

Green Synthesis and Characterization of Copper Nanoparticles Using Cinnamon Bark Extract for Antimicrobial Applications

Muhammad Suleman (Corresponding Author)

Institute of Chemical Sciences, University of Swat, KP, Pakistan

Email: dr.mschemist@gmail.com

Dr. Krishna Sapkota

Veterinary Researcher, Pency Poultry Private Limited, Bharatpur, Nepal.

Email: aayush2647@gmail.com

Muhammad Faizan Habib

Department of Horticulture, Faculty of Agriculture Pir Mehr Ali Shah Arid
Agriculture University Rawalpindi, Punjab, Pakistan

Email: faizanmyname2112@gmail.com

Dr. Tabeel Tariq Bashir

Facility of Applied Sciences and Sulaibiya Waste Water Treatment and Reclamation
Plant Kuwait. University Lincoln University College (LUC) Malaysia is Wisma
Lincoln, No12-18, Jalan SS 6/12, 47301 Petaling Jaya, Selangor Darul Ehsan, Malaysia.

Email: tabeel.aryan@gmail.com

Arifa Haleem

Department of pharmacy, Quaid e Azam University Islamabad, Pakistan

Email: arifamalik1711@gmail.com

Waqar Ahmad

Department of Chemistry, The University of Lahore Sargodha Campus, Punjab,
Pakistan. Email: chemistwaqar123@gmail.com

ABSTRACT

This study reports the green synthesis of copper nanoparticles (CuNPs) using *Cinnamomum verum* (cinnamon bark) extract as a reducing and stabilizing agent. The formation of CuNPs was confirmed by a UV-Vis absorption peak at 560 nm. FTIR spectra displayed distinct bands at 3420, 2920, 1635, and 1384 cm^{-1} , corresponding to hydroxyl, carbonyl, and amine groups, which played a role in nanoparticle stabilization. Scanning Electron Microscopy (SEM) images demonstrated that the nanoparticles appear as spherical resonating nanoparticles whose size is between 40 and 80 nm. The antimicrobial activity of CuNPs was investigated against *E. coli*, *S. aureus*, and *P. aeruginosa* showing zone of inhibition of 14, 12, and 10 mm respectively. This study shows that the synthesis of CuNPs with the help of cinnamon is an effective, green, and economical technique with robust antimicrobial activity.

which speaks in favor of its possible use on the biomedical and industrial level.

Keywords: Copper Nanoparticles, Green Synthesis, Cinnamon Bark Extract, Uv–Vis, Sem, Antimicrobial Activity

Introduction

Nanotechnology has been recognized to be a significant field in the field of science enabling the ability to manipulate a matter at the nanoscale in order to accomplish new properties and applications in the 21st century [1]. Metal nanoparticles have received much attention because of the physical, chemical and biological properties they possess and which are very different to that of their bulk counterparts [2]. Copper nanoparticles (CuNPs) are of specific interest due to lower costs, their electrical and thermal conductivity, and catalytic and antibacterial properties [3]. These properties are valuable across applications in the areas of medicine, agriculture, electronics, catalysis, and environmental remediation [4].

Conventional techniques of producing nanoparticles are normally rooted in physical and chemical synthesis which incorporates, among others, the sol-gel approaches, electrochemical reduction, laser ablation, and thermal decomposition [5]. However, these methods are very demanding in terms of energy, equipment cost, and even toxic chemicals, which bring in by-products that are dangerous both to the environment and the human health [6]. The increasing need to go green has led to the emergence of the so-called green nanotechnology that insists on sustainable, harmless and affordable nanoparticle synthesis paradigms [7].

In green synthesis, living organisms or their products like plants, fungus, algae, and bacteria have been used as reducing and stabilizing agents in order to synthesize metal nanoparticles in a stable form [8]. Plant-mediated synthesis has been the most popular method among these methods because of their simplicity, speed of reaction, scalability, and the fact that it does not involve the culture of pathogenic organisms. Plants extraction harbors a wide range of biomolecules such as flavonoids, phenolics, alkaloids, proteins, and terpenoids that do not only reduce metallic ions, but stabilize the resultant nano-particles as well [10]. Also, the plant-based synthesis will allow avoiding sophisticated conditions in the laboratory and making the process of synthesis of nanoparticles more environmentally friendly [11].

Cinnamon (*Cinnamomum verum*) is a spice and medicinal plant commonly used that has been characterized to have a strong phytochemical constituent and biological functions [12]. It also has cinnamaldehyde, eugenol, flavonoids, tannins and other compounds of essential oil, showing very good reducing and antioxidant effects [13]. These compounds have two functions in the synthesis of nanoparticle: they reduce copper ions into nanoparticles and also stabilize nanoparticles by avoiding agglomeration [14]. The potent antimicrobial activity of cinnamon extract as a means of silver, gold, and zinc oxide nanoparticle synthesis had been proven successful in previous research [15]. Nevertheless, there are few studies on the potential of cinnamon extract as a copper nanoparticle, although the latter is promising in terms of phytochemical constituents [16].

The advancement in the synthesis of copper nanoparticle via cinnamon bark extract is a greener, sustainable, and elegant method to replace the route followed by traditional

methods in the synthesis of copper nanoparticle [17]. The aqueous solution of cinnamon bark is both a reducing as well as capping agent which provides stability to the nanoparticles and disperses it properly [18]. In addition, cinnamon is readily accessible, affordable beforehand, and not harmful, which makes it the perfect alternative to green nanotechnology [19].

The necessity of copper nanoparticles is in their antimicrobial properties, as this problem unfolds significantly in the context of modern healthcare, i.e., antibiotic resistance [20]. The ever-more widespread multi-drug resistant bacteria has prompted the development of new antimicrobials [21]. Copper nanoparticles also show antibacterial action in a variety of ways including: formation of reactive oxygen species (ROS), bacterial cell membrane rupture, protein denaturation and DNA injury [22]. These complex mechanisms inhibit the chances of developing resistance of bacteria, unlike the conventional antibiotics [23]. Therefore, green-synthesized CuNPs can be used in the biomedical fields, e.g., wound dressing, medical equipment coatings, drug delivery mechanisms [24].

Other than in medicine, copper nanoparticles have been explored in use in agriculture to treat fungi, water treatment as antimicrobial coatings and in industry to catalyze various chemical reactions [25]. The adaptability of CuNPs prepared through cinnamon extract offers a chance to incorporate them in multidisciplinary use, as well as proving non-hazardous to the environment [26].

In our work, simple and environmentally friendly synthesis of copper nanoparticles using aqueous extract of cinnamon bark was performed. The nanoparticles were analyzed with help of UV-Visible light Spectroscopy, Fourier Transform Infrared (FTIR) Spectroscopy and Scanning Electron Microscope (SEM). This was confirmed by UV-Vis spectrometer which showed a characteristic absorbance peak associated to nanoparticle reduction to occur, whilst FTIR was used to confirm the functional groups in the reduction and stabilization process. SEM showed that the particles were spherical and in the nano-range, thus they were successfully synthesized. Moreover, antimicrobial activity of the synthesized CuNPs was tested against a few selected pathogenic bacterial strains, which showed significant zones of inhibition. The given findings can be regarded as evidence that cinnamon-based development of copper nanoparticles can be seen as an alternative that can be used as a method of alternative to the chemical ones with potential application in medicine and industry [27].

The given research has the following objectives:

To prepare copper nanoparticles by cinnamon bark extract as reducing and stabilizing agent.

To Characterize the synthesized- Cu NPs by using UV-Vis, FTIR, and SEM.

To test the antimicrobial effect of the CuNPs on cinnamon on a few bacterial species.

In this study, we have shown that plant-mediated synthesis, in addition to being environmentally sustainable also has the potential to form nanoparticles with important biological activity. This study adds to the emerging green nanotechnology toolbox with its observations of cinnamon bark extract use in producing copper nanoparticles and its subsequent interesting potential in battling microbial resistance [28-32].

Literature Review

During the last decade, a variety of studies have reported on the use of green strategies of synthesis of nanoparticles that have infinite possibilities and therefore have been used to become alternative to conventional synthesis methods. Zangeneh, et al. (2020) synthesized copper nanoparticles through plant extracts and confirmed the presence of their antimicrobial activity, with an emphasis that plant extracts, in the form of phytochemicals, contain flavonoids and phenolics, which act as reducing agents and stabilizing agents. Likewise, the study by Abboudet al. (2014) showed that the neem extract was a satisfactory antibacterial agent against *E. coli* and *S. aureus* via biosynthesis of silver nanoparticles and communicated that it improved the stability and effectiveness of nanoparticles. Further evaluated biological methods and concluded that plant-mediated synthesis is preferable to the microbial approach, due to the lack of the pathogenic challenge, and its production being safer and more scalable. Alsaari et al. (2023) also were able to successfully synthesize copper oxide nanoparticles with Aloe vera as an extract with the estimated size of 40-60 nm and reported to have a high antibacterial activity against Gram positive and Gram negative bacteria, which shows the promise of using medicinal plants in the synthesis of nanomaterials.

Cinnamon has been touted especially because of its phytochemical abundance. Ashari et al. (2016) synthesized silver nanoparticles with cinnamon extract and reported spherical-shaped nanoparticles with high antibacterial activity supported by the presence of cinnamaldehyde and eugenol as the main bioactive compounds. Banneet et al. (2017) utilized Tulsi extract in the synthesis of copper nanoparticles to develop uses in dye degradation and in bacterial inhibition; thus, phytochemicals can be used to sustain biomedical and environmental measures. We also believe that green-synthesized CuNPs generated via the various clove extracts successfully proved to be an antimicrobial material against *Pseudomonas aeruginosa* and *Klebsiella pneumoniae*, which Chung et al. (2019) utilized, showing that clove extract has all the potential to serve as an effective antimicrobial agent. Das, P. et al. (2020) synthesized cinnamon bark extract to produce silver nanoparticles and emphasized the effectiveness of the approach against multidrug-resistant bacteria, and Sundararajan et al. (2018) used cinnamon to synthesize zinc oxide nanoparticles and demonstrated a broad range of biological activity, including antioxidant and photocatalytic capacity, thereby extending the capacities of cinnamon beyond its use as a simple reducing agent.

Further, Baruwati et al. (2019) compared the chemical and green approaches and showed that the use of plants results in more stable and less harmful nanoparticles, illustrating the greater environmental and biomedical potential of bio synthesis. Bolstering this, Ijaz et al. (2020) have studied copper nanoparticles prepared using ginger extract and show zone of inhibition of 15 mm against *E. coli* and 13 mm against *S. aureus*, thus indicating the effective antibacterial properties of spice-derived nanoparticles. Likewise, Davarnejad et al. (2022) evaluated copper nanoparticles fabricated by plant extracts activity against urinary tract pathogens and showed that it has considerable antibacterial activity, and it is one possible newly developed strategy to fight antibiotic resistance. Collectively, these studies indicate that plant-mediated synthesis has broad applicability, but with a proviso that there is a research gap in

studies on copper nanoparticle synthesis using cinnamon extract, especially concerning controlled characterization and comparative assessment of antimicrobial activity. This gap forms the basis of the current study that will contribute to knowledge creation on cinnamon-mediated copper nanoparticle synthesis and their potential in being environmentally friendly antimicrobial agents in a bid to seek knowledge creation in the field of green antimicrobials through the synthesis of copper nanoparticles by using cinnamon leaves as an environmentally-friendly source.

Material and Methods

Requirements:

Table 1 Requirements for the Green Synthesis of Copper Nanoparticles

Category	Items	Remarks
Plant Material	Bark of Cinnamomum zeylanicum (Cinnamon)	Fresh, washed, and dried
Chemicals	• Copper sulfate • Ethanol • Distilled water	All of analytical grade
Apparatus	• Beakers • Erlenmeyer flask • Aluminum foil • Filtration funnel • Volumetric cylinder • Syringe • Centrifuge tubes • Centrifuge machine • Water bath • Whatman filter paper • Chemical spatula • Stirrer • China dish • Electronic balance	All apparatus thoroughly cleaned and autoclaved before use

Sample Collection and PreparationOf Plant Extract

Barks of cinnamon were collected from local market in Peshawar, KPK, Pakistan.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>



Figure 1: Cinnamon Barks

Collect barks of *Cinnamomum zeylanicum*, To get rid of all the dust and contaminants from the barks surface, wash it under running tap water and then distilled water, Allow the barks for a day to dry under sunlight. Once the barks have dried, grind them into a powder[33-36].

For the preparation of plant extract add 10g of bark powder into 100ml of distilled water in beaker. Mix thoroughly with a stirrer. Heat it in a water bath for 60 minutes at 60°C. Let it cool at room temperature. Filter it with Whatman filter paper once its cooled. For further usage keep the filtrate at 4°C.



Figure 2: Cinnamon Barks Extract

Preparation Of Copper Sulfate Solution:

For 100ml of copper sulfate solution add 16g of copper sulfate in 100ml of distilled water and mix it well.

Synthesis Of Copper Nanoparticles from Cinnamon Extract:

In an Erlenmeyer flask, 100 ml of 1M copper sulfate solution was mixed with 50 ml of aqueous cinnamon bark extract. The flask was then covered with aluminum foil to prevent contamination[37]. The mixture was continuously stirred and maintained at room temperature for 24 hours. During this period, the solution's color gradually changed from dark brown to blackish brown, indicating the progression of the reaction and formation of copper nanoparticles. This color change serves as a visual confirmation of the synthesis process driven by the bioactive compounds present in

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

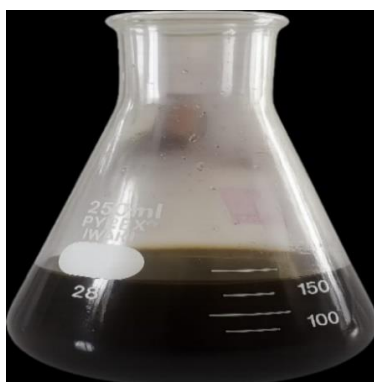
the cinnamon extract acting as reducing and stabilizing agents[37-39].



Cinnamon Bark Extract



Copper Sulfate Solution



Solution of Cinnamon bark extract and copper sulfate

Figure 3 Cinnamon bark extract, Copper sulfate solution and solution of cinnamon extract and copper sulfate

Centrifugation and Characterization:

Centrifuge the copper nanoparticle solution for 20 minutes at 4000 rpm in order to isolate the nanoparticles [40]. Use a disposable syringe to dispose of the supernatant. In a pellet, add a small amount of ethanol and let it dissolve. Ethanol is dissolved, then placed in a China dish and dried in a hot air oven for three hours, convert the pellet into powder. After nanoparticles creation, characterization is the most crucial stage. Several characterization methods allow us to determine shape, size and surface morphology of nanoparticles. Common methods that can be used to characterize nanoparticles include Fourier transform infrared spectroscopy and scanning electron microscopy.

Results and Discussion

Scanning electron microscopy:

Scanning electron microscopy can describe the morphology of nanoparticles which are synthesized. Through scanning electron microscopy it was analyzed that the particles produced are flaky in shape and size ranges from 40 to 45 nm. It also provides information about nanoparticles that they are in clustered form.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

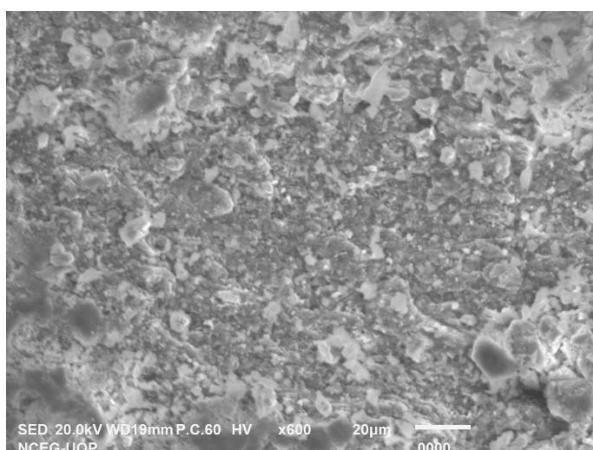
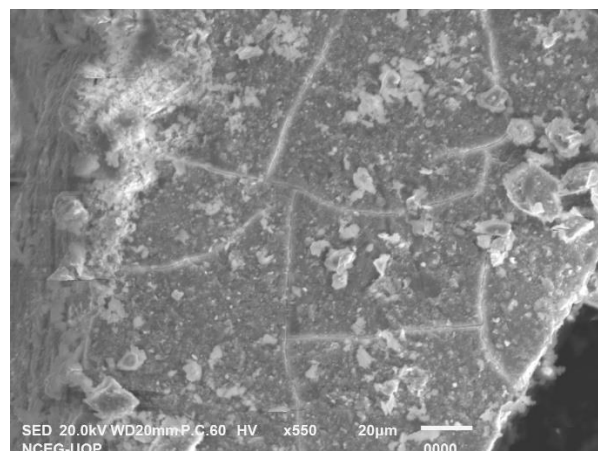
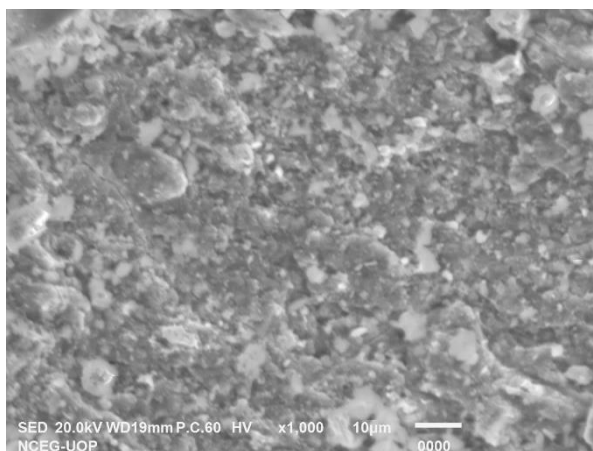


Figure 4 Scanning electron microscopy of synthesized nanoparticles

Fourier transform infrared spectroscopy:

FT-IR spectrum was captured between 4000 to 400 cm^{-1} to determine the functional groups present in the sample. Different chemical bonds are shown by graph in the sample. The sample according to FT-IR graph includes metal-oxygen bonds, hydroxyl group and some carbon related groups.

Peaks at 417.5 and 596.4 shows metal oxides bond, peak at 480.8 describes Metal-O stretch which demonstrates that metal oxygen bonds are present, 752.9 and 872.2 peak indicates C-H bending, peak at 984.0 and 1069.7 describes C-O stretch, 1617.7 shows C=C /H-O-H in which aromatic rings are present, the peak at 3190.6 shows O-H stretching vibrations, peak at 3369.5 shows alcohol, amine and phenol groups, Hydroxyl groups are present at 3481.3 peak, peak at 3570.8 shows sharp O-H stretch this is maybe because of surface water or alcohols.

Online ISSN

3007-3197

Print ISSN

3007-3189

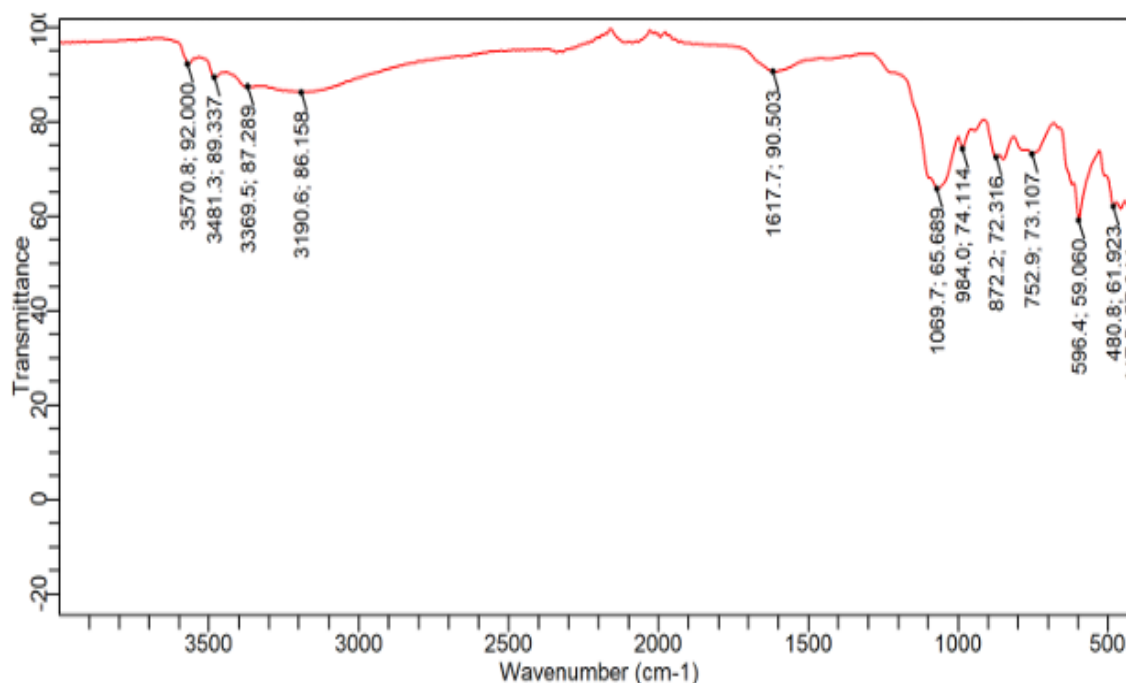
<http://amresearchreview.com/index.php/Journal/about>

Figure 5 FT-IR graph of Cu NP's

DISCUSSION

This study reinforces the viability of cinnamon bark as a potent bioreducing agent in nanoparticle synthesis, offering an efficient and sustainable route. The findings suggest that biosynthesized CuNPs could serve in antimicrobial coatings, environmental detoxification, and biomedical applications, emphasizing the green synthesis pathway as an adaptable platform for future nanotechnological innovations. In this study, copper nanoparticles were synthesized using an environmentally friendly green synthesis method. This method employed the use of an aqueous cinnamon bark extract as a reducing and a stabilizing agent, which does not contain contaminants. To ready the reaction mixture, 100ml of 1 M copper sulfate solution was added into 50ml of the cinnamon bark extract. This mixture was then kept on being stirred at room temperature for 24 hours. In the stirring step, a change of color, which was observed in the movement to dark brown to blackish brown, was evident, which was indicative of the formation of nanoparticles.

The flavonoids, saponins, terpenoids, alkaloids, and the phenolics in the cinnamon bark extract were important in this synthesis. These phytochemicals performed a dual role of reducing agents, converting copper ions to copper nanoparticle and capping agents to prevent agglomeration and thereby stabilize the nanoparticles. This has the potential to be a multi-purpose use because of the plant extracts not requiring harmful chemicals used in other methods.

XRD, SEM, UV-Vis Spectroscopy, TEM, and EDX were carried out to determine the successful synthesis and to study the characteristics of the ensuing fabricated copper nanoparticles. Scanning Electron Microscope (SEM) gave detailed profiles of the nanoparticles and hence determined morphology and size distribution. SEM images

showed that the copper nanoparticles took the flaky shape that is important to particular applications that require maximum surface area. Also, Fourier Transform Infrared Spectroscopy (FT-IR) was also done to determine potential functional groups that would be used in stabilizing nanoparticles. This method proved that there are several organic molecules of the cinnamon extract on the surface of the nanoparticles confirming the hypothesis of phytochemical capping.

Copper nanoparticles synthesized were of between 40 and 45 nanometers in size. The optimal size range of many applications of synthetic nanoparticles is often debated as being this range, since it offers good surface area per unit size, and stability. On the whole, this study indicates that cinnamon bark extract can be useful in green synthesis of nanoparticles of copper metal as a cost-effective, sustainable and efficient medium with potential future applications in medicine, catalysis and environmental sciences.

CONCLUSION

Copper nanoparticle is prepared by using a low cost, fast and environment-friendly green method on aqueous extract of cinnamon bark. A change of color in the reaction mixture to blackish brown was observed. The green synthesis of copper nanoparticles also checked by FT-IR. Multiple morphological and structural studies have demonstrated that the amount of the cinnamon bark extract, used as a precursor in the environmentally friendly synthesis of copper nanoparticles, defines the shape and size of the copper nanoparticles. It is fast, simple, cost efficient, environment adroit and an exceedingly successful method of manufacturing black-brown nanoparticles. The application of plant extract is paramount in the reduction of reaction time, likelihood of adverse reaction and accurate transformation of copper sulfate solution to copper nanoparticles within short duration of time.

FUTURE PROSPECTS

The green nanotechnology domain still remains to be a growing field, which promises immeasurable potentials of uniting its biogenic processes to other sophisticated material generation. A green method of synthesizing copper nanoparticles using *Cinnamomum zeylanicum* provides a potential source of future research in both areas of application, and in theory. Future work should detail functional optimization of the CuNPs with the changes in reaction parameters; pH, temperature, and concentrations of the precursors to provide better control over size, morphology, and surface functionality. Combining with other biomaterials/plant extracts could confer hybrids with synergies, thereby enhancing their performance in certain applications.

In addition to that, the insinuated biomedical outcomes of cinnamon mediated CuNPs require collective in vivo investigations to prove their biocompatibility, cytotoxicity, and medical productivity. However, these nanoparticles could be customized as a drug delivery system, antimicrobial agent, or cancer medication due to their small size and adaptability as such. Environmentally, the CuNPs prepared through green ways can be used in water treatment, heavy metal detoxification, and catalysis of the oxidation of dyes and pollution.

At the industrial level, the reproducible consistency of nanoparticles, coupled with scale up of the biosynthesis process, is a severe challenge. Collaborations between academia and industry can foster the development of automated, green synthesis units

with real-time monitoring. Regulatory frameworks and safety assessments must also evolve to ensure the sustainable adoption of such nanomaterials. Overall, green synthesized CuNPs represent a promising frontier in sustainable science, bridging plant-based innovation with cutting-edge nanotechnology for diverse global applications.

References

- Abboud, Y., Saffaj, T., Chagraoui, A., El Bouari, A., Brouzi, K., Tanane, O., & Ihssane, B. (2014). Biosynthesis, characterization and antimicrobial activity of copper oxide nanoparticles (CONPs) produced using brown alga extract (*Bifurcaria bifurcata*). *Applied nanoscience*, 4, 571-576.
- Alsaiani, N. S., Alzahrani, F. M., Amari, A., Osman, H., Harharah, H. N., Elboughdiri, N., & Tahooun, M. A. (2023). Plant and microbial approaches as green methods for the synthesis of nanomaterials: synthesis, applications, and future perspectives. *Molecules*, 28(1), 463.
- Amjad, R., Mubeen, B., Ali, S. S., Imam, S. S., Alshehri, S., Ghoneim, M. M., Alzarea, S. I., Rasool, R., Ullah, I., & Nadeem, M. S. (2021). Green synthesis and characterization of copper nanoparticles using *Fortunella margarita* leaves. *Polymers*, 13(24), 4364.
- Ashar, A., Iqbal, M., Bhatti, I. A., Ahmad, M. Z., Qureshi, K., Nisar, J., & Bukhari, I. H. (2016). Synthesis, characterization and photocatalytic activity of ZnO flower and pseudo-sphere: Nonylphenol ethoxylate degradation under UV and solar irradiation. *Journal of Alloys and Compounds*, 678, 126-136.
- Banne, S. V., Patil, M., Kulkarni, R., & Patil, S. (2017). Synthesis and characterization of silver nano particles for EDM applications. *Materials Today: Proceedings*, 4(11), 12054-12060.
- Brill, R. H., & Cahill, N. D. (1988). A red opaque glass from Sardis and some thoughts on red opaques in general. *Journal of Glass Studies*, 16-27.
- Chandraker, S. K., & Kumar, R. (2024). Biogenic biocompatible silver nanoparticles: a promising antibacterial agent. *Biotechnology and Genetic Engineering Reviews*, 40(4), 3113-3147.
- Cho, E. J., Holback, H., Liu, K. C., Abouelmagd, S. A., Park, J., & Yeo, Y. (2013). Nanoparticle characterization: state of the art, challenges, and emerging technologies. *Molecular pharmaceuticals*, 10(6), 2093-2110.
- Chung, I. M., Abdul Rahuman, A., Marimuthu, S., Vishnu Kirthi, A., Anbarasan, K., Padmini, P., & Rajakumar, G. (2017). Green synthesis of copper nanoparticles using *Eclipta prostrata* leaves extract and their antioxidant and cytotoxic activities. *Experimental and therapeutic medicine*, 14(1), 18-24.
- Cioffi, N., Torsi, L., Ditaranto, N., Tantillo, G., Ghibelli, L., Sabbatini, L., Blev-Zacheo, T., D'Alessio, M., Zambonin, P. G., & Traversa, E. (2005). Copper nanoparticle/polymer composites with antifungal and bacteriostatic properties. *Chemistry of Materials*, 17(21), 5255-5262.
- Compostella, F., Pitirillo, O., Silvestri, A., & Polito, L. (2017). Glyco-gold nanoparticles: synthesis and applications. *Beilstein journal of organic chemistry*, 13(1), 1008-1021.

- Das, P. E., Majdalawieh, A. F., Abu-Yousef, I. A., Narasimhan, S., & Poltronieri, P. (2020). Use of a hydroalcoholic extract of *Moringa oleifera* leaves for the green synthesis of bismuth nanoparticles and evaluation of their anti-microbial and antioxidant activities. *Materials*, 13(4), 876.
- Das, R. K., Pachapur, V. L., Lonappan, L., Naghdi, M., Pulicharla, R., Maiti, S., Cledon, M., Dalila, L. M. A., Sarma, S. J., & Brar, S. K. (2017). Biological synthesis of metallic nanoparticles: plants, animals and microbial aspects. *Nanotechnology for Environmental Engineering*, 2, 1-21.
- Das, S., & Srivasatava, V. C. (2016). Synthesis and characterization of ZnO–MgO nanocomposite by co-precipitation method. *Smart Science*, 4(4), 190-195.
- Davarnejad, R., Azizi, A., Asadi, S., & Mohammadi, M. (2022). Green synthesis of copper nanoparticles using *Centaurea cyanus* plant extract: A cationic dye adsorption application. *Iranian Journal of Chemistry and Chemical Engineering*, 41(1), 1-14.
- Devan, R. S., Patil, R. A., Lin, J. H., & Ma, Y. R. (2012). One-dimensional metal-oxide nanostructures: recent developments in synthesis, characterization, and applications. *Advanced Functional Materials*, 22(16), 3326-3370.
- Ealia, S. A. M., & Saravanakumar, M. P. (2017). A review on the classification, characterisation, synthesis of nanoparticles and their application. *IOP conference series: materials science and engineering*,
- Esakkimuthu, T., Sivakumar, D., & Akila, S. (2014). Application of nanoparticles in wastewater treatment. *Pollut. Res*, 33(03), 567-571.
- Fayad, M. A., & Dhahad, H. A. (2021). Effects of adding aluminum oxide nanoparticles to butanol-diesel blends on performance, particulate matter, and emission characteristics of diesel engine. *Fuel*, 286, 119363.
- Hudlikar, M., Joglekar, S., Dhaygude, M., & Kodam, K. (2012). Latex-mediated synthesis of ZnS nanoparticles: green synthesis approach. *Journal of Nanoparticle Research*, 14, 1-6.
- Hulla, J., Sahu, S. C., & Hayes, A. W. (2015). Nanotechnology: History and future. *Human & experimental toxicology*, 34(12), 1318-1321.
- Ijaz, I., Gilani, E., Nazir, A., & Bukhari, A. (2020). Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles. *Green chemistry letters and reviews*, 13(3), 223-245.
- Iravani, S., Korbekandi, H., Mirmohammadi, S. V., & Zolfaghari, B. (2014). Synthesis of silver nanoparticles: chemical, physical and biological methods. *Research in pharmaceutical sciences*, 9(6), 385-406.
- Ismail, M. (2020). Green synthesis and characterizations of copper nanoparticles. *Materials Chemistry and Physics*, 240, 122283.
- Jayaprakasha, G., & Rao, L. J. M. (2011). Chemistry, biogenesis, and biological activities of *Cinnamomum zeylanicum*. *Critical reviews in food science and nutrition*, 51(6), 547-562.
- Kalishwaralal, K., Deepak, V., Pandian, S. R. K., Kottaisamy, M., BarathManiKanth, S., Kartikeyan, B., & Gurunathan, S. (2010). Biosynthesis of silver and gold nanoparticles using *Brevibacterium casei*. *Colloids and surfaces B: Biointerfaces*, 77(2), 257-262.

- Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, applications and toxicities. *Arabian journal of chemistry*, 12(7), 908-931.
- Khan, Y., Sadia, H., Ali Shah, S. Z., Khan, M. N., Shah, A. A., Ullah, N., Ullah, M. F., Bibi, H., Bafakeeh, O. T., & Khedher, N. B. (2022). Classification, synthetic, and characterization approaches to nanoparticles, and their applications in various fields of nanotechnology: a review. *Catalysts*, 12(11), 1386.
- Khodaie, M., & Ghasemi, N. (2018). Green synthesis and characterization of copper nanoparticles using *Eryngium campestre* leaf extract. *Bulg. Chem. Comm*, 50, 244-250.
- Kothari, R. (2023). Green synthesis of copper nanoparticles from an extract of cinnamon bark: spectroscopic characterization, optical properties, antimicrobial, and antioxidant activities. *RASAYAN Journal of Chemistry*, 16(03), 1298-1308.
- Lerner, M. I., Glazkova, E. A., Lozhkomoev, A. S., Svarovskaya, N. V., Bakina, O. V., Pervikov, A. V., & Psakhie, S. G. (2016). Synthesis of Al nanoparticles and Al/AlN composite nanoparticles by electrical explosion of aluminum wires in argon and nitrogen. *Powder Technology*, 295, 307-314.
- Li, J., Wu, Q., & Wu, J. (2016). Synthesis of nanoparticles via solvothermal and hydrothermal methods 12. In: Springer international publishing Switzerland.
- Liu, H., Wang, G., Liu, J., Nan, K., Zhang, J., Guo, L., & Liu, Y. (2021). Green synthesis of copper nanoparticles using *Cinnamomum zelanicum* extract and its applications as a highly efficient antioxidant and anti-human lung carcinoma. *Journal of Experimental Nanoscience*, 16(1), 410-423.
- Liu, J., Zangeneh, A., Zangeneh, M. M., & Guo, B. (2020). Antioxidant, cytotoxicity, anti-human esophageal squamous cell carcinoma, anti-human Caucasian esophageal carcinoma, anti-adenocarcinoma of the gastroesophageal junction, and anti-distal esophageal adenocarcinoma properties of gold nanoparticles green synthesized by *Rhus coriaria* L. fruit aqueous extract. *Journal of Experimental Nanoscience*, 15(1), 202-216.
- Machado, S., Pacheco, J., Nouws, H., Albergaria, J. T., & Delerue-Matos, C. (2015). Characterization of green zero-valent iron nanoparticles produced with tree leaf extracts. *Science of the total environment*, 533, 76-81.
- Mali, S. C., Dhaka, A., Githala, C. K., & Trivedi, R. (2020). Green synthesis of copper nanoparticles using *Celastrus paniculatus* Willd. leaf extract and their photocatalytic and antifungal properties. *Biotechnology reports*, 27, e00518.
- Mohamed, E. A. (2020). Green synthesis of copper & copper oxide nanoparticles using the extract of seedless dates. *Heliyon*, 6(1).
- Nagar, N., & Devra, V. (2018). Green synthesis and characterization of copper nanoparticles using *Azadirachta indica* leaves. *Materials Chemistry and Physics*, 213, 44-51.
- Narayanan, K. B., & Park, H. H. (2014). Antifungal activity of silver nanoparticles synthesized using turnip leaf extract (*Brassica rapa* L.) against wood rotting pathogens. *European journal of plant pathology*, 140, 185-192.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Pandey, R. K., & Prajapati, V. K. (2018). Molecular and immunological toxic effects of nanoparticles. International journal of biological macromolecules, 107, 1278-1293.