Texila International Journal of Public Health
ISSN: 2520-3134
DOI: 10.21522/TIJPH.2013.12.03.Art039

Green Synthesis of Selenium Nanoparticles using *Cinnamomum Verum* Extract and their Antibacterial, Antioxidant, and Brine Shrimp Toxicity Effects

Archana Behera[1], Yamuna devi M. S[2], Iadalin Ryntathiang[1], Mukesh Kumar Dharmalingam Jothinathan[1]*

[1]*Centre for Global Health Research, Saveetha Medical College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai, India*

[2]*Department of Pharmacology, Saveetha Medical College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai, India*

Abstract

Nanotechnology holds the potential to transform biomedicine through the development of nanomaterials that are compatible with biological systems. The application of selenium nanoparticles (SeNPs) synthesized by Cinnamomum verum aqueous extract, is aimed at offering environmentally friendly agents for the biomedical sector, with antibacterial, and antioxidant properties. Exploiting the ability of C. verum extract to reduce Sodium Selenite (Na_2SeO_3) to SeNPs. The synthesized SeNPs analyzed the antibacterial features of microbial pathogens such as gram-positive and gram-negative using standard microbiological methods. Using different characterization techniques like UV-visible spectroscopy and Fourier-Transform Infrared (FTIR), the analysis shows the synthesis of SeNPs succession and clarifies the material's composition. Scanning Electron Microscopy (SEM) in conjunction with Energy Dispersive X-ray spectroscopy (EDAX) analysis further provides detailed information about SeNP's structural morphology and elemental composition. Furthermore, their antioxidant capabilities are examined, which were evaluated in the range of 30–60 µg/mL for their ability to scavenge free radicals as 80–90% using the DPPH (2,2-Diphenyl-1-Picrylhydrazyl) assay and 100–500 µg/mL concentrations used for the Ferric-Reducing Antioxidant Powder (FRAP) assay. As the concentration of SeNPs increased, their ability to scavenge DPPH and FRAP radicals also increased in a dose-dependent manner. Importantly, SeNPs displayed lower toxicity in brine shrimp assays at lower concentrations, indicating their potential safety for use in biomedical contexts. At the end of this synthesis, C. verum-mediated SeNPs are presented as a promising option beneficial in nanotechnology development applied in medicine and especially treatment of a bacterial infection which can even extend to cancer.

Keywords: *Antibacterial Activity, Antioxidant Activity, Brine Shrimp, Cinnamomum Verum Bark, Phytochemical Test, Selenium Nanoparticles, Toxicity Test.*

Introduction

Nanotechnology is rapidly advancing, focusing on manipulating materials at the atomic and molecular levels. Nanoparticles are essential in the field of nanomedicine and are primarily used for diagnostics and drug delivery systems. Selenium nanoparticles (SeNPs) are important nanoparticles that are considered to be a significant micronutrient essential for the health of people and animals. Their cost-effectiveness in manufacturing, with their capacity to synergize with various biological substances, boosts their total biological

Received: 11.06.2024 ***Accepted: 13.08.2024*** ***Published on: 30.09.2024***

****Corresponding Author: itsmemukesh@gmail.com***

qualities [1]. Excessive selenium intake can lead to severe side effects, including fatal outcomes. To address this concern, scientists globally are exploring nanoscale selenium particles as an alternative to optimize selenium's benefits while mitigating overdose risks. SeNPs offer advantages like low toxicity, unique therapeutic properties, biocompatibility, and enhanced bioavailability, making them valuable in various biomedical and physiological applications [2].

Biosynthesis of SeNPs using cinnamon (*Cinnamomum verum*), a popular powder and bark extract. Although there are more than 300 species of cinnamon, their morphology and chemical makeup vary. More specifically, notable variations in volatile phenol and polyphenol content have been noted between genotypes at the phytochemical level. Cinnamon has applications in the production of personal care products and the healthcare sector because of its antimicrobial, antioxidant, anti-hypertriglyceridemia [3], anti-inflammatory, antitumor, anticarcinogenic, hepatoprotective, and neuroprotective properties [4]. Recent studies have focused on the use of plant extracts for environmentally friendly nanoparticle production. This is due to the easy access to plants, safe handling, and abundant presence of metabolites, which not only help in the reduction process but also match their biological properties [5]. Many researchers have conducted the green synthesis of SeNPs and other metal nanoparticles using cinnamon extract [6], which demonstrates strong antibacterial efficacy [7] against a variety of bacterial infections [8-10]. The antimicrobial activity of SeNPs was tested combined with cinnamon oil against diarrhoea-causing pathogens in buffaloes, specifically *Escherichia coli* and *Candida albicans*, which were found in animal feed, drinking water, and faeces of affected animals [11]. The antioxidant capacity of SeNPs is synthesized from cinnamon bark aqueous solutions. SeNPs have a zero-oxidation state, making them biologically inert with lower therapeutic factors and delicate toxicity margins. In contrast, SeNPs exhibit less toxicity and potential therapeutic applications, including their role as antioxidants, reducing the risk of certain cancers, and protecting against cardiovascular disorders. Recognizing the significant antioxidant effects of SeNPs [10].

Another approach uses SeNPs, which have enhanced biological activity [10], reduced toxicity [12], and serve as a superior feed supplement compared with mineral or organic selenium forms. The brine shrimp lethality test (BSLA) demonstrates the lack of toxicity of SeNPs synthesized using a plant extract on brine shrimps [13].

In this paper, we provide a comprehensive analysis of the synthesis of SeNPs by *C. verum*, the characterization of cell-associated SeNPs by a variety of analytical techniques, the testing of the nutritional effect of SeNPs enriched biomass on a model aquaculture system, *Artemia salina*, and evaluation of the efficacy of SeNPs against bacterial pathogens (v) Antiradical activity of SeNPs.

Materials and Methods

Collection and Preparation of Cinnamon Aqueous Extract

The plant *C. verum* was obtained from a local merchant, and the sample was authenticated by the Centre for Advanced Studies in Botany at the University of Madras, Chennai, Tamil Nadu, India. Cinnamon was washed with double distilled water to remove contaminants, dried in an oven at 55 °C for 48 h, and ground into a biosorbent [14]. For solution preparation, 25g of cinnamon was mixed with 500 mL distilled water, heated to 60 °C for 20 min, filtered, and stored at 4°C.

Synthesis of Selenium Nanoparticles

A standard stock solution of Sodium Selenite (Na_2SeO_3) (5mM) was prepared by dissolving it in 100 mL of distilled H_2O. To synthesize SeNPs, approximately 10 mL of extract of *C.*

verum aqueous (CVAE) was mixed separately with a 90 mL solution of Na_2SeO_3 (5 mM) [15]. The reaction mixture was incubated at varying pH values, causing colour changes that indicated nanoparticle synthesis, while the control without Na_2SeO_3 showed no colour change.

Characterization of Selenium Nanoparticles

Distinct reaction times were detected for the produced nanoparticles' UV-vis spectroscopy using a Labman Scientific Ultraviolet-visible spectrophotometer. The instrument operates in the 200-400 nm range with a specified resolution. Fourier-Transform Infrared (FTIR) spectrometry was performed across the 400-4000 cm^{-1} range using an FTIR Spectrometer. This facilitated the identification and assignment of various vibration modes, enabling the determination of distinct functional groups in CVAE. Scanning Electron Microscopy (SEM) in conjunction with Energy Dispersive X-ray spectroscopy (EDAX) analysis was performed to examine the surface geometry and chemical constituents. This combined approach allowed the investigation of purity, elemental composition, and dispersion of the elements constituting the nanoparticles.

Antioxidant Activity

DPPH Assay

The assay was examined based on the previous study [15]. The assay gauges the antioxidant activity of CVAE by assessing their capability to scavenge free radicals using a reliable and consistent free radical DPPH (2,2-Diphenyl-1-Picrylhydrazyl). The test substance in different concentrations of 30-60 mg/mL was mixed with 1 mM DPPH in ethanol and incubated.

FRAP Assay

This procedure was based on the method described [16]. Distilled water (2 mL) and FRAP solution (3 mL) were mixed and incubated at 37 °C for 5 min. Subsequently, this mixture was combined with different concentrations of SeNPs (100-500 µL) and further incubated for 10 min at 37°C.

Antibacterial Activity

Collection of Test Bacterial Culture

Two species were collected in both Gram-negative and positive cultures (*Pseudomonas aeruginosa* and *E. coli*, and *Staphylococcus aureus* and *Bacillus subtilis*).

Assay of the Antibacterial Activity

The test for antibacterial effectiveness was conducted with a modified version of the procedure described [17]. Subsequently, 50µL of SeNPs, CVAE, Na_2SeO_3, and a control (Gentamycin) were loaded into each well and incubated at 37°C for 24 h. After incubation, the Zone of Inhibitions (ZOIs) was measured and calculated (mm).

Phytochemical Test

As per the previous studies [15, 18, 19], phytochemical tests were conducted on CVAE to identify the detection of compounds with antioxidant and antibacterial properties. CVAE was subjected to a series of reactions with diverse reagents as part of preliminary phytochemical testing.

Toxicity Assay

The toxicity assay was conducted based on the previous study [15, 20]. Toxicity assessment was performed using a bioassay using *Artemia franciscana* (Brine Shrimp) by BSLA. For the toxicity test, a positive control [0.5 mL dimethyl sulfoxide (DMSO) in seawater (5 mL)), a negative control (Each nanomaterial dissolved in DMSO (1 mg/mL)), and a normal control (5 mL seawater) were used. Negative control was prepared in different concentrations ranging from 100-500 µg/mL in triplicate through serial dilutions, each adjusted to 5 mL using seawater.

Statistical Analysis

The experiments were conducted in triplicate to assess the antioxidant, antibacterial, and toxicity effects. Data were collected accordingly. The error bars shown in the graphical representations are expressed as means ± standard deviation (SD) and percentages, using Origin 2018 software. The significance level (p-value) was indicated as <0.05.

Results

Figure 1 (A) displays the collected *C. Verum* bark for synthesising SeNPs. By changing the nanoparticle solution colour, it transitions from pale yellow (Figure 1. B (i)) to dark brown. CVAE could synthesize the bioreduction of Na_2SeO_3 to SeNPs. After 4 h of incubation at 25°C, no more colour changes were observed. The color changes indicate that the SeNPs were depicted as shown in Figure 1. B (iii)). Na_2SeO_3 solution (Figure 1. B (ii)) was maintained as a control without adding CVAE.

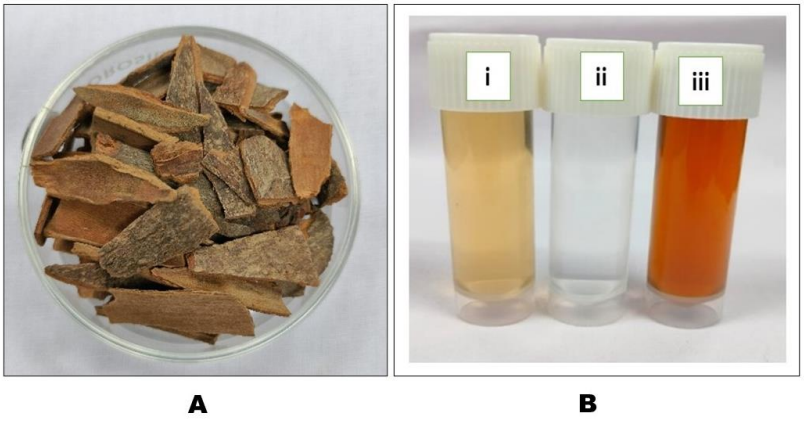

Figure 1. (A) *Cinnamomum verum* Bark and (B) (i) *Cinnamomum verum* Aqueous Extract (ii) Na_2SeO_3 and, (iii) Selenium Nanoparticles Synthesized using *Cinnamomum verum* Aqueous Extract

Characterization

UV-Visible Spectroscopy

This study showed that CVAE possesses the ability to synthesize SeNPs. Examining the UV-visible spectra confirmed the reduction reaction of the SeNPs. Absorption maxima of SeNPs were recorded after overnight incubation. The newly generated SeNPs UV-vis spectra were obtained, and the absorption result revealed a peak at 284 nm as shown in Figure 2.

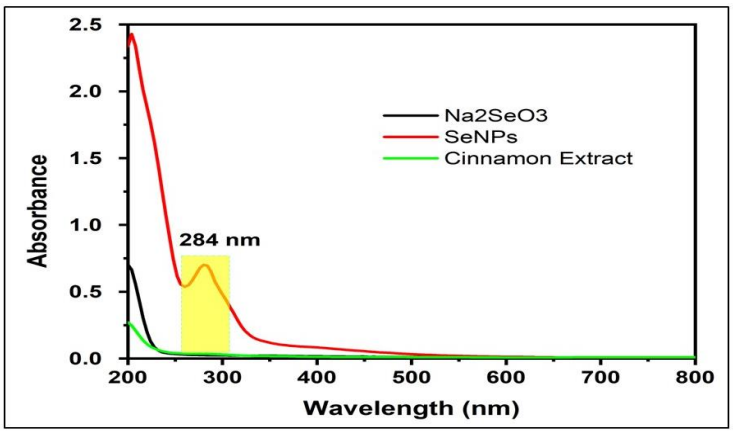

Figure 2. Ultraviolet-Visible Spectrum of Selenium Nanoparticles Synthesized using *Cinnamomum verum* Aqueous Extract

FAIR

To determine the potential biomolecules responsible for the reduction and capping of the bioreduce SeNPs produced by CVAE. In Figure 3 (A), the spectrum exhibits peaks at 3278, 1597, 1382 and 1095 cm^{-1}, distinctive bands can be observed at specific wavenumbers 3278 cm^{-1} are characteristic of O-H stretching and carboxyl group with a strong and broad peak appearing. Both C=C stretching, and N-H bending are responsible for the strong band at 1597 cm^{-1}, amine and cyclic alkene groups [21]. The band detected at 1382 cm^{-1} results from the bending of C-H, bending of O-H, stretching of C-F, and stretching of S=O, methyl group, and gem dimethyl group with carboxylic acid, sulfate, alkane, and aldehyde compounds. The wide absorption spectrum was visible at 1095 cm^{-1} due to C-N Stretching and C=O stretching with a strong appearance and amino and aliphatic ether compounds.

Figure 3 (B), the band at 2987 cm^{-1} has three stretching groups: N-H, C-H, and O-H within the alcohol, alkane, carboxylic acid, and amine salt compound classes. The band at 2360 cm^{-1} has stretching of O=C=O and 1447 cm^{-1} has C-H bending with alkane compound classes. The FTIR study indicated that several compounds, possibly contributing to the antioxidant and antibacterial properties, were involved in capping the synthesized SeNPs.

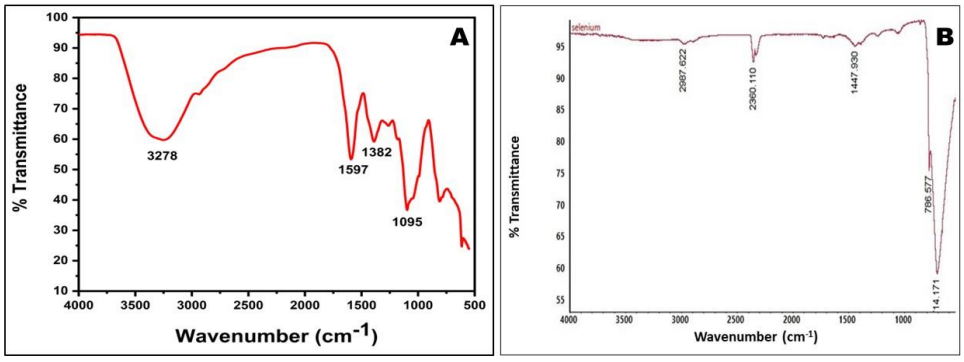

Figure 3. (A). FTIR Spectrum of Sodium Selenite-Derived Nanoparticles Obtained by *Cinnamomum verum* Aqueous Extract, and (B) FTIR Spectra of Sodium Selenite

SEM with EDAX

Green-synthesized SeNPs were morphologically studied using SEM with EDAX. Most of the spherical SeNPs are shown in the SEM images (Figure 4A). SeNPs' EDAX spectra (Figure 4B) showed that their composition was 6.0% selenium, 44.5% carbon, 37.1% oxygen, and 4.3% sodium. The organic matter around the synthesized SeNPs is linked to the presence of selenium, which facilitates the identification of the carbon and oxygen compositions.

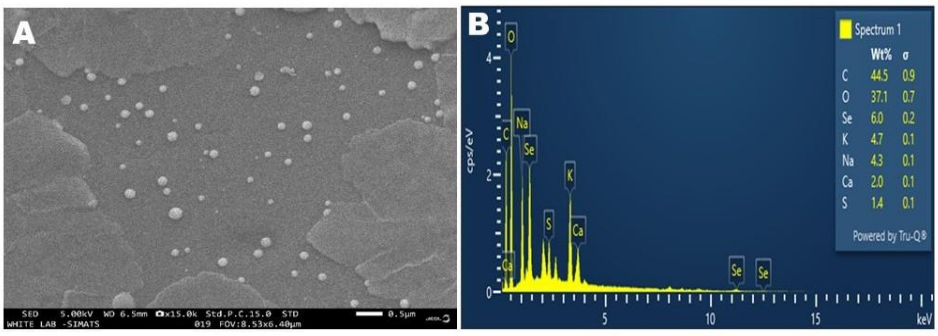

Figure 4. (A) SEM Images SeNPs, and (B) EDAX of Selenium Nanoparticles Synthesized from *Cinnamomum verum* Aqueous Extract

Antioxidant Activity

DPPH Radical Scavenging Assay

The DPPH approach is shown in Figure 5. C to illustrate the radical-scavenging capability of SeNPs synthesized using CVAE. The antioxidant activity of SeNP concentrations (30, 40, 50, and 60 mg/mL) was assessed using DPPH. Ascorbic acid served as a positive control in the study to examine how well nanoparticles might inhibit the activity of free radicals. The nanoparticles' IC50 values were found to be approximately 2.38 mg/mL.

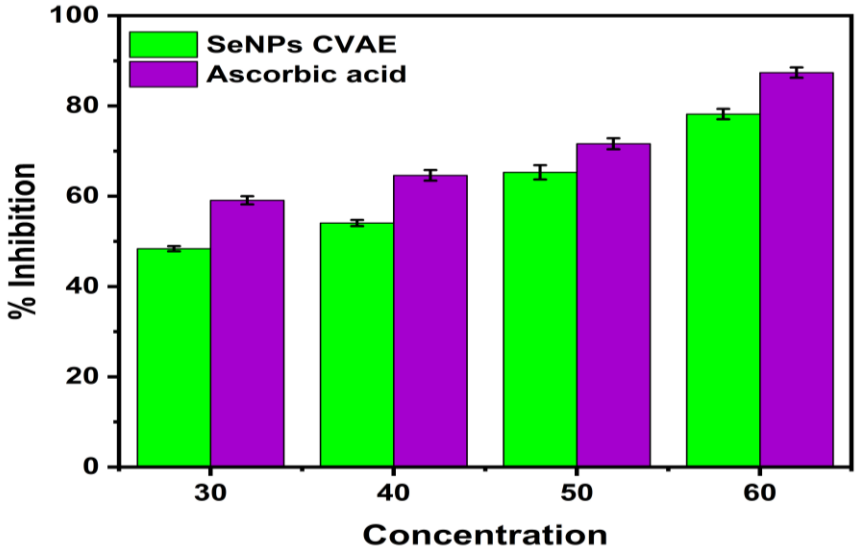

Figure 5. Antioxidant Activity of Selenium Nanoparticles Synthesized by *Cinnamomum verum* Extract

FRAP assay

Figure 6 illustrates the antioxidant activity of SeNPs green synthesized by CVAE using the FRAP assay, which involves the reduction of ferric ions to ferrous ions by the molecule. At a concentration of 500 µg/mL, normal Iron (II) sulfate shows a percentage of 93%, whereas SeNPs display 82%. At a concentration of 100 µg/mL, SeNPs exhibited a yield of 37%, while the standard Iron (II) sulfate exhibited a yield of 48%. This suggests that the dose concentration exclusively determines the effectiveness of the medicine.

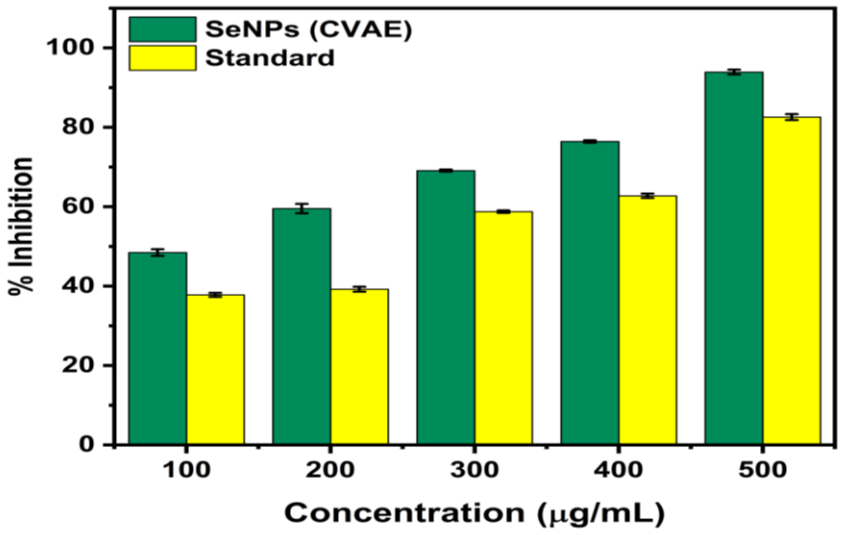

Figure 6. Ferric Reducing Antioxidant Power Assay of Selenium Nanoparticles Synthesized by *Cinnamomum verum* Extract

Antibacterial Activity

The ZOIs in Figure 7. A illustrates the agar well diffusion method to assess the antibacterial activity of SeNPs that were synthesized from CVAE in the present study. The results demonstrated that SeNPs had antibacterial activity that was comparable with that of gentamycin. Figure 7. B shows the graphical representation of SeNPs synthesized by CVAE, in which *E. coli* shows the highest ZOIs in antibacterial action compared with *S. aureus*, *B. subtilis* and *P. aeruginosa*.

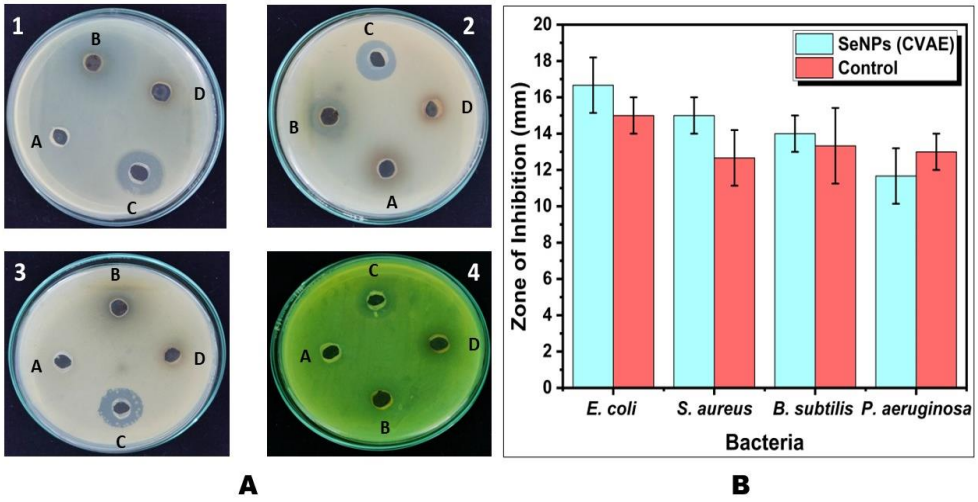

Figure 7 (A): Antibacterial Activity Of The Agar Well Diffusion Method Using Selenium Nanoparticles Synthesized by *Cinnamomum verum* Extract. 1. *Escherichia coli*, 2. *Staphylococcus aureus*, 3. *Bacillus subtilis*, and 4. *Pseudomonas aeruginosa*. (A) Sodium Selenite, (B) Selenium Nanoparticles, (C) Control, and (D) *Cinnamomum verum* Extract. (B): Graphical Representation of Antibacterial Activity of Selenium Nanoparticles expressed as inhibition zone diameters (mm)

Phytochemical Test

CVAE undergoes phytochemical testing, where the secondary metabolites react with various reagents to identify the presence of compounds with antibacterial properties. The analysis of the extract through phytochemical screening indicated the existence of secondary metabolites such as tannins, flavonoids, phenols, Glycosides, steroids, and saponins, as illustrated in Table 1 and Figure 8. This aligns with the findings of [22]. Antibacterial activities can be attributed to secondary metabolites.

Figure 8. Phytochemical test of *Cinnamomum verum* Aqueous Extract

Table 1. Phytochemical Constituents of the *Cinnamomum verum* Aqueous Extract [18, 19]

S. NO	CHEMICAL COMPOUND	METHOD	RESULTS
1	Saponins	Shuffling + D. H_2O	+
2	Phenols	Ferric Chloride test	+
3	Tannins	Ferric chloride test	+
4	Flavonoids	Alkaline reagent test	+
5	Glycosides	Salkowski's test	+
6	Steroids	Chloroform + Con. H_2SO_4	+
7	Protein	Ninhydrin test	-
8	Terpenoid	Bontrager's test	-
9	Anthraquinone glycoside	Nitric acid test	-

Key: (+) Present, (-) not Present

Toxicity Assay

This study investigated the toxicological effects of SeNPs at different concentrations on newly hatched *A. nauplii*. The nauplii were exposed to a spectrum of SeNP concentrations that included 100, 200, 300, 400, and 500 µg/mL, and the resulting mortality rates and probits are presented in Table 2. At the maximum concentration rate of 500 µg/mL, a 10% fatality rate was recorded, whereas no mortality was observed in the control group. These findings indicate that SeNPs are not acutely harmful to *A. nauplii*, even at elevated concentrations like 500 µg/ mL. The nauplii maintained their normal appearance and behaviour at this concentration, and no mortality was noted at concentrations up to 400 µg/ mL. This underscores their potential safety and applicability in various biological contexts. SeNPs aggregates collected inside the guts (Figure 9. B) because of a lack of nutritional uptake after exposure to SeNPs for 24 and 48 h, which led to toxicity. Hence, the study effectively demonstrated that these nanomaterials are biocompatible in nauplii, indicating SeNPs up to a 500 µg/mL concentration rate do not significantly induce toxicity in *A. nauplii* compared to the control group (Figure 9. A).

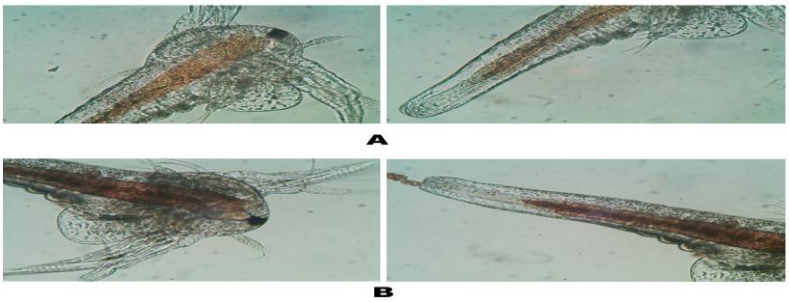

Figure 9. Brine Shrimp Lethality Assay Without Adding SeNPs (Control) (A) and with Selenium Nanoparticles (Test) (B)

Table 2. Toxicity Test of SeNPs using Brine Shrimp

Conc. (µg/mL)	Total No. of Brine Shrimp	Treatment		% of Mortality	Probits
		Death	Live		
100	10	0	10	0	-
200	10	0	10	0	-
300	10	0	10	0	-
400	10	0	10	0	-
500	10	1	9	10	3.72

Discussion

In recent years, SeNPs have developed significant interest for their distinctive characteristics and potential biological effects [23]. This study focused on synthesizing SeNPs using CVAE as a green synthesis method. SeNPs were created using an easy-to-use and sustainable process. Throughout the synthesis, CVAE functioned as both a stabilizing and a reducing agent. The addition of CVAE to a clear Na_2SeO_3 solution resulted in the formation of dark brown SeNPs. The better stability was verified for more than 24 hours, and the colour slightly turned reddish-brown. The colour change from a dark brown to a reddish-brown colour in the SeNPs after 24 h is most probably caused by slight modifications in the size, shape, or surface chemistry of the nanoparticles as time progresses.

The characterization of SeNPs by using UV-vis spectroscopy is examined, which showed an absorption peak at 284 nm based on its synthesis. Similar UV-vis spectroscopy reports were depicted in the analysis of SeNPs [24]. Further characterization was conducted using FTIR, which revealed their functional groups, that acted as reducing agents to the Se^{+1} ions as well as capping agents, which showed major peaks at 3418 cm^{-1} corresponding to O-H group stretching in alcohol and phenols, and at 1629 cm^{-1} for carbonyl groups with significant peaks. These results align with previous FTIR analysis research to identify functional groups in SeNPs [25-27].

The features of the SeNPs were further examined using energy-dispersive analysis with EDAX methods. The study revealed that the EDAX peak corresponded to Se (6.0%). The outcome revealed that the reaction product exists in the form of SeNPs. The SEM analysis showed the size variation of the synthesized SeNPs. The SEM image demonstrates that the synthesized nanoparticles exhibit spherical morphology.

The green synthesis of SeNPs involved the interaction of SeNPs with phytochemicals from *C. verum* extracts. Cinnamon extract is a widely documented chemical constituent attributed to its rich alkaloid, flavonoid, steroid, quinone, tannin, phenols, and saponin phytochemicals [28–30]. In this present study, similar plant chemicals were identified by phytochemical analysis methods. *C. verum* bark consists of many phytoconstituents, but cinnamonaldehyde is the main phytochemical component. It oxidates to produce SeNPs [21].

This experiment evaluated the impact of SeNPs on antioxidant capacity using DPPH and FRAP assays. The results were compared with the control without any SeNP supplementation. *In vitro* antioxidant assays using DPPH demonstrated that SeNPs have a scavenging activity of 78%, compared to ascorbic acid as standard 87% at 60 mg/mL. Similarly, the antioxidant activity of SeNPs was synthesized using *Polygonatum sibiricum* polysaccharide

(PSP) by DPPH and ABTS radical scavenging assays. The experiment on SeNPs (PSP) [31] showed less activity compared to this study, possibly due to the presence of reducing agents. An antioxidant material supplies hydrogen to the process, which relies on DPPH reduction. In the FRAP assay, SeNPs exhibited a scavenging activity of 82% at 500 µg/mL, compared to standard iron (II) sulfate at 93%. SeNPs showed excellent scavenging activity using both assays.

The SeNPs' antibacterial properties enhance the overall efficacy of the antibacterial system. The ineffectiveness of CVAE against different infections may be due to the selectivity of its phytochemicals, insufficient concentrations, bacterial resistance mechanisms, or the absence of necessary synergistic components. In a comparable investigation, the antibacterial efficacy was assessed against *P. aeruginosa, E. coli, B. subtilis,* and *S. aureus*. The results indicated that SeNPs had minimal action against *S. aureus* while displaying the maximum level of activity against *E. coli*, as shown by the measurement of ZOI.

Furthermore, our study compared this determination of brine shrimp toxicity at different concentration level. The significantly elevated fatality rate found following an extra 48 h is most likely attributed to the cumulative impact of prolonged exposure to SeNPs, which provides the nanoparticles with more opportunity to engage with and disrupt biological processes in the brine shrimp. The harmful impacts of increasing concentrations can get stronger toxic effects on brine shrimp, resulting in higher death rates. This toxicity assessment, which emphasizes exposure concentration, would, in turn, emphasize the safety of SeNPs for biomedical applications.

Overall, this study provides significant knowledge regarding the environmentally friendly production of SeNPs and their prospective uses in the field of medicine. Although the initial findings from laboratory experiments are encouraging, additional experiments conducted on living organisms are necessary to validate the effectiveness and safety of SeNPs for the treatment of bacterial infections and potentially cancer. The transition to organic nanoparticles, which have fewer adverse effects in comparison to synthetic medications, represents a notable progression in the field of biomedical research.

Conclusion

This study concentrates on the green synthesis of SeNPs using *C. verum* bark extract, which can be considered a useful development in the area of green nanotechnology. The nanoparticles were characterized by UV-vis, FTIR, and SEM with EDAX. The results of the antioxidant activity demonstrated that SeNPs have radical scavenging activity. The importance of the present study lies in the possibility that the next-generation NPs conjugated plant bioactive molecules may be more effective in the treatment of bacterial infection, especially against *E. coli*. Therefore, excessive concentrations of SeNPs will be proven to disrupt the cell functions and metabolic processes of bacteria. The study into the toxicity of SeNPs showed that at the highest concentration of 500 µg/mL, the seawater shrimps recorded a 100% mortality rate. These findings showed that SeNPs may be applied in pharmacology and diverse research areas in the future in the field of biology.

Acknowledgement

We would like to express our sincere gratitude to the Centre for Global Health Research, Saveetha Medical College and Hospitals, Saveetha Institute of Medical and Technical Sciences (SIMATS), Saveetha University, Chennai, India, for providing support for this research work. Finally, we thank all those who contributed to this work, directly or indirectly, and helped make this research possible.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

The authors have no relevant financial or non-financial interests to disclose.

References

[1]. Khudier, M. A, Hammadi, H. A, Atyia, H. T, Al-Karagoly, H, Albukhaty, S, Sulaiman, G. M, Dewir, Y. H, Mahood, H. B. 2023. Antibacterial Activity of Green Synthesized Selenium Nanoparticles using Vaccinium Arctostaphylos (L.) Fruit Extract. *Cogent Food & Agriculture*, 9:2245612. https://doi.org/10.1080/23311932.2023.2245612

[2]. Vahidi, H, Barabadi, H, Saravanan, M, 2020, Emerging Selenium Nanoparticles to Combat Cancer: A Systematic Review. *Journal of Cluster Science*, 31:301-9. https://doi.org/10.1007/s10876-019-01671-z

[3]. Muhammad, D. R, Dewettinck, K, 2017, Cinnamon and its Derivatives As Potential Ingredient in Functional Food—A Review. *International Journal of Food Properties*, 20:2237-63. https://doi.org/10.1080/10942912.2017.1369102

[4]. Nabavi, S. F, Di Lorenzo, A, Izadi, M, Sobarzo-Sánchez, E, Daglia, M, Nabavi, S. M., 2015. Antibacterial Effects of Cinnamon: From Farm to Food, Cosmetic and Pharmaceutical Industries. Nutrients. 79:7729-48. https://doi.org/10.3390/nu7095359

[5]. Manojkumar, U., Kaliannan, D., Srinivasan, V., Balasubramanian, B., Kamyab, H., Mussa, Z. H., Palaniyappan, J., Mesbah, M., Chelliapan, S. and Palaninaicker, S., 2023. Green Synthesis of Zinc Oxide Nanoparticles Using Brassica Oleracea Var. Botrytis Leaf Extract: Photocatalytic, Antimicrobial and Larvicidal Activity. *Chemosphere.* 323:138263. https://doi.org/10.1016/j.chemosphere.2023.138263

[6]. Alghuthaymi, M. A., Diab, A. M., Elzahy, A. F., Mazrou, K. E., Tayel, A. A. and Moussa, S. H., 2021. Research Article Green Biosynthesized Selenium Nanoparticles by Cinnamon Extract and Their Antimicrobial Activity and Application as Edible Coatings with Nano-Chitosan. *Journal of Food Quality*, 2021:1-0. https://doi.org/10.1155/2021/6670709

[7]. Ansari, M. A., Murali, M., Prasad, D., Alzohairy, M. A., Almatroudi, A., Alomary, M. N., Udayashankar, A. C., Singh, S. B., Asiri, S. M. M., Ashwini, B. S. and Gowtham, H. G., 2020. *Cinnamomum verum* Bark Extract Mediated Green Synthesis of ZnO Nanoparticles and their Antibacterial Potentiality. *Biomolecules.* 10:336. https://doi.org/10.3390/biom10020336

[8]. Długosz, O., Ochnik, M., Sochocka, M., Franz, D., Orzechowska, B., Anna, C. K., Agata, D. and Banach, M., 2022. Antimicrobial and Antiviral Activity Of Selenium Sulphide Nanoparticles Synthesised in extracts from Spices in Natural Deep Eutectic Solvents (NDES). *Sustainable Materials and Technologies*, 32:00433. https://doi.org/10.1016/j.susmat.2022.e00433

[9]. Abd-Elraoof, W. A., Tayel, A. A., Shaymaa, W., Abukhatwah, O. M. W., Diab, A. M., Abonama, O. M., Assas, M. A. and Abdella, A., 2023. Characterization and Antimicrobial Activity Of A Chitosan-Selenium Nanocomposite Biosynthesized Using Posidonia Oceanica. *RSC Advances*, 13:26001-14. https://doi.org/10.1039/D3RA04288J

[10]. Chellapa, L. R., Shanmugam, R., Indiran, M. A. and Samuel, S. R., 2020. Biogenic Nanoselenium Synthesis, Its Antimicrobial, Antioxidant Activity And Toxicity. *Bioinspired Biomimetic and Nanobiomaterials.* 9:184-9. https://doi.org/10.1680/jbibn.19.00054

[11]. Hassan, A., Yousif, M. H., Abd-Elkhaliq, H. M. M., Wahba, A. K. A. and El-Hamaky, A. M. A., 2021. The Antimicrobial Potential Of Selenium Nanoparticles Singly And In Combination with Cinnamon Oil Against Fungal And Bacterial Causes of Diarrhea in Buffaloes. Advances in Animal and Veterinary Sciences, 9:1238-1248.

http://dx.doi.org/10.17582/journal.aavs/2021/9.8.1238.1248

[12]. Hamza, F., Vaidya, A., Apte, M., Kumar, A.R. and Zinjarde, S., 2017. Selenium Nanoparticle-Enriched Biomass of Yarrowia lipolytica Enhances Growth and Survival of Artemia Salina. *Enzyme and Microbial Technology*, 106:48-54. https://doi.org/10.1016/j.enzmictec.2017.07.002

[13]. Francis, T., Rajeshkumar, S., Roy, A. and Lakshmi, T., 2020. Anti-Inflammatory And Cytotoxic Effect of Arrow Root Mediated Selenium Nanoparticles. *Pharmacognosy Journal*, 12:1363-1367. http://dx.doi.org/10.5530/pj.2020.12.188

[14]. Najafi, S., Razavi, S. M., Khoshkam, M. and Asadi, A., 2020. Effects of Green Synthesis of Sulfur Nanoparticles from Cinnamomum Zeylanicum Barks on Physiological and Biochemical Factors of Lettuce (Lactuca sativa). *Physiological and Molecular Plant Pathology*, 26:1055-66. https://doi.org/10.1007/s12298-020-00793-3

[15]. Behera, A., Jothinathan, M. K. D., Ryntathiang, I., Saravanan, S. and Murugan, R., 2024. Comparative Antioxidant Efficacy of Green-Synthesised Selenium Nanoparticles from Pongamia pinnata, Citrus sinensis, and Acacia auriculiformis: An *In Vitro* Analysis. *Cureus*. 16: e58439. https://doi.org/10.7759%2Fcureus.58439

[16]. Harris, J, Malaiappan, S, Rajeshkumar, S, 2023, The Development and Evaluation of Melatonin-Loaded, Calcium Oxide Nanoparticle-Based Neem and Clove Extract: An *In Vitro* Study. *Cureus.* 15: e46293. https://doi.org/10.7759%2Fcureus.46293

[17]. Behera, A., Jothinathan, M. K. D., Saravanan, S., Selvan, S. T., Renuka, R. R. and Srinivasan, G. P., 2024. Green Synthesis of Selenium Nanoparticles from Clove and their Toxicity Effect and Anti-Angiogenic, Antibacterial And Antioxidant Potential. *Cureus.* 16: e55605. https://doi.org/10.7759%2Fcureus.55605

[18]. Gajbhiye, N. I, Koyande, A. R, 2022, Antimicrobial Activity And Phytochemical Screening Of Methanolic Extract Of Cinnamomum Zeylanicum (Commercial Species). *Asian Journal of Microbiology, Biotechnology & Environmental Sciences*, 23:198-203. http://doi.org/10.53550/AJMBES.2022.v24i01.031

[19]. Sivapriya, T, John, S, 2020, Qualitative, Quantitative, And Antioxidant Analysis of Phytochemicals Present in Cinnamomum Zeylanicum Species. *Indian Journal of Health Sciences and Biomedical Research KLEU*. 13:105-11. Doi: 10.4103/kleuhsj.kleuhsj_8_20

[20]. Vijayaraj, R, Sri Kumaran, N, Altaff, K, 2022, Toxicity Evaluation of Novel Antidiabetic Compound (11-methoxy-2- methyltridecane-4-ol) from Marine Macro Alga, Gracilaria edulis. *Journal of Biologically Active Products from Nature*, 12:223-31. https://doi.org/10.1080/22311866.2022.2069153

[21]. Granja Alvear, A, Pineda-Aguilar, N, Lozano, P, Lárez-Velázquez, C, Suppan, G, Galeas, S, Debut, A, Vizuete, K, De Lima, L, Saucedo-Vázquez, J. P, Alexis, F., 2024. Synergistic Antibacterial Properties of Silver Nanoparticles and Its Reducing Agent from Cinnamon Bark Extract. Bioengineering, 11:517. https://doi.org/10.3390/bioengineering11050517

[22]. Idris FZ, Habibu UA., 2021. In-vitro Antibacterial Activity Of Cinnamon Bark Extracts On Clinical Multi-Drug Resistant (mdr) Staphylococcus Aureus, Klebsiella Pneumoniae And Pseudomonas Aeruginosa Isolates. *Bayero Journal of Pure and Applied Sciences*, 14:38-44. https://doi.org/10.4314/bajopas.v14i1.6

[23]. Sentkowska, A, Pyrzyńska, K., 2022. The Influence Of Synthesis Conditions On The Antioxidant Activity Of Selenium Nanoparticles. *Molecules*, 27:2486. https://doi.org/10.3390/molecules27082486

[24]. Cittrarasu, V., Kaliannan, D., Dharman, K., Maluventhen, V., Easwaran, M., Liu, W. C., Balasubramanian, B. and Arumugam, M., 2021. Green Synthesis Of Selenium Nanoparticles Mediated from Ceropegia Bulbosa Roxb Extract And Its Cytotoxicity, Antimicrobial, Mosquitocidal and Photocatalytic Activities. *Scientific Reports*, 11:1032. https://doi.org/10.1038/s41598-020-80327-9

[25]. Pérez Gutiérrez, R. M., Soto Contreras, J. G., Martínez Jerónimo, F. F., de la Luz Corea Téllez, M.

and Borja-Urby, R., 2022. Assessing the Ameliorative Effect Of Selenium Cinnamomum Verum, Origanum Majorana, And Origanum Vulgare Nanoparticles In Diabetic Zebrafish (Danio rerio). *Plants.* 11:893. https://doi.org/10.3390/plants11070893

[26]. 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*, 26:5929. https://doi.org/10.3390/molecules26195929

[27]. Ahmed, H. M., Ramadhani, A. M., Erwa, I. Y., Ishag, O. A. O. and Saeed, M. B., 2020. Phytochemical Screening, Chemical Composition And Antimicrobial Activity of Cinnamon Verum Bark. *International Research Journal of Pure and Applied Chemistry*, 21:36-43. Doi: 10.9734/IRJPAC/2020/v21i1130222

[28]. Goyal, D., Saini, A., Saini, G. S. S. and Kumar, R., 2019. Green Synthesis of Anisotropic Gold Nanoparticles Using Cinnamon With Superior Antibacterial Activity. *Materials Research Express*, 6:075043. DOI 10.1088/2053-1591/ab15a6

[29]. Parisa, N., Islami, R. N., Amalia, E., Mariana, M. and Rasyid, R. S. P., 2019. Antibacterial Activity of Cinnamon Extract (Cinnamomum Burmannii) Against Staphylococcus Aureus and Escherichia Coli *In Vitro*. Bioscientia Medicina: *Journal of Biomedicine and Translational Research*, 3:19-28. https://doi.org/10.32539/bsm.v3i2.85

[30]. Jha, N., Esakkiraj, P., Annamalai, A., Lakra, A. K., Naik, S. and Arul, V., 2022. Synthesis, Optimization, And Physicochemical Characterization Of Selenium Nanoparticles From Polysaccharide of Mangrove Rhizophora Mucronata With Potential Bioactivities. *Journal of Trace Elements and Minerals*, 2:100019. https://doi.org/10.1016/j.jtemin.2022.100019

[31]. Chen, W, Cheng, H, Xia, W., 2022. Construction of Polygonatum sibiricum Polysaccharide Functionalized Selenium Nanoparticles for the Enhancement of Stability and Antioxidant Activity. Antioxidants, 11:240. https://doi.org/10.3390/antiox11020240