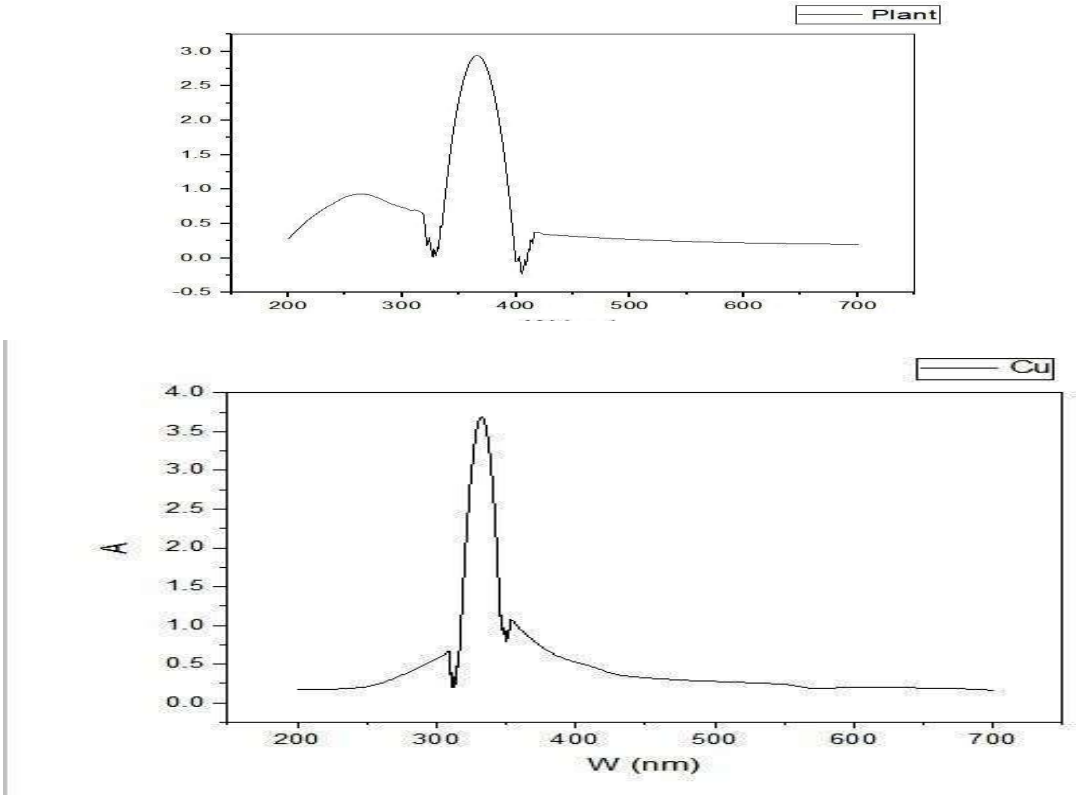

Fig.-6: UV-Visible Spectra of Cinnamon extract and Bio-Synthesized Copper Nanoparticles

FT-IR Spectral Analysis of Green Synthesized Copper Nanoparticles

The comparative FT-IR spectra of cinnamon bark extract and Cu NP's are depicted in Fig.-7. FT-IR measurements of the aqueous extract of cinnamon bark and the synthesized dried Cu NP's were carried

out to identify the possible phytochemicals responsible for the reduction, capping, and efficient stabilization of the bio-reduced copper nanoparticles. Table-2 displays the major IR peaks, wave numbers, and the interpretation of the possible functional groups. The absorption bands of cinnamon bark powder appear at 3358, 2925, 2864, 2740, 2253, 1675,118, 1125, 688, and 580 cm^{-1} are due to O-H, C-H, C-N, C-O, and C-Cl functional groups, respectively. Simultaneously, absorption bands for the CZ-Cu NP's appear at 3368, 2089, 1625, 1088, 993, 778, 614, 490 cm^{-1} corresponding to the functional groups of O-H, C-H, C-N, C-O, and C-Cl and might be responsible for the bio reduction of Cu^{2+} ions into Cu^0 nanoparticles..

Table-2: FT-IR Analysis and Probable Functional Groups of Cinnamon Bark Powder and Cu NP's

S. No.	Cinnamon bark powder wave number (cm^{-1})	Probable functional groups	Green synthesized copper nanoparticles Wave number(cm^{-1})	Probable functional groups
1.	3358	Broad for O-H	3368	Broad for O-H
2.	2253	Strong for C-H	2089	Strong for C-H
3.	1518	Medium for C=N	1625	Broad for C=N
4.	1125	Medium for C-O	1088	Medium for C-O
5.	688	Strong for C-Cl	614	Strong for C-Cl
6.	580	Strong	490	Strong for Cu-S

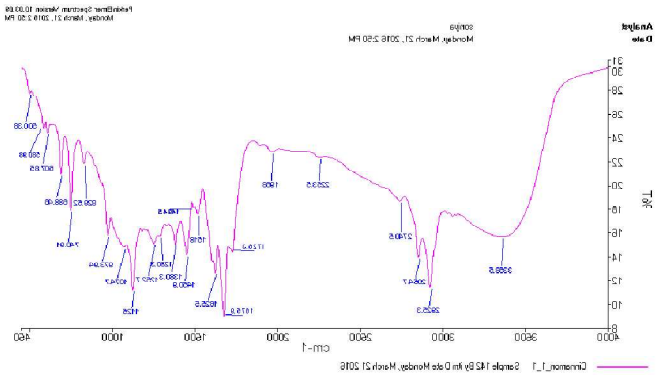

Fig.-7: FT-IR Spectra of Aqueous Extract of Cinnamon Bark Powder

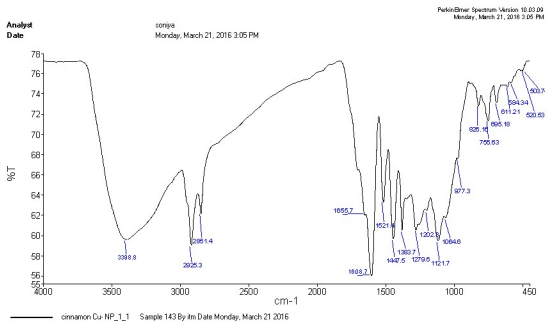

Fig.-8: FT-IR Spectra of Bio-Synthesized Copper Nanoparticles

XRD Analysis of Biosynthesized Copper Nanoparticles

The XRD technique is a very important crystallographic technique for the identification of the crystalline nature of nanomaterials via classical methods or modern methods like ultra-sonication, green synthesis, sol-gel method and microwave-assisted synthesis. The crystalline phase of the Cu NP's was characterized by XRD analysis. The diffraction intensities were recorded from 0 to 80^0 at 2θ angles, suggesting a monoclinic configuration. Six characteristics peaks were observed at 2θ angles of 16.85^0,32.36^0,39.82^0,48.91^0,54.25^0 and 62.41^0 and these correspond to the h, k, l values of the reflections

from (110),(111),(220),(810),(714) and (610) corresponding with the values of the JCPDA card (card no. 89-5899).

The Scherrer formula $D = 0.9\lambda/\beta\ Cos\theta$

Where, λ= Wave length and β=full width at half maximum at the θ angle. Was used to calculate the average crystalline size of the CuNP's, showing $13\pm$ nm on the (111) plane.

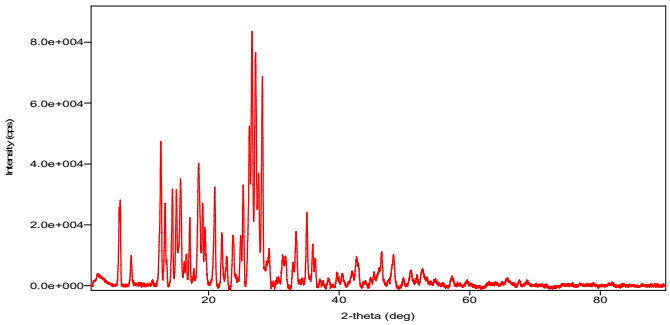

Fig.-9: XRD Spectra of the Green Synthesized Copper Nanoparticles

Morphological Analysis of Green Synthesized Copper Nano Particles (SEM Analysis)

The surface morphology of the Cu NP's was examined using FESEM (Field Emission Scanning Electron Microscopy). Figure-10 represents the SEM images of the Cu NP's at different resolutions. Scanning Electron microscopic micrographs explains the well-dispersed, versatile, and oval shape of green synthesized Cu NP's. The presence of solvent does not change the shape of Cu NP's but its presence initiates the process of nucleation of synthesis of nanoparticles. Generally, in the case of higher concentrations of plant extract, SEM micrographs revealed that Cu NP's were assembled in a very open and quasi-linear structure as compared to dense closely packed assemblies.

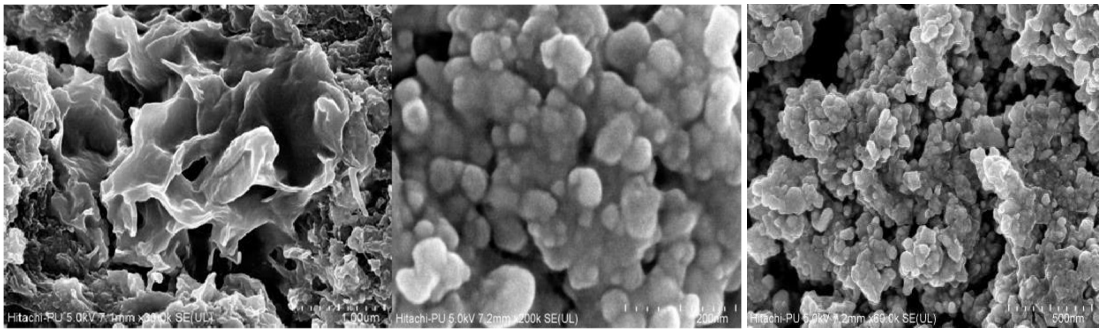

Fig.-10: SEM Image of Green Synthesized Copper Nanoparticles

TEM Analysis of the Green Synthesized Copper Nanoparticles

TEM (Transmission Electron Microscopy) is an important characterization tool for the direct imaging of nanoparticles o obtain quantitative measurements of particle size, size distribution, shape, and lattice fringes. The nanoparticle size and lattice fringes are measured using HRTEM. The thickness and radius of Cu NPs are estimated using Gatan Software. Reduced FFT shown in Fig.-11 indicates the highly crystalline behavior of green synthesized Cu NP's and a clear occurrence of lattice fringes in Cu NP's. The formation of dark and bright fringes confirms the formation of very good-quality crystalline nanomaterial. The nanoparticles have been separated by well–defined boundaries, and are visible and uniformly distributed.

Antibacterial Screening of Cu NP's

In-vitro antibacterial efficacy of cinnamon bark extract and green synthesized copper nanoparticles were studied by incorporating various concentrations of compounds on agar plates that were incubated with a range from 50 microgram/ml to 3.125 microgram/ml against a broad range of bacterial strains including gram-positive and gram-negative bacteria like *E. coli* (MTCC -1687), *Enterococcus faecalis* (MTCC—439) and *S. aureus* (MTCC -737) by disc diffusion method using nutrient agar medium.

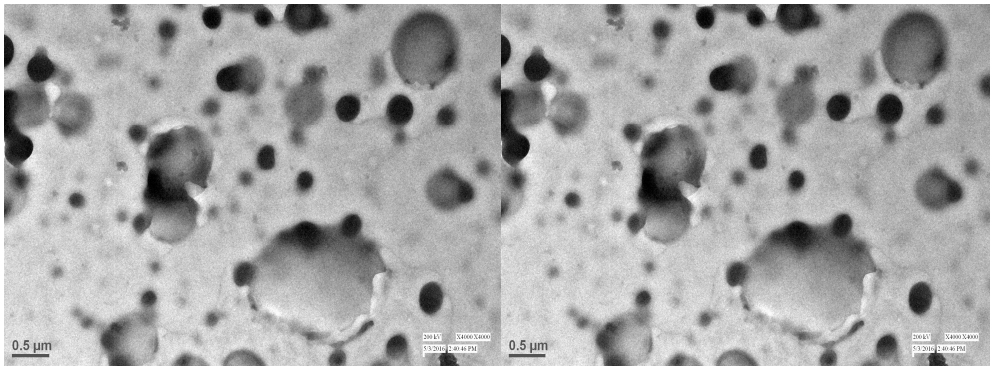

Fig.-11: TEM Images of Green Synthesized Copper Nanoparticles

The bacterial strains were sub-cultured in the agar medium and were incubated for 24 hours at 37^0C. The discs having a diameter of 5 mm were then soaked in the test solutions of cinnamon bark extract and green synthesized nanoparticles sterile filter paper discs (Whatman filter paper number-1) with the equivalent amount of cinnamon extract and green synthesized copper nanoparticles dissolved in acetone at concentrations of 50 μg/ml to 3.15 μg/ml and were placed in Petri dishes on an appropriate medium previously seeded with bacterial strains and placed in an incubator for 24 hours. After 24 hours of incubation, an inhibition zone around each disc was measured and the results were recorded in the form of an inhibition zone (diameter measured in mm). To clarify the effect of solvent on the biological screening, separate studies were carried out using DMSO as a negative control and it showed no activity against ant-tested bacterial strains. Streptomycin antibiotic was used as a positive control in this evaluation of in–vitro antibacterial activity. The higher antibacterial activity of green synthesized copper nanoparticles may be due to the adsorption of phytochemicals on the surface of copper nanoparticles which tends to make copper nanoparticles a potent bacteriostatic agent, thus inhibiting the growth of bacteria. The results of the antibacterial activities of cinnamon bark extract and green synthesized copper nanoparticles also revealed that these compounds are non-toxic in nature and are stable at room temperature.

Table-3: Inhibition of Standard Streptomycin Drug Against Broad Range of Bacterial Strains

S. No.	Microorganisms (Bacterial Strains)	Diameter of Zone of inhibition (in mm) at different drug (Streptomycin) concentrations				
		50$\mu g/ml$	25 μg/ml	12.5 μg/ml	6.25 μg/ml	3.125 μg/ml
1.	*E. coli* (MTCC -1687)	12mm	10mm	8mm	5mm	3mm
2.	*Enterococcus faecalis* (MTCC -439)	32 mm	30mm	28 mm	24 mm	22mm
3.	*S. aureus* (MTCC -737)	25mm	23 mm	21mm	18mm	16mm

Table-4: In-vitro Antibacterial Activities of Cinnamon Extract and Green Synthesized Copper Nanoparticles

S. No.	Concentrations ($\mu g/ml$	*E. coli* (MTCC -1687)	*Enterococcus faecalis* (MTCC -439)	S. aureus (MTCC -737)
1.	50 $\mu g/ml$	10mm	24 mm	20mm
	25 $\mu g/ml$	8mm	21mm	18mm
	12.5 $\mu g/ml$	6mm	18mm	14mm
	6.25 $\mu g/ml$	5mm	16mm	11mm
	3.125 $\mu g/ml$	3mm	11mm	2mm
2.	50 $\mu g/ml$	12mm	26mm	22mm
	25 $\mu g/ml$	10mm	22mm	14mm
	12.5 $\mu g/ml$	8mm	18mm	8mm
	6.25 $\mu g/ml$	4mm	14mm	6mm
	3.125 $\mu g/ml$	2mm	7mm	4mm

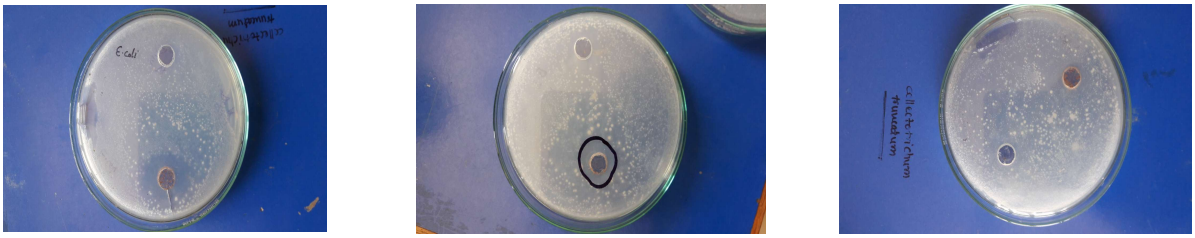

Fig.-12: Antibacterial Activities of Green Synthesized Copper Nanoparticles Against *E. coli* (MTCC -1687), *Enterococcus faecalis* (MTCC -439), S. aureus (MTCC -737) Bacterial Strains

In-vitro Antioxidant Activities of the Green Synthesized Copper Nanoparticles via DPPH Method

Both the compounds (aqueous extract of cinnamon bark and green synthesized copper nanoparticles were screened for antioxidant activity using the DPPH method. DPPH is a stable free radical compound and has been widely used to test the free radical scavenging activity of natural as well as synthetic compounds. The results showed that synthesized copper nanoparticles showed more antioxidant activity than quercetin (positive control). Green synthesized copper nanoparticles showed greater antioxidant activities than standard ascorbic acid and it is very encouraging to note that the DPPH activity of green synthesized copper nanoparticles is greater than the aqueous extract of cinnamon bark. The results of the antioxidant activities of compounds are in accordance with the theoretical aspects because the position and the number of functional groups as well as the degree of conjugation in the whole molecule are important. The antioxidant efficacy of natural flavonoids of similar conjugation levels is proportional to the presence of a total number of hydroxyl groups in the benzene ring.

Table-5: The Trolox Equivalent Antioxidant Activities of Compounds

S. No.	Compound	DPPH activity (IC_{50} $\mu g/ml$
1.	Aqueous extract of cinnamon bark extract	2.20
2.	Green synthesized copper nanoparticles	3.72
3.	Quercetin	2.80
4.	Ascorbic acid	3.60

Note-Trolox equivalent antioxidant capacity has been calculated from molar absorptivity by dividing 1.64 X 10^4

CONCLUSION

In summary, novel green synthesized copper nanoparticles from an aqueous extract of cinnamon bark are a simple, fast and eco-friendly green chemistry approach. During the chemical reaction, the color of the reaction mixture turned from dark brown to black brown, indicating the formation of copper nanoparticles and this was also confirmed by UV-Vis spectroscopic measurements. The absorption peaks at 233.7nm and 252.5nm in the UV-Vis spectroscopy results confirmed the formation of stable copper nanoparticles from the green approach. Also, results of FT-IR spectroscopy also confirmed the green synthesis of copper nanoparticles. From various structural and morphological studies, it has been observed that the shape and size of CuNP's depends upon the concentration of aqueous extract of cinnamon bark which was used as a precursor for the green synthesis of copper nanoparticles. The use of the aqueous extract of cinnamon bark extract helps to decompose copper sulfate very fast in the spherical shapes of copper nanoparticles within a short time. This is a simple, very efficient, fast eco-friendly, and cost-effective method for the preparation of black-brown copper nanoparticles. The use of plant extract plays a very important role in reducing reaction time, reducing minimum possibilities of side reactions, and proper conversion of copper sulphate solution into copper nanoparticles in the presence of plant extract in very less time. This eco-friendly method has very strong potential to be utilized for the large-scale industrial production of copper nanoparticles. From the results of the biological activities of compounds, it has been concluded that green synthesis of copper nanoparticles from cinnamon bark extract in an aqueous environment can be considered a good drug candidate for various biomedical applications like antibacterial, antioxidant, and anti-inflammatory agents in the future for human

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CONFLICT OF INTERESTS

The author declared that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The author contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the author can be verified from her ORCID id, given below:

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REFERENCES

1. G. Huang, T. Chen, Z. Wang, K. Chang, W. Chen, *Journal of Power Sources*, **235** ,122(2013), https://doi.org/10.1016/j.jpowsour.2013.01.093
2. R. C. Hoodless, R. B. Moyes, P.B. Wells, D-tracer, *Catalysis Today*, **114**, 377(2006) https://doi.org/10.1016/J.Cattod.2006.02.078
3. H. L. Wang, Y. Y. Liang, Y.G. Li, H.J. Dai, Co1−XS, *Angew American Chemical Society*, **50**,10969(2011), https://doi.org/10.1002/anie.201104004
4. D. Podstawczyk, A. Pawłowska, A. Bastrzyk, M. Czeryba andJ. Oszmia´nski, American , *American Chemical Society Sustainable Chemical Enggnering*, **7**,17535(2019), https://doi.org/10.1021/acssuschemeng.9b05078
5. K. Cheirmadurai, S. Biswas, R. Murali and P. Thanikaivelan, *RSC Advanced*, **4**, 19507(2014), https://doi.org/10.1039/C4RA01414F
6. Z. Moln´ar, V. B´odai, G. Szakacs, B. Erd´elyi, Z. Fogarassy,G. S´afr´an, T. Varga, Z. K´onya, E. T´oth-Szeles, R. Sz}ucs and I. Lagzi, *Scientific Reports*, **8**, 3943(2018), https://doi.org/10.1016/j.biotechadv.2022.107914
7. M. K. Ghosh, K. Jain, S. Khan, K. Das and T. K. Ghorai , *ACS Omega*, **5**, 4973(2020), https://doi.org/10.1021/acsomega.9b03875
8. N. Nazar, I. Bibi, S. Kamal, M. Iqbal, S. Nouren, K. Jilani,M. Umair and S. Ata, *International Journal of Biology Macromolecule*,**106**,1203(2018), https://doi.org/10.1016/j.ijbiomac.2017.08.126
9. S. Vasantharaj, S. Sathiyavimal, M. Saravanan, P. Senthilkumar, K. Gnanasekaran, M. Shanmugavel, E. Manikandan and A. Pugazhendhi, *Journal Photochemistry and Photobiology, B*, **191**, 143(2019), https://doi.org/10.1016/j.jphotobiol.2018.12.026
10. L. Zhao, Q. Hu, Y. Huang, A. N. Fulton, C. Hannah-Bick, A. S. Adeleye and A. A. Keller, *Environmental Science: Nanotechnology*, **4**, 1750(2017), https://doi.org/10.1039/C7EN00358G
11. A. P. Ingle, N. Duran and M. Rai, *Applied Microbiology Biotechnology*, **98**, 1001(2014), https://doi.org/10.1007/s00253-013-5422-8
12. F. Duman, I. Ocsoy and F. O. Kup, *Material Science Engineering C*, **60**, 333(2016), https://doi.org/10.1016/j.msec.2015.11.052
13. T. Dayakar, K. V. Rao, K. Bikshalu, V. Rajendar and S. H. Park, *Journal of Material Science: Material Medicine*, **28**, 109(2017), https://doi.org/10.1007/s10856-017-5907-6
14. H. J. Lee, J. Y. Song and B. S. Kim, *Journal of Chemical Technology and Biotechnology*, **88**, 1971(2013), https://doi.org/10.1002/jctb.4052

15. S. Yallappa, J. Manjanna, M. A. Sindhe, N. D. Satyanarayan, S. N. Pramod and K. Nagaraja, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy,* **110**, 108(2013), https://doi.org/10.1016/j.saa.2013.03.005
16. J. Ramyadevi, K. Jeyasubramanian, A. Marikani, G. Rajakumar, A. A. Rahuman, T. Santhoshkumar, A. V. Kirthi, C. Jayaseelan and S. Marimuthu, *Parasitology Research*,**109**, 1403(2011), https://doi.org/10.1007/s00436-011-2387-3
17. Y. Abboud, T. Saffaj, A. Chagraoui, A. El Bouari, K. Brouzi, O. Tanane and B. Ihssane, *Applied Nanoscience*, **4**, 571**(**2014), https://doi.org/10.1007/s13204-013-0233-x
18. R. Sivaraj, P. K. Rahman, P. Rajiv, H. A. Salam and R. Venckatesh, *Spectrochim. Acta, Part A*, **133**, 178(2014), https://doi.org/10.1016/j.saa.2014.05.048
19. S. P. Goutam, G. Saxena, V. Singh, A. K. Yadav, R. N. Bharagava and K. B. Thapa, *Chemical Engineering Journal*, **336**, 386(2018), https://doi.org/10.1016/j.cej.2017.12.029
20. N. Chauhan, A. K. Tyagi, P. Kumar and A. Malik, *Frontiers in Microbiology*, **7**, 1748, (2018), https://doi.org/10.3389/fmicb.2016.01748
21. S. K. Chandraker, M. Lal and R. Shukla, *RSC Advanced*, **9**, 23408(2019), https://doi.org/10.1039/C9RA03590G
22. N. Senthilkumar, E. Nandhakumar, P. Priya, D. Soni,M. Vimalan and I. V. Potheher, *New Journal of Chemistry*, **41**,10347(2017), https://doi.org/10.1039/C7NJ02664A
23. M. Ganapathy, N. Senthilkumar, M. Vimalan, R. Jeysekaran and I. V. Potheher, *Material Research. Express*, **5**, 045020(2018), https://doi.org/10.1088/2053-1591/aab91b
24. M. Jayapriya, D. Dhanasekaran, M. Arulmozhi,E. Nandhakumar, N. Senthilkumar and K. Sureshkumar, *Research on Chemical Intermediates*, **45**, 3617(2019), https://doi.org/10.1007/s11164-019-03812-5
25. E. Nandha Kumar, P. Priya, P. Selvakumar, E. Vaishnavi,A. Sasikumar and N. Senthilkumar, *Material Research Express*, **6**, 095036(2019), https://doi.org/10.1088/2053-1591/ab2eb9
26. N. Senthilkumar, V. Aravindhan, K. Ruckmani and I. V. Potheher, *Material Research Express*, **5**, 055032(2018), https://doi.org/10.1088/2053-1591/aac312
27. M. K. Ghosh, S. Sahu, I. Gupta and T. Kumar Ghorai, *RSC Advanced*, **10**, 22027(2020), https://doi.org/10.1039/d0ra03186k
28. R Amjad, B.Mubeen, S. Shahbaz Ali, S. Sarim Imam, S.Alshehri, M. M. Ghoneim, S. I. Alzarea, R. Rasool, I. Ullah, M. S. Nadeem, and I. Kazmi, *Polymers*, **13(24)**, 4364(2021), https://doi.org/10.3390/polym13244364
29. C. A. Murthy, T. Desalegn, M. Kassa, B. Abebe, and T. Assefa, *Journal of Nano Materials*, 3924081(2020), https://doi.org/10.1155/2020/3924081

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