Piper Betel Mediated Green Synthesis of Curcumin-Coated Selenium Nanoparticles- Synthesis, Characterization, and in-Vitro Biological Studies

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**Abstract:** The green synthesis of nanomaterials has gained significant interest due to its environmentally friendly approach, which reduces pollution and health risks. Selenium, known for its excellent biological properties, has become a focal point in this field. This study utilized Piper betel, a plant often used in traditional Indian medicine, as a natural reducing agent and curcumin, a naturally occurring flavonoid, as a capping agent to synthesize curcumin-functionalized selenium nanoparticles (PCSN). The synthesis was carried out using a green approach, and the nanoparticles were characterized by UV-Visible spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, scanning electron microscopy, and EDX analysis. Biocompatibility was evaluated using a hemolytic assay, and the nanoparticles' antioxidant activity was assessed. The synthesis of PCSN was successfully achieved with Piper betel leaf extract, and characterization confirmed the nanoparticles' morphology, crystallinity, functionalization, elemental composition, size, and stability. In vitro bioactivity testing revealed that PCSN exhibited significant antioxidant activity as measured by the DPPH radical scavenging assay, and showed minimal hemolytic potential. These results suggest that PCSN may be a promising candidate for antioxidant applications, although further studies are required to fully evaluate its effectiveness and potential toxicity.

**Keywords:** Green synthesis, selenium nanoparticles, *Piper betel*, curcumin, antimicrobial, novel therapeutics.

# INTRODUCTION

The field of nanotechnology has made remarkable strides in recent years, leading to significant developments across a wide range of scientific disciplines. Nanoparticles, due to their unique physicochemical properties, have attracted considerable attention for their potential applications in various industries (Joseph et al., 2023). Among these, selenium nanoparticles (SeNPs) have shown great promise owing to their exceptional properties and biocompatibility (Ikram et al., 2021; Zambonino et al., 2023). Additionally, functionalizing nanoparticles with biologically active compounds offers the potential to enhance their therapeutic efficacy and broaden their applications (Jayavarsha et al., 2022; Upadhyay et al., 2023).Curcumin, a polyphenolic compound found in *Curcuma longa* rhizomes, has garnered interest due to its various pharmacological properties, including anti-inflammatory, antioxidant, and anticancer activities (Giordano & Tommonaro, 2019). However, its clinical use is limited by poor bioavailability and stability (Sohn et al., 2021). To overcome these challenges, surface modification techniques have been explored to enhance the bioactivity and stability of curcumin by incorporating it onto nanoparticles (Ajay, Rakshagan, et al., 2022; Ajay, Sasikala, et al., 2022; Chidambaram et al., 2022).Sustainable and environmentally friendly methods for nanoparticle synthesis, often referred to as "green synthesis," have gained popularity in recent years (Ajay, Suma, et al., 2022; Katyal et al., 2021; Maiti, 2021). These methods utilize natural sources, such as plant extracts, to reduce and stabilize nanoparticles, reducing the need for toxic chemicals and imparting additional biological properties to the nanoparticles (Hano & Abbasi, 2021).*Piper betel*, a tropical plant, is known for its rich array of bioactive compounds with various therapeutic applications (Deepika et al., 2022; Harsha & Subramanian, 2022; Solanki et al., 2022). Several studies have shown the potential of *Piper betel* extracts for synthesizing nanoparticles, owing to their inherent reducing and stabilizing properties (Lagashetty et al., 2019; Maity et al., 2019; Rao et al., n.d.). However, the use of *Piper betel* extract in the green synthesis of curcumin-functionalized selenium nanoparticles (PCSN) and their biological evaluation remains largely unexplored.This research investigates the synthesis of selenium nanoparticles using *Piper betel* leaf extract, with curcumin as a stabilizing agent. The synthesized nanoparticles were characterized using a variety of techniques, including UV-Vis spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, scanning electron microscopy, and energy-dispersive X-ray (EDX) analysis. Biocompatibility was evaluated using a hemolytic assay, and the bioactivity was assessed through antioxidant and antimicrobial tests. The study provides an initial assessment of the PCSN, but further investigations are necessary to fully understand their efficacy and potential toxicity.

# MATERIALS AND METHODS

## Collection of Samples

The leaf extract of *Piper betel* was employed for nanoparticle preparation(Rafi et al., 2024). The leaves were collected from Chennai, India, and their authenticity was confirmed by a botanist.

## Chemicals and Reagents

Sodium selenite, antibiotic discs, and curcumin were obtained from SRL. All other chemicals used were of analytical grade, and MilliQ water was used throughout the experiments.

## Preparation of Extract

The leaves of *Piper betel* were thoroughly washed with distilled water to remove any impurities. Afterward, the leaves were air-dried at room temperature and ground into a coarse powder. Two grams of the powdered leaves were then mixed with 50 mL of double-distilled water and boiled for 30 minutes. The solution was then filtered using Whatman filter paper, and the resulting extract was used to synthesize the P-SeNPs.

## Synthesis of P-SeNPs

Twenty milliliters of 50 mM sodium selenite solution were added to the leaf extract while stirring. The mixture was stirred for 3 hours at 37°C, during which a precipitate formed (Tuluwengjiang et al., 2024). The precipitate was separated by centrifugation, washed with distilled water, and then dried overnight at 70°C.

## Functionalization of P-SeNPs with Curcumin

One milliliter of a 1% aqueous PEG 4000 solution was added to 20 mL of P-SeNPs and stirred for 1 hour at room temperature. Following this, a curcumin solution (20 mg/mL in DMSO) was added to the mixture, which was stirred for an additional 30 minutes. The precipitate obtained was then used for further characterization and biocompatibility testing.

## Characterization of Nanoparticles

The P-SeNPs and PCSN were re-dispersed in deionized water for analysis. UV-visible absorption spectra were recorded using a Jasco UV-visible spectrophotometer in the range of 200–800 nm. Dynamic Light Scattering (ZEN3600) was used to measure the nanoparticles' size, size distribution, and zeta potential. Fourier-transform infrared (FTIR) spectroscopy (Bruker IR spectrometer, 4000–500 cm⁻¹, ATR mode) was performed to identify the functional groups. X-ray diffraction (XRD) analysis was conducted using a diffractometer with Cu-Kα radiation (λ = 1.5406 Å), scanning from 20° to 80° at a rate of 0.05°/minute and a time constant of 2 seconds. Scanning electron microscopy (SEM, JEOL JSM-IT800, Japan) and energy-dispersive X-ray (EDX) analysis were performed using an Oxford X-MaxN 50 mm² silicon drift detector (Oxford Instruments, UK) to examine the surface morphology.

## In-vitro Antioxidant Activity: DPPH Radical Scavenging Assay

The antioxidant potential of PCSN was evaluated by measuring the decrease in absorbance of the DPPH radical at 517 nm. The procedure followed the methods described by Rather et al. (2017) and Shahid-Ul-Islam et al. (2019). In the assay, 1.5 mL of 0.1 mM methanolic DPPH solution was mixed with various concentrations of the nanoparticles. The mixture was shaken and left undisturbed for 20 minutes at 27°C. Antioxidant activity was calculated using the formula:

**Percentage Inhibition** = (Control−SampleControl]×100\left( \frac{\text{Control} - \text{Sample}}{\text{Control}} \right] \times 100(ControlControl−Sample​]×100.

## Hemolytic Assay

The hemolytic activity of SeNPs and CSN was assessed using a hemocompatibility assay based on the protocol by Francis et al. (2018). Human blood collected in EDTA vacutainers was centrifuged at 1500 ×g for 5 minutes to isolate the erythrocytes. The RBCs were washed three times with phosphate-buffered saline (PBS, pH 7.4) and diluted to 10% of their original concentration. A 200 µL suspension of RBCs was incubated with varying concentrations of the samples (12.5, 25, 50, 100, and 200 µL/mL) in PBS, and the final volume was adjusted to 1 mL. After 1 hour of incubation at 37°C, the mixture was centrifuged, and the supernatant was transferred to a 96-well plate. Absorbance was measured at 540 nm using an ELISA plate reader. PBS-treated cells were used as the negative control, and cells treated with deionized water served as the positive control. The experiment was repeated in triplicate, and the percentage of hemolysis was calculated using the formula:

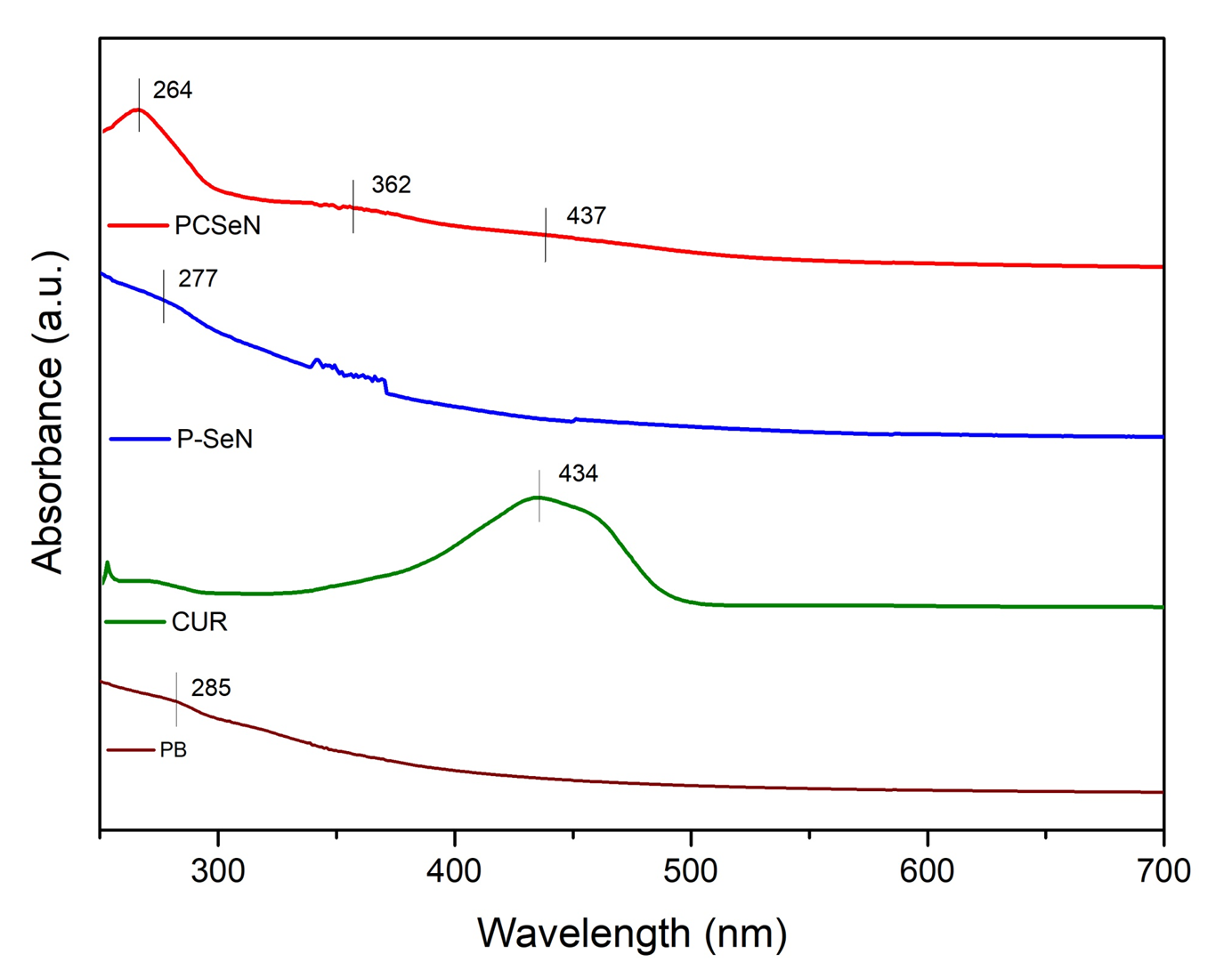
% Hemolysis = (Absorbance of sample−Absorbance of negative controlAbsorbance of positive control−Absorbance of negative control]×100\left( \frac{\text{Absorbance of sample} - \text{Absorbance of negative control}}{\text{Absorbance of positive control} - \text{Absorbance of negative control}} \right] \times 100(Absorbance of positive control−Absorbance of negative controlAbsorbance of sample−Absorbance of negative control​]×100.

# RESULTS

In the present study, P-SeNPs were synthesized using P. betel and stabilized with curcumin. The nanoparticles were characterized through various techniques, including UV-Vis spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, scanning electron microscopy, and energy-dispersive X-ray (EDX) analysis (Imtiaz et al., 2021). The bioactivity of the nanoparticles was assessed through anti-inflammatory and antimicrobial assays.

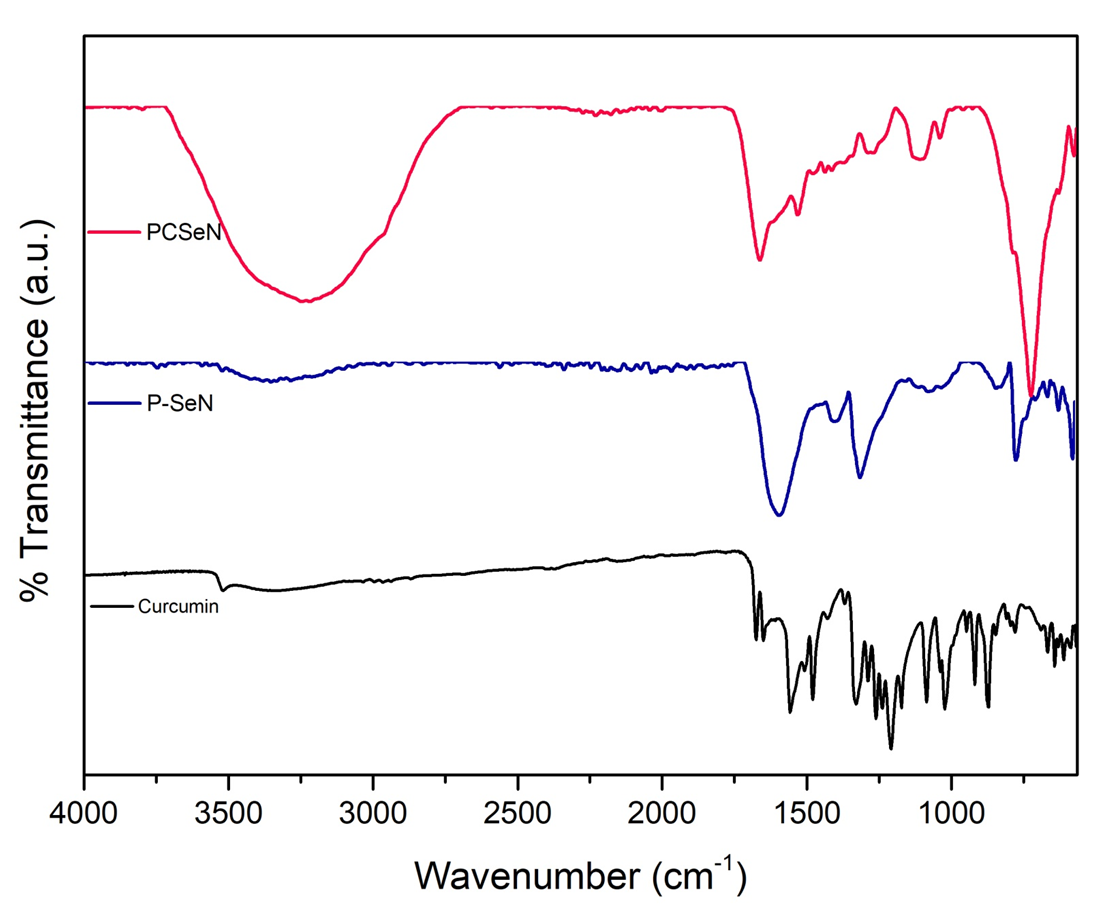
## Characterization of PCSN

The UV-Visible spectral analysis of both PCSN and P-SeNPs revealed distinct surface plasmon resonance (SPR) peaks, with maximum absorbance observed at 264 nm for PCSN and 277 nm for P-SeNPs. These absorbance peaks confirm the successful formation of P-SeNPs, as indicated by the shift in maximum absorbance when compared to the extract. Figure 1 illustrates the UV spectra of PCSN.



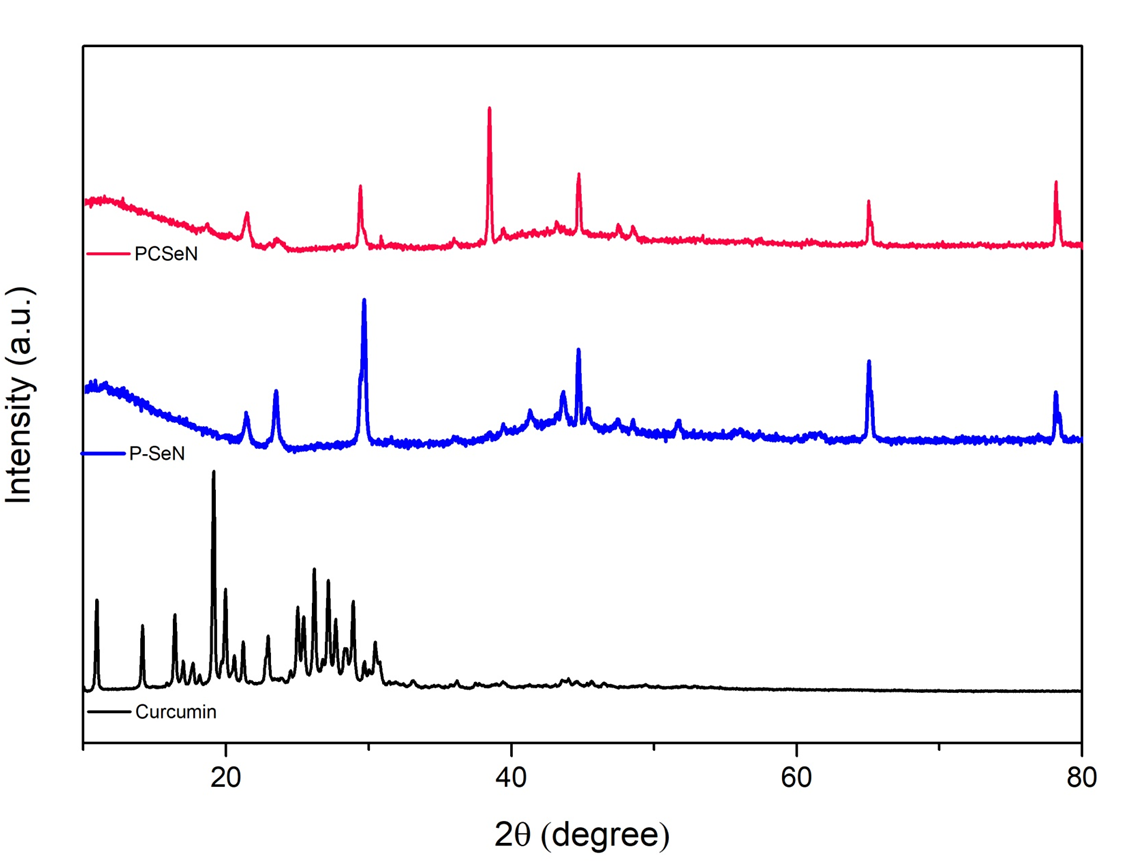
**Figure 1.** UV spectra of PCSN

FT-IR spectra were obtained in the range of 4000 to 500 cm⁻¹, as shown in Figure 2, representing the results for P-SeNPs and the synthesized PCSN. The FT-IR spectrum of P-SeNPs displayed prominent absorption bands at 3351, 2335, 2148, 1588, 1308, 1072, and 836 cm⁻¹. A significant stretching band at 3176 cm⁻¹ confirms the presence of the OH group from the extract used in P-SeNPs formation, with the observed shift in maximum absorbance compared to the extract itself. Likewise, the FT-IR spectrum of PCSN exhibited strong absorption bands at 3176, 1642, 1513, 1255, 1028, and 718 cm⁻¹. The characteristic stretching at 3351 cm⁻¹ further validates the presence of the OH group in the extract, again marked by the shift in maximum absorbance relative to the extract.



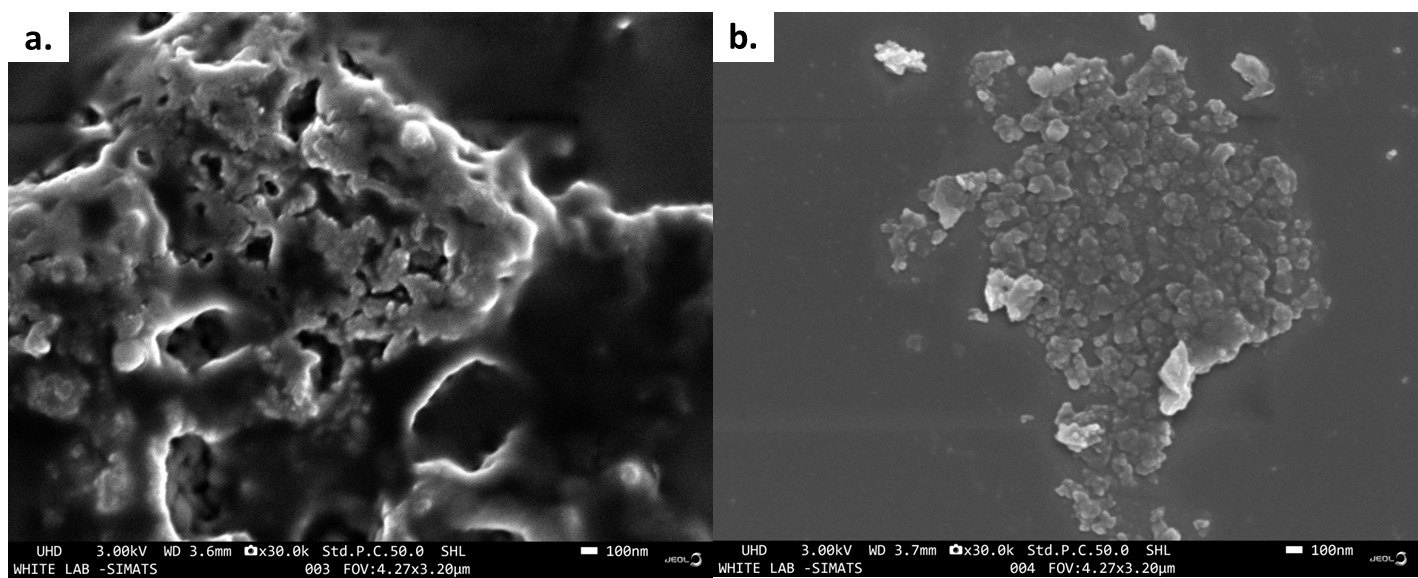
**Figure 2** FT-IR spectra of P-SeNPs and PCSN

Figure 3 represents the XRD pattern of Cur, P-SeNPs, and PCSN and displays several sharp peaks. The positions of the peaks were compared to the standard Se pattern reported in JCPDS database, which revealed that the sample has a monoclinic crystal structure, consistent with selenium. The peak observed at 10 degrees indicates the successful coating of curcumin on P-SeNPs.

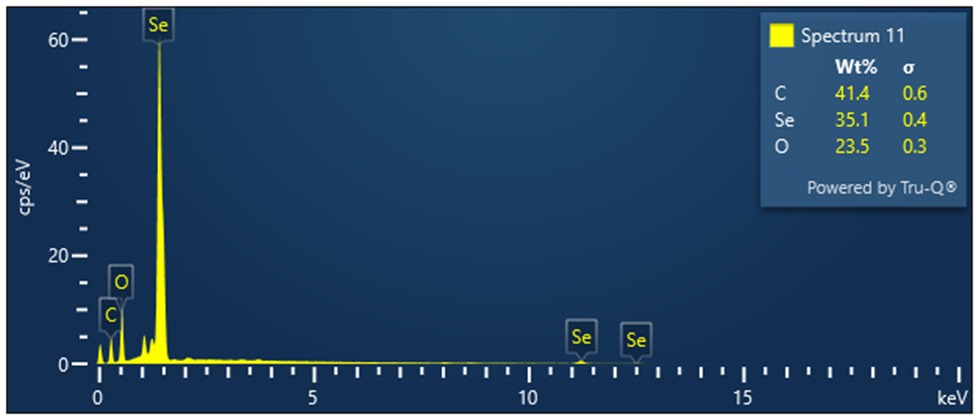


**Figure 3** XRD pattern of Cur, P-SeNPs, and PCSN

The morphology of the synthesized nanoparticles was examined using scanning electron microscopy (SEM). The PCSN displayed agglomerated spherical shapes with an approximate size of 100 nm. In contrast, the curcumin coating resulted in an increase in particle size to around 140 nm. Figure 3 illustrates the morphology of both P-SeNPs and PCSN. The EDX spectrum of PCSN showed that the weight percentage of selenium (Se) and carbon in the green-synthesized PCSN were 35.1% and 41.4%, respectively, confirming the successful capping of P-SeNPs with curcumin (Figure 4).



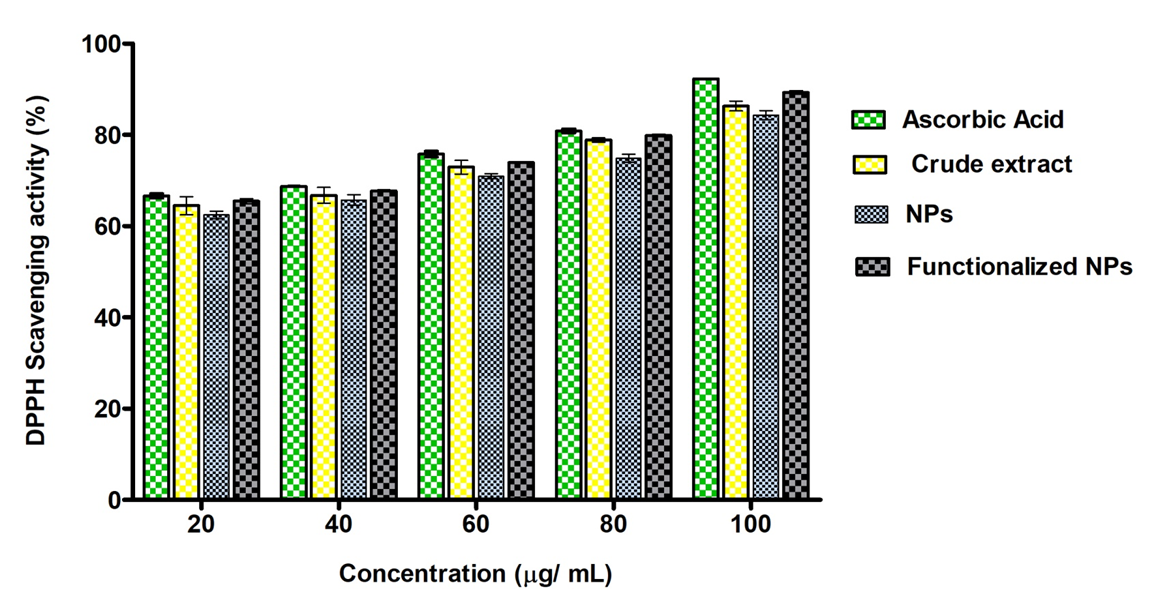
**Figure 4.** SEM micrograph of a) P-SeNPs and b) PCSN



**Figure 5** represents the EDAX of Synthesized PCSN

## In-vitro Anti-oxidant Activity

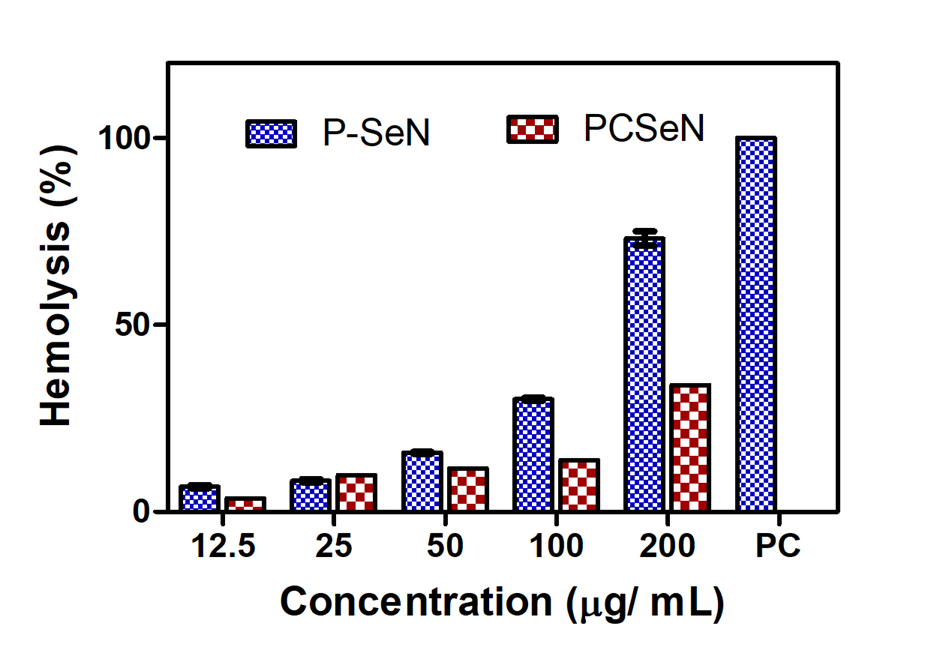
In this study, the DPPH radical scavenging assay was employed to evaluate the antioxidant activity of the crude extract, P-SeNPs, and PCSN. The results indicated that the nanoparticles demonstrated significant antioxidant activity, effectively scavenging the DPPH free radicals in the test system.



**Figure 6** Anti-oxidant activity of PCSN

## Hemolytic Assay

PCSN showed less than 5 % hemolysis in erythrocytes at various concentrations of 200, 100, 50, 25, and 10 μg/mL in comparison with the control. Although, P-SeNPs showed > 5 % hemolysis at higher concentrations. Figures 8 represent the hemolytic assay test results of PCSN.



**Figure 7** Hemolytic activity of PCSN

# DISCUSSION

The UV-visible spectrum of P-SeNPs exhibited a peak at 264 nm, which is consistent with previously published studies (Hernández-Díaz et al., 2021). The shift in the peak corresponding to the leaf extract indicates its involvement in the bio-reduction of selenium. These UV-Vis results suggest that the green synthesis method was successful in producing P-SeNPs, which exhibit a broad size distribution, high concentration, and a slightly smaller size compared to bulk selenium. These characteristics make the nanoparticles suitable for applications in photocatalysis, sensing, and biomedical imaging.The FT-IR spectrum of P-SeNPs displayed a peak at 3351 cm⁻¹, corresponding to the medium N-H stretching of an aliphatic primary amine. Similar findings were reported by Kalishwaralal et al. in 2016, who synthesized SeNPs using BSA (Kalishwaralal et al., 2016). Other peaks observed include 2335 cm⁻¹ (strong stretch), 2148 cm⁻¹ (strong S-C≡N stretching of thiocyanate), 1588 cm⁻¹ (medium N-H bending of amine), 1308 cm⁻¹ (medium O-H bending of phenol), 1072 cm⁻¹ (strong C-O stretching of primary alcohol), and 836 cm⁻¹ (medium C=C bending of trisubstituted alkene). The FT-IR spectrum of PCSN revealed a peak at 3176 cm⁻¹, indicating weak, broad O-H stretching of intramolecular bonded alcohol, as well as peaks at 1642 cm⁻¹ (medium C=N stretching of imine/oxime), 1513 cm⁻¹ (strong N-O stretching of a nitro compound), 1255 cm⁻¹ (strong C-O stretching of alkyl aryl ether), 1028 cm⁻¹ (strong S=O stretching of sulfoxide), and 718 cm⁻¹ (strong C=C bending of disubstituted cis-alkene). The FT-IR results suggest that the green synthesis method successfully produced P-SeNPs with hydroxyl groups on their surface, which could be further functionalized.

The XRD patterns of Cur, P-SeNPs, and PCSN showed a monoclinic crystal structure consistent with selenium (Balaji Ganesh S & Sugumar, 2021; Jabin et al., 2021). The peak positions allowed the estimation of lattice parameters, which aligned with the monoclinic selenium oxide structure described in previous studies (Ruiz Fresneda et al., 2018). The XRD pattern displayed some peak broadening, indicating a degree of size polydispersity in the sample. These data suggest that the green-synthesized P-SeNPs possess a highly crystalline monoclinic structure, a small average crystallite size, and some level of size polydispersity (Govindaraj & Dinesh, 2021; Rajeshkumar et al., 2021; Sushanthi 2021).SEM images of P-SeNPs revealed a narrow size distribution with an average size of around 50 nm, similar to results reported by Blinov et al. in 2022 (Blinov et al., 2022). Most nanoparticles appeared spherical, with some irregularities observed in a few particles, which aligns with previous studies (Ferro et al., 2021). The surface texture appeared smooth and uniform, indicating successful synthesis with minimal aggregation (Graf et al., 2023; Ramamurthy & Jaiganesh, 2021; Tiwari & Jain, 2023). The distribution of the nanoparticles was homogeneous and well-dispersed, suggesting good stabilization. Overall, the SEM results suggest that the green synthesis method produced well-defined, uniformly distributed nanoparticles with a smooth surface. These characteristics may make the nanoparticles suitable for various applications, including catalysis, biomedicine, and environmental remediation. EDX analysis revealed that the P-SeNPs consisted of 35.1% selenium, 23.5% oxygen, and 41.4% carbon.The antioxidant potential of PCSN was assessed using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay. The results indicated that PCSN exhibited higher antioxidant activity compared to the extract and P-SeNPs. The scavenging activity of the nanoparticles increased with concentration, demonstrating a dose-dependent response. The IC50 value, representing the concentration required to scavenge 50% of DPPH radicals, was found to be 22.5 µg/mL, reflecting the nanoparticles' effective free radical scavenging. Previous studies have similarly shown that SeNPs have superior antioxidant activity compared to herbal extracts (Sentkowska & Pyrzyńska, 2023).The hemolytic activity of PCSN was evaluated in vitro using human erythrocytes. The results showed a slight increase in hemolytic activity at higher concentrations. In contrast, P-SeNPs exhibited less than 5% hemolysis at higher concentrations. Studies have indicated that SeNPs typically have less than 5% hemolytic potential, as demonstrated by Rajkumar et al., who reported less than 4% hemolysis with SeNPs synthesized using Pseudomonas stutzeri (Rajkumar et al., 2020). These findings suggest that a minimal concentration of P-SeNPs should be used for in-vivo applications. These properties make PCSN suitable for various applications, including drug delivery, catalysis, and water treatment.

# Conclusion

Recent advances in nanotechnology have propelled its transition from laboratory-scale experiments to large-scale industrial applications in pharmaceuticals, medicine, and other fields like nutraceuticals and biomedicine. This study highlights the green synthesis of P-SeNPs using Piper betel leaf extract. Characterization of PCSN was performed using UV spectrophotometry, FTIR, SEM, and EDX analysis. The hemolytic assay demonstrated the biocompatibility of PCSN, and it also exhibited excellent antimicrobial activity against Streptococcus mutans and Enterococcus faecalis. Based on these findings, P-SeNPs synthesized from plant extract are biocompatible, minimally toxic to cells, and hold promise as ideal nanoparticles for medicinal applications. This green synthesis approach thus fosters further research opportunities in the field.

# REFERENCES

1. [Ajay, R., Rakshagan, V., Queenalice, A., Vinothkumar, S., Ravivarman, C., & Saravanadinesh, P. (2022). Effect of triazine comonomer substitution on the structure and glass transition temperature of monomethacrylate-based resin polymer: An in vitro study. The Journal of Contemporary Dental Practice, 23(2), 202–207.](http://paperpile.com/b/EhErwI/TDnqG)
2. [Ajay, R., Sasikala, R., Rakshagan, V., Raghunathan, J., LalithaManohari, V., & Baburajan, K. (2022). Evaluation of cytocompatibility of thermopolymerized denture base copolymer containing a novel ring-opening oxaspiro comonomer. World Journal of Dentistry, 13(2), 127–132.](http://paperpile.com/b/EhErwI/14CXi)
3. [Ajay, R., Suma, K., Sasikala, R., Rakshagan, V., Baburajan, K., & Kalarani, G. (2022). Evaluation of linear dimensional stability of monomethacrylate-based dental polymer containing a novel tricyclic diacrylate cross-linker using a novel surface-level index technique. World Journal of Dentistry, 13(6), 568–573.](http://paperpile.com/b/EhErwI/xmr5)
4. [Balaji Ganesh S, & Sugumar, K. (2021). Internet of Things—A novel innovation in dentistry. Journal of Advanced Oral Research, 12(1), 42–48.](http://paperpile.com/b/EhErwI/CoK7p)
5. [Blinov, A. V., Nagdalian, A. A., Siddiqui, S. A., Maglakelidze, D. G., Gvozdenko, A. A., Blinova, A. A., Yasnaya, M. A., Golik, A. B., Rebezov, M. B., Jafari, S. M., & Shah, M. A. (2022). Synthesis and characterization of selenium nanoparticles stabilized with cocamidopropyl betaine. Scientific Reports, 12(1), 21975.](http://paperpile.com/b/EhErwI/oa2vZ)
6. [Bulmus, V., Woodward, M., Lin, L., Murthy, N., Stayton, P., & Hoffman, A. (2003). A new pH-responsive and glutathione-reactive, endosomal membrane-disruptive polymeric carrier for intracellular delivery of biomolecular drugs. Journal of Controlled Release: Official Journal of the Controlled Release Society, 93(2), 105–120.](http://paperpile.com/b/EhErwI/zNPjP)
7. [Chidambaram, S. R., George, A. M., Muralidharan, N. P., Prasanna Arvind, T. R., Subramanian, A., & Rahaman, F. (2022). Current overview for chemical disinfection of dental impressions and models based on its criteria of usage: A microbiological study. Indian Journal of Dental Research : Official Publication of Indian Society for Dental Research, 33(1), 30–36.](http://paperpile.com/b/EhErwI/BODmH)
8. [Deepika, B. A., Ramamurthy, J., Girija, S., & Jayakumar, N. D. (2022). Evaluation of the antimicrobial effect of Ocimum sanctum L. oral gel against anaerobic oral microbes: An in vitro study. World Journal of Dentistry, 13(S1), S23–S27.](http://paperpile.com/b/EhErwI/sbUS)
9. [Ferro, C., Florindo, H. F., & Santos, H. A. (2021). Selenium Nanoparticles for Biomedical Applications: From Development and Characterization to Therapeutics. Advanced Healthcare Materials, 10(16), e2100598.](http://paperpile.com/b/EhErwI/enf5M)
10. [Francis, A. P., Gurudevan, S., & Jayakrishnan, A. (2018). Synthetic polymannose as a drug carrier: synthesis, toxicity and anti-fungal activity of polymannose-amphotericin B conjugates. Journal of Biomaterials Science. Polymer Edition, 29(13), 1529–1548.](http://paperpile.com/b/EhErwI/jl2Vl)
11. [Giordano, A., & Tommonaro, G. (2019). Curcumin and Cancer. Nutrients, 11(10). https://doi.org/](http://paperpile.com/b/EhErwI/ubjj9)[10.3390/nu11102376](http://dx.doi.org/10.3390/nu11102376)
12. [Govindaraj, A., & Dinesh, S. P. S. (2021). Effect of chlorhexidine varnish and fluoride varnish on White Spot Lesions in orthodontic patients- a systematic review. The Open Dentistry Journal, 15(1), 151–159.](http://paperpile.com/b/EhErwI/U4QTg)
13. [Graf, S., Thakkar, D., Hansa, I., Pandian, S. M., & Adel, S. M. (2023). 3D metal printing in orthodontics current trends, biomaterials, workflows and clinical implications. Seminars in Orthodontics. https://doi.org/](http://paperpile.com/b/EhErwI/U10ln)[10.1053/j.sodo.2023.01.001](http://dx.doi.org/10.1053/j.sodo.2023.01.001)
14. [Hano, C., & Abbasi, B. H. (2021). Plant-Based Green Synthesis of Nanoparticles: Production, Characterization and Applications. Biomolecules, 12(1). https://doi.org/](http://paperpile.com/b/EhErwI/SAuat)[10.3390/biom12010031](http://dx.doi.org/10.3390/biom12010031)
15. [Harsha, L., & Subramanian, A. K. (2022). Comparative assessment of pH and degree of surface roughness of enamel when etched with five commercially available etchants: An in vitro study. The Journal of Contemporary Dental Practice, 23(2), 181–185.](http://paperpile.com/b/EhErwI/mW0r)
16. [Hernández-Díaz, J. A., Garza-García, J. J., León-Morales, J. M., Zamudio-Ojeda, A., Arratia-Quijada, J., Velázquez-Juárez, G., López-Velázquez, J. C., & García-Morales, S. (2021). Antibacterial Activity of Biosynthesized Selenium Nanoparticles Using Extracts of Calendula officinalis against Potentially Clinical Bacterial Strains. Molecules , 26(19). https://doi.org/](http://paperpile.com/b/EhErwI/85QpB)[10.3390/molecules26195929](http://dx.doi.org/10.3390/molecules26195929)
17. [Ikram, M., Javed, B., Raja, N. I., & Mashwani, Z.-U.-R. (2021). Biomedical Potential of Plant-Based Selenium Nanoparticles: A Comprehensive Review on Therapeutic and Mechanistic Aspects. International Journal of Nanomedicine, 16, 249–268.](http://paperpile.com/b/EhErwI/RtDt)
18. [Imtiaz, T., Priyadharshini, R., Rajeshkumar, S., & Sinduja, P. (2021). Green synthesis and Characterization of Silver Nanoparticles Synthesized Using Piper longum and its Antioxidant Activity. Journal of Pharmaceutical Research International, 342–352.](http://paperpile.com/b/EhErwI/hu5BX)
19. [Jabin, Z., Nasim, I., Vishnu Priya, V., & Agarwal, N. (2021). Quantitative Analysis and Effect of SDF, APF, NaF on Demineralized Human Primary Enamel Using SEM, XRD, and FTIR. International Journal of Clinical Pediatric Dentistry, 14(4), 537–541.](http://paperpile.com/b/EhErwI/Hhe7X)
20. [Jayavarsha, V., Rajeshkumar, S., Lakshmi, T., & Sulochana, G. (2022). Green synthesis of selenium nanoparticles study using clove and cumin and its anti- inflammatory activity. Journal of Complementary Medicine Research, 13(5), 84.](http://paperpile.com/b/EhErwI/FOLh)
21. [Joseph, T. M., Kar Mahapatra, D., Esmaeili, A., Piszczyk, Ł., Hasanin, M. S., Kattali, M., Haponiuk, J., & Thomas, S. (2023). Nanoparticles: Taking a Unique Position in Medicine. Nanomaterials (Basel, Switzerland), 13(3). https://doi.org/](http://paperpile.com/b/EhErwI/UGcpb)[10.3390/nano13030574](http://dx.doi.org/10.3390/nano13030574)
22. [Kalishwaralal, K., Jeyabharathi, S., Sundar, K., & Muthukumaran, A. (2016). A novel one-pot green synthesis of selenium nanoparticles and evaluation of its toxicity in zebrafish embryos. Artificial Cells, Nanomedicine, and Biotechnology , 44(2), 471–477.](http://paperpile.com/b/EhErwI/1vcFX)
23. [Katyal, D., Subramanian, A. K., Venugopal, A., & Marya, A. (2021). Assessment of Wettability and Contact Angle of Bonding Agent with Enamel Surface Etched by Five Commercially Available Etchants: An In Vitro Study. International Journal of Dentistry, 2021, 9457553.](http://paperpile.com/b/EhErwI/XzVa)
24. [Lagashetty, A., Ganiger, S. K., & Shashidhar. (2019). Synthesis, characterization and antibacterial study of Ag-Au Bi-metallic nanocomposite by bioreduction using piper betle leaf extract. Heliyon, 5(12), e02794.](http://paperpile.com/b/EhErwI/HggSx)
25. [Maiti, S. (2021). Comparative analysis of abrasion resistance in relation to different temporary acrylic crown material using toothbrush simulator- an in vitro study. International Journal of Dentistry and Oral Science, 2153–2157.](http://paperpile.com/b/EhErwI/ZtYk)
26. [Maity, T. R., Samanta, A., Saha, B., & Datta, S. (2019). Evaluation of Piper betle mediated silver nanoparticle in post-harvest physiology in relation to vase life of cut spike of Gladiolus. Bulletin of the National Research Centre, 43(1), 1–11.](http://paperpile.com/b/EhErwI/PWdVf)
27. [Rajeshkumar, Sabarathinam, J., & Madhulaxmi. (2021). Development of anti inflammatory and antimicrobial silver nanoparticles coated suture materials. International Journal of Dentistry and Oral Science, 2006–2013.](http://paperpile.com/b/EhErwI/ohQSo)
28. [Rajkumar, K., Mvs, S., Koganti, S., & Burgula, S. (2020). Selenium Nanoparticles Synthesized Using Pseudomonas stutzeri (MH191156) Show Antiproliferative and Anti-angiogenic Activity Against Cervical Cancer Cells. International Journal of Nanomedicine, 15, 4523–4540.](http://paperpile.com/b/EhErwI/P6Yv7)
29. [Ramamurthy, & Jaiganesh. (2021). Evaluation of antioxidant and anti inflammatory activity of grape seed oil infused with silver nanoparticles an in vitro study. International Journal of Dentistry and Oral Science, 3318–3322.](http://paperpile.com/b/EhErwI/M2NvZ)
30. [Rao, S. P., Byrappa, K., Keerthiraj, N., Chatterjee, J., & Mustak, M. S. (n.d.). Phyto-Fabrication of ZnO Nanoparticles Using Piper betel Aqueous Extract and Evaluation of its Applicability in Dentistry. Pharmaceutical Nanotechnology, 6(3), 201–208.](http://paperpile.com/b/EhErwI/pM2vY)
31. [Rather, L. J., Akhter, S., Padder, R. A., Hassan, Q. P., Hussain, M., Khan, M. A., & Mohammad, F. (2017). Colorful and semi durable antioxidant finish of woolen yarn with tannin rich extract of Acacia nilotica natural dye. In Dyes and Pigments (Vol. 139, pp. 812–819). https://doi.org/](http://paperpile.com/b/EhErwI/pGcKR)[10.1016/j.dyepig.2017.01.018](http://dx.doi.org/10.1016/j.dyepig.2017.01.018)
32. Rafi, D. M., Lakshmi, T. V., Shirley, C. P., Ravivarman, G., & Senthilkumar, G. (2024, April). Improving Prostate Cancer Diagnosis with Weakly Supervised Learning and Radiology-Confirmed Negative MRI Data. In 2024 International Conference on Inventive Computation Technologies (ICICT) (pp. 1183-1188). IEEE.
33. [Ruiz Fresneda, M. A., Martín, J. D., Bolívar, J. G., Fernández Cantos, M. V., Bosch-Estévez, G., Martínez Moreno, M. F., & Merroun, M. L. (2018). Green synthesis and biotransformation of amorphous Se nanospheres to trigonal 1D Se nanostructures: impact on Se mobility within the concept of radioactive waste disposal. Environmental Science: Nano, 5(9), 2103–2116.](http://paperpile.com/b/EhErwI/Gbof7)
34. [Sentkowska, A., & Pyrzyńska, K. (2023). Antioxidant Properties of Selenium Nanoparticles Synthesized Using Tea and Herb Water Extracts. NATO Advanced Science Institutes Series E: Applied Sciences, 13(2), 1071.](http://paperpile.com/b/EhErwI/Wgjkl)
35. [Shahid-Ul-Islam, Butola, B. S., & Verma, D. (2019). Facile synthesis of chitosan-silver nanoparticles onto linen for antibacterial activity and free-radical scavenging textiles. International Journal of Biological Macromolecules, 133, 1134–1141.](http://paperpile.com/b/EhErwI/71BYB)
36. [Sohn, S.-I., Priya, A., Balasubramaniam, B., Muthuramalingam, P., Sivasankar, C., Selvaraj, A., Valliammai, A., Jothi, R., & Pandian, S. (2021). Biomedical Applications and Bioavailability of Curcumin-An Updated Overview. Pharmaceutics, 13(12). https://doi.org/](http://paperpile.com/b/EhErwI/MAmuj)[10.3390/pharmaceutics13122102](http://dx.doi.org/10.3390/pharmaceutics13122102)
37. [Solanki, L., Shantha Sundari, K. K., Muralidharan, N. P., & Jain, R. (2022). Antimicrobial effect of novel gold nanoparticle oral rinse in subjects undergoing orthodontic treatment: An ex-vivo study. Journal of International Oral Health: JIOH, 14(1), 47.](http://paperpile.com/b/EhErwI/dtgI)
38. [Sushanthi, (2021). Vernonia amygdalina mediated copper nanoparticles and its characterization and antimicrobial activity - an in vitro study. International Journal of Dentistry and Oral Science, 3330–3334.](http://paperpile.com/b/EhErwI/5TmxD)
39. Tuluwengjiang, G., Rasulova, I., Ahmed, S., Kiasari, B. A., Sârbu, I., Ciongradi, C. I., & Samaniego, S. S. C. (2024). Dendritic cell-derived exosomes (Dex): Underlying the role of exosomes derived from diverse DC subtypes in cancer pathogenesis. Pathology-Research and Practice, 254, 155097.
40. [Tiwari, A., & Jain, R. K. (2023). Comparative evaluation of White Spot lesion incidence between NovaMin, probiotic, and fluoride containing dentifrices during orthodontic treatment using laser fluorescence - A prospective randomized controlled clinical trial. Clinical and Investigative Orthodontics, 1–8.](http://paperpile.com/b/EhErwI/rMqpX)
41. [Uma Maheswari, T. N., Chaithanya, M., & Rajeshkumar, S. (2021). Anti-inflammatory and antioxidant activity of lycopene, raspberry, green tea herbal formulation mediated silver nanoparticle. Journal of Indian Academy of Oral Medicine and Radiology, 33(4), 397.](http://paperpile.com/b/EhErwI/GSlb5)
42. [Upadhyay, K., Tamrakar, R. K., Thomas, S., & Kumar, M. (2023). Surface functionalized nanoparticles: A boon to biomedical science. Chemico-Biological Interactions, 380, 110537.](http://paperpile.com/b/EhErwI/KdBR)
43. [Zambonino, M. C., Quizhpe, E. M., Mouheb, L., Rahman, A., Agathos, S. N., & Dahoumane, S. A. (2023). Biogenic Selenium Nanoparticles in Biomedical Sciences: Properties, Current Trends, Novel Opportunities and Emerging Challenges in Theranostic Nanomedicine. Nanomaterials (Basel, Switzerland), 13(3). https://doi.org/](http://paperpile.com/b/EhErwI/6taq)[10.3390/nano13030424](http://dx.doi.org/10.3390/nano13030424)