Optical and Paper-based Dual Sensing of Hg$^{2+}$ and Colorimetric Reduction of Cr(VI) by Green Synthesized Silver Nanoparticles Prepared from the Bark Extract of Sweetinia mahagoni and Their Promising Antimicrobial Applications

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Abstract

This study was conducted to identify promising applications of green silver nanoparticles (AgNPs) prepared from a bark extract of Sweetinia mahagoni (Sm). The green synthesized Sm-AgNPs were characterized using various spectroscopy methods. AgNPs were first investigated using ultraviolet−visible spectroscopy, and the metal nanoparticles exhibited an intense surface plasmon resonance (SPR) peak at different wavelengths. The green synthesized Sm-AgNPs had an SPR peak at 430 nm, which confirms the formation of Sm-AgNPs. In addition, Fourier transform infrared (FTIR) spectroscopy was conducted to determine the bioactive compounds of bark extract that actively participate in the reduction of Sm-AgNPs, and the results revealed O−H stretching of free hydroxyl alcohol and phenols, N−H bonds of primary amines, S=O stretching of sulfoxide in aromatic groups, C−I stretching due to aliphatic iodo compounds, and C−Br stretching by halo compounds of the bark extract which might reduce and stabilize Sm-AgNPs. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) results revealed that Sm-AgNPs were approximately irregular spheres. EDS results revealed the complete reduction of silver to elemental silver. The particle size analysis of Sm-AgNPs was conducted using dynamic light scattering (DLS), and the results revealed that Sm-AgNPs were polydisperse with an average size range from 35.8 to 47.8 nm, an average mean size of 41.3 nm, and a $Z$ average of 37.7 nm. Sm-AgNPs had a negative zeta potential value of −19.0 mV, indicating that Sm-AgNPs were very stable in colloidal form. Further studies were carried out to demonstrate their usefulness in industrial and biomedical applications. In these studies, Sm-AgNPs exhibited a very good antibacterial activity against both Gram-negative and Gram-positive bacteria. In addition to regular assays, we also investigated important industrial applications such as the reduction of toxic hexavalent chromium to a nontoxic form and sensing of Hg$^{2+}$ ions. The results revealed that Sm-AgNPs had an excellent performance in biosensor applications such as sensing and detecting mercury at parts per million/parts per billion levels. In conclusion, green Sm-AgNPs are promising materials in therapeutic and industrial applications.
Keywords: green Sm-AgNPs; spectral characterization; antibacterial activity; chromium reduction and detection; dual sensing of mercury; optical method; paper-based bio-sensing

Introduction

The towering industrial development in the past twenty years has resulted in environmental pollution due to industrial waste and toxic elements, and researchers actively focus on this major problem. These contaminants are the main etiology of several human diseases and disorders. These toxic elements are also a major cause of contamination of soil and water resources. Furthermore, the agricultural crops growing in these contaminated soils cause gastrointestinal problems, anemia, and skin disorders [1–3]. According to the World Health Organization (WHO), the maximum concentration of Cr(VI) should not exceed 0.05 mg/L [4]. Cr(VI) is highly toxic in nature and induces carcinogenic and mutagenic changes in humans, leading to cancer and other disorders, which is confirmed and evaluated by the International Agency for Research on Cancer [5].

Environmental pollution caused by chromium (Cr(VI)) accumulation in water bodies and soil is a problem for various industries (e.g., chemicals, leather tanning, chrome plating, wood preservation, alloy manufacturing, and dye manufacturing), applications and products [6]. Therefore, scientists must work on how to reduce Cr(VI) contamination to preserve a suitable habitat for humans. Researchers have investigated a variety of methods using nanotechnology to reduce Cr(VI) to Cr(III), since Cr(III) is believed to be less toxic in nature, has a poor fluidity, easily precipitates in the presence of various natural adsorbents, and is easily reduced by various metal nanoparticles.

Another major environmental problem is the accumulation of mercury in water and soil, which can lead to major health problems in humans and animals. Mercury is highly soluble in water and exists primarily on the water surface. Once mercury enters an aquatic ecosystem, this toxic element accumulates in the food chain in the form of methyl mercury (a neurotoxin), especially in edible fishes, causing prenatal brain damage, various cognitive and motion disorders, and the deadly Minamata disease [7]. According to the WHO, the maximum permissible level of mercury in drinking water is 1 μg/L. Thus, excess intake of mercury can cause serious health problems in humans due to its extremely toxic nature, such as damage to the brain, kidneys, immune system, and nervous system [8]. Therefore, monitoring the mercury ions in aqueous water bodies is highly important for environmental protection. Different advanced analytical instruments are available for mercury (Hg²⁺) detection, such as inductively coupled plasma-optical emission spectroscopy (ICP-OES), inductively coupled plasma-mass spectroscopy (ICP-MS), and high performance liquid chromatography (HPLC), as well as old analytical instruments such as atomic absorption spectroscopy (AAS) and gas chromatography-mass spectroscopy (GC-MS) [9–12]. Although these instruments are sophisticated, the detection of mercury is very expensive and requires skilled personnel to operate, thus these experiments are not suitable for field operation. Hence, a simple, rapid, affordable, and highly sensitive method or device for the detection of mercury is still needed.

Nanotechnology has been an emerging research area in the last two decades, and these technologies have resulted in the development of a wide range of optical and electrochemical sensors for the detection of mercury [13–16]. These technologies are better than conventional tools due to their low cost of analysis, shorter analysis time, field readiness, high specificity, and ultra-sensitivity. Silver nanoparticles (AgNPs) have gained more attention for mercury sensor development among the nanomaterials [17–19]. During the past decade, scientists have developed numerous AgNP-based colorimetric sensing modalities for the detection of mercury [20]. AgNPs have been used in combination with chemicals or bio-chemicals to conduct mercury sensing. An anti-aggregation-based colorimetric sensor was designed for the detection of mercury ions by the addition of 6-thioguanine during the assay [21], and the addition of
various techniques such as ultraviolet–visible using bark extract, to characterize this material with conducted to develop the green synthesis of AgNPs, the present research study was conducted to develop the green synthesis of AgNPs using the bark extract of Swietenia mahagoni has not been studied thus far. Green synthesis of AgNPs and other metal nanoparticles has been widely carried out for the past two decades due to their simple, efficient, and environmentally safe processes that avoid external toxic chemicals. These green AgNPs fabricated with different parts of plants have various important biomedical and industrial applications. Fabricated AgNPs have been used in the diagnosis of disease, detection of nuclear acids, and agriculture and food industries, as well as biosensor, optical, and electrochemical applications. AgNPs also have a large surface area, tunable size, excellent catalytic activity, and superior antimicrobial and anticancer properties.

Materials and Methods

Materials and chemicals

We used silver nitrate (Sigma-Aldrich, Munich, Germany), mercuric chloride (Qualigens, Waltham, MA, USA), chromium(VI) (Sigma-Aldrich), nutrient agar, nutrient broth (Himedia, Mumbai, India), potassium bromide (Sigma-Aldrich), antibiotic discs (Himedia), glassware (Borosil, Mumbai, India), and Whatman No. 1 filter paper (Maidstone, UK) in our experiments. Swietenia mahagoni tree bark (Fig. 1) was collected from the plantation area of Sri Venkateswara Veterinary University campus, Tirupati, Andhra Pradesh, India.

Preparation of the Swietenia mahagoni bark extract

Fresh bark was collected from an S. mahagoni tree, brought to the laboratory, rinsed with tap water followed by distilled water, and cut into small pieces. Bark pieces were weighed, and 5 g of bark was added to 150 mL of Milli-Q water (MilliporeSigma, Burlington, MA, USA) and heated in a water bath for 30 min at 70 °C. The bark extract was cooled, incubated overnight at room temperature, and filtered through Whatman No. 1 filter paper. The filtrate was collected and stored at 4 °C for further experiments.
Green synthesis of AgNPs

Aqueous 1 mmol/L silver nitrate (AgNO₃) was prepared using Milli-Q water and stored at room temperature in an amber reagent bottle. A diluted 0.2 mmol/L AgNO₃ solution was used for the green synthesis. 5 mL of diluted filtrate of S. mahagoni bark extract was added to 10 mL of 0.2 mmol/L AgNO₃ solution to reduce Ag⁺ ions and form AgNPs. The filtrate acted as a reducing and stabilizing agent for the reduction of 0.2 mmol/L AgNO₃. The samples were incubated at room temperature until the color of solution changed from colorless to brown and subsequently dark brown, as shown in Fig. 2. The current study demonstrated that the green synthesis of Sm-AgNPs using a bark extract of S. mahagoni was possible without toxic and hazardous chemicals.

Purification of Sm-AgNPs

The solution containing Sm-AgNPs was centrifuged at 10 000 r/min for 20 min to obtain green Sm-AgNPs pellets. The Sm-AgNPs pellets were re-dispersed in 15 mL of Milli-Q water and centrifuged again at 10 000 r/min for 20 min to remove any unbound plant molecules. The centrifugation and re-dispersion in Milli-Q water were repeated thrice to obtain pure green Sm-AgNPs that were free of unbound plant extract residues. The purified green Sm-AgNPs pellets were then used to conduct particle size analysis, zeta potential analysis, SEM, and EDS.

Spectral characterization of Sm-AgNPs

Green synthesized Sm-AgNPs, as well as the bark extract of S. mahagoni, were analyzed by UV–Vis absorbance spectroscopy within the wavelength range of 220–750 nm using a NanoDrop 8000 (Thermo Fisher Scientific, Waltham, MA, USA) UV–Vis spectrophotometer available at the DST-PURSE Center, Sri Venkateswara University, Tirupati, India. Green synthesized Sm-AgNPs were analyzed at room temperature using the NanoDrop 8000 spectrophotometer at a resolution of 1 nm to detect the surface plasmon resonance (SPR) of green

Fig. 1 (a) S. mahagoni tree, (b) tree trunk, and (c) tree bark.

Fig. 2 The color change of S. mahagoni bark extract, 1 mL of bark extract + 10 mL of 0.02 mol/L silver nitrate, and 2 mL of bark extract + 10 mL of 0.02 mol/L silver nitrate after a 70 °C water bath for 10 min.
Bacterial cultures of the above bacteria were prepared, 100 μL of these cultures were spread on nutrient agar plates, and then sterile Whatman Grade 1 filter paper discs were placed on the nutrient agar plates. The amounts of bark extract of *S. mahagoni* and green synthesized Sm-AgNPs deposited on the sterile discs were 20 and 40 μg, respectively. Amoxyclav (30 μg, Himedia SD063) discs were used as the standard antibiotic. Nutrient agar plates loaded with the bark extract of *S. mahagoni*, Sm-AgNPs, and antibiotic were incubated at 37 °C overnight. In the next day, the zone of inhibition (ZOI) was calculated, and photographs were acquired for further analysis.

**Colorimetric detection of Cr(VI) by green Sm-AgNPs**

Reduction of chromium (Cr(VI)) by green synthesized Sm-AgNPs was chosen to quantify the catalytic activity [40]. The colorimetric detection of Cr(VI) was carried out by adding 350 μL of Cr(VI) to 650 μL of freshly prepared Sm-AgNPs and observed for instant coloration or color change. The reaction mixture was mixed thoroughly and its absorption spectrum was recorded using the above mentioned NanoDrop 8000 spectrophotometer in the range of 220–750 nm with a 1 cm path length.

**Colorimetric sensor for the detection of Hg²⁺ ions using green Sm-AgNPs**

The colorimetric detection of Hg²⁺ ions was conducted using green synthesized Sm-AgNPs. The reaction was carried out as follows: 200 μL of Sm-AgNPs stock solution, 300 μL of Milli-Q water, and 500 μL of Hg²⁺ solution were added to form a reaction mixture. The resulting reaction mixture was equilibrated by stirring on a Vortex machine for an optimum incubation time and then the UV–Vis spectrum in the wavelength range of 200–800 nm was recorded. The protocol was previously described by Vasileva et al [41].

**Paper-based sensor detection of Hg²⁺ ions using green Sm-AgNPs**

To develop a paper-based colorimetric sensing strip for Hg²⁺ detection, 5 μL of a green synthesized colloidal solution of Sm-AgNPs was added to Whatman filter paper No. 1 (pore size is 11 μm) at eight different spots and then dried at room temperature for 15 min. These Sm-AgNP-immobilized paper strips were used for mercury detection. For this experiment, mercury solutions of...
varying concentrations (100, 50, 10, and 1 mmol/L) and (100, 50, 10, and 1 μmol/L) were dispensed shot-wise (shot volume is 5 μL) at an interval of 1 min on four different Sm-AgNP spots in the sensing test line (T line) until spot discoloration was observed. The volume of mercury solution consumed to achieve discoloration of the Sm-AgNP spot was noted for all the concentrations. For the control experiments, deionized (DI) water, i.e., an equivalent volume of mercury solution consumed to achieve discoloration of the spot, was added to the Sm-AgNP spot in a shot-wise fashion (shot volume is 1 μL) in the control line (C line). The experiment was done according to the protocol of Nain et al. [16] with a slight modification suitable to our lab conditions.

Results and Discussion

UV–Vis spectral analysis of Sm-AgNPs

The detection of green synthesized AgNPs and other metal nanoparticles can be easily analyzed via UV–Vis spectroscopy. In this study, the results revealed that the bark extract of S. mahagoni reduced the 0.2 mol/L silver nitrate solution to an ionic form of $\text{Ag}^+$. This reduction is visually confirmed by the colorless reaction solution changing to a dark brownish color (Fig. 2). The green synthesized AgNPs, thus named as Sm-AgNPs, consists of free electrons, which gives rise to the SPR absorption peak present in the UV–Vis spectral analysis. The SPR peak of green synthesized Sm-AgNPs was obtained at 430 nm (Fig. 3). Metal nanoparticles can be synthesized by various physical and chemical methods using organic chemicals which are highly toxic, expensive, and time consuming to prepare. To avoid the use of toxic chemicals and environmental contamination, scientists have developed a simple, rapid method known as “green synthesis” of metal nanoparticles using various parts of plants and their extracts as reducing agents for the generation of metal nanoparticles. Green synthesized AgNPs have been prepared from the different parts of plant extracts such as the leaf extracts of Melia dubia [42], Argeria nervosa [36], Flemingia wightiana [43], Amaranthus viridis [31], and Achyranthus aspera [44]; fruit extracts of Ficus carica [1], Tinospora cordifolia [45], and Terminalia belarica [46]; and insectivorous plant extract of Drosera spatulata [35], and all these AgNPs have a similar SPR band in the range of 410–450 nm comparable to that of the biosynthesized AgNPs in this study. The results are shown in Table 1.

FTIR analysis of biosynthesized Sm-AgNPs

FTIR spectroscopy is a unique technique which is used to obtain infrared spectra of absorption,
emission, and photoconductivity of solids and colloidal solutions. FTIR analyses of the bark extract of *S. mahagoni* and green synthesized Sm-AgNPs are shown in Figs. 4(a) and 4(b). The bark extract of *S. mahagoni* exhibited FTIR peaks at 3,904.93, 3,845.05, 3,372.18, 2,956.65, 1,612.63, 1,518.01, 1,434.90, 1,257.52, 1,111.47, 1,038.07, 789.92, 730.56, and 695.26 cm\(^{-1}\). The peak at 3,722.18 cm\(^{-1}\) corresponds to the O−H stretching of free hydroxyl alcohols and phenols. The peak at 2,956.65 cm\(^{-1}\) represents C–H, and the peak at 1,612.63 cm\(^{-1}\) is due to the N–H bond of primary amines and C–C and stretching of alkenes and aromatic groups. The peak at 1,518.01 cm\(^{-1}\) corresponds to the N–H bending of alkyl halides. The peak at 1,434.90 cm\(^{-1}\) is due to the stretching of C–C=O in inorganic carbonate. The peaks at 1,257.52 and 1,111.47 cm\(^{-1}\) are due to C−O–C of the CO group in lactones. Finally, the peaks at 730.56 and 695.26 cm\(^{-1}\) are due to the C−H groups of aromatic C–H bonds. The FTIR analysis of green synthesized Sm-AgNPs revealed several prominent peaks after reduction such as 3,346.67, 1,636.81, 1,023.77, and 634.31 cm\(^{-1}\). The peak at 3,346.67 cm\(^{-1}\) is due to the O−H bonds of alcohol and phenols; the intensity of this peak decreased after the addition of Sm-AgNPs compared to that of the bark extract. The peak at 1,636.81 cm\(^{-1}\) corresponds to the stretching and bending of N–H by primary amines and alkenes of the aromatic groups. The peak at 1,023.77 cm\(^{-1}\) is due to the S=O stretching of sulfoxide. Finally, the peak at 634.31 cm\(^{-1}\) is due to the C−I stretching of aliphatic iodo compounds and C–Br stretching of halo compounds. An analysis of the FTIR data clearly illustrates that different bioactive compounds were present in the aqueous bark extract of *S. mahagoni*, such as flavonoids, antraquinones, phospholipids, alkaloids, phenols, saponins, terpenoids, cardiac glycosides, volatile oils, long chain unsaturated acids, and 45 limonoids (swietenolide, swiemahogin A, and swiemahogin B); these compounds are actively involved in the reduction of silver nitrate to Sm-AgNPs by capping and stabilization. Various other plant materials have been used to synthesize AgNPs by green methods, such as *A. viridis* [31], *D. spatulata* [35], *A. nervosa* [36], *F. wightiana* [43], and fruit extracts of *T. cordifolia* [45] and *T. belarica* [46]; FTIR analysis in these studies also indicates that bioactive components such as flavonoids, tanins, phenols, saponins, terpenoids, and stabilizers.
phospholipids, alkaloids, glycosides, and proteins are present in the extracts and actively involved in the reduction and stabilization of nanoparticles.

**Particle size analysis of green synthesized Sm-AgNPs**

The size of green synthesized Sm-AgNPs was detected using the DLS method (Fig. 5(a)). The results reveal that the size of green Sm-AgNPs was in the range of 35.8–47.8 nm with an average mean size of 41.3 nm and a Z average of 37.7 nm. This result reveals that 10% of Sm-AgNPs were less than 35.8 nm, 50% were less than 42.8 nm, and 90% were less than 47.8 nm, indicating that green Sm-AgNPs were polydisperse with a polydispersity index (PDI) of 0.169.

**Zeta potential analysis of green synthesized Sm-AgNPs**

The zeta potential analysis of green Sm-AgNPs reveals that the particles were negatively charged. The net surface charge of green Sm-AgNPs was approximately −19 mV, as shown in (Fig. 5(b)), indicating that these samples were stable.

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**Fig. 5** (a) Particle size (DLS) analysis of Sm-AgNPs. (b) Zeta potential analysis of Sm-AgNPs.
nanoparticles in the aqueous colloidal form. Zeta potential is an important physical property which reveals the net surface charge of Sm-AgNPs; this value indicates that the nanoparticles were well dispersed without any agglomeration.

**SEM and EDS analysis of green synthesized Sm-AgNPs**

The morphology and size of green Sm-AgNPs were observed using SEM, and the size of Sm-AgNPs were in the range of (30 ± 2–50 ± 2) nm with a roughly spherical shape and an average size of (47 ± 2) nm (Fig. 6(a)), which agreed with the DLS data. A similar result was observed in an earlier study [17].

The elemental composition of green Sm-AgNPs was determined using EDS, and the highest proportion peak of Ag was obtained at 3.0 keV, followed by some minor peaks of C, O, and Cu and major peaks of Ag and Si. The high peak of Si is due to depositing Sm-AgNPs on a glass slide. EDS data show the mass percentages of elemental Ag, Cu, C, O, Na, Mg, and Ca were 36.19%, 8.86%, 16.25%, 24.45%, 14.70%, 11.06%, and 13.72%, respectively (Fig. 6(b)).

**Antibacterial activity of green synthesized Sm-AgNPs**

The antibacterial activity of green synthesized Sm-AgNPs was determined against both Gram-negative and Gram-positive bacterial strains. The results confirm that green Sm-AgNPs had an exceptionally good antibacterial activity. The ZOI values of Sm-AgNPs against four different bacterial species at amounts of 20, 30, and 40 μg along with those of the bark extract of *S. mahagoni* and standard antibiotic Amoxyclav (30 μg, Himedia-SD063) are shown in Fig. 7, and the ZOI values measured are tabulated in Table 2. Green Sm-AgNPs had a very good antibacterial activity compared with that of 30 μg of Amoxyclav. The bark extract did not have any activity, whereas Sm-AgNPs had an excellent activity with an increase in amount from 20 to 40 μg when compared with that of the standard antibiotic, as shown in Fig. 7. In earlier studies, metal nanoparticles established their antimicrobial activity. Among the metal nanoparticles, AgNPs are known to have an excellent antimicrobial activity against various bacterial species. Presently, several bacterial strains have developed antibiotic resistance due to the prolonged use of antibiotics, which causes a severe illnesses and diseases in humans.

**Colorimetric detection of Cr(VI) using green Sm-Ag NPs**

The results revealed that the green synthesized colloidal solution of Sm-AgNPs had a strong SPR band.
1 mmol/L Cr(VI) stock solution was prepared for this experiment. The maximum optical density (OD) was 8.369 at 360 nm, whereas the maximum absorbance decreased to 2.504 OD after the addition of Sm-AgNPs to the 1 mmol/L Cr(VI) solution, which indicates the interaction of AgNPs with the chromium solution; the color of Cr(VI) changed from orange to dark purple. The results are shown in Fig. 8(a). Similar results were observed using hexavalent chromium (Cr(VI)) and biosynthesized fig fruit (FF)-AgNPs polyvinylprrolidone (PVP-FF-AgNPs) [1], biogenic Pd(0) nanoparticles [47], and AgNPs biosynthesized from a leaf extract of *Anacardium occidentale* [48]. Inorganic nanoparticles act as a catalyst and reducing agent of hexavalent chromium, and the use of inorganic nanomaterials/nanoparticles in the nano-catalyzed reduction of Cr(VI) has attracted a significant attention [49].

**Colorimetric sensor detection of Hg²⁺ ions using green Sm-AgNPs**

The optical and colorimetric detection of Hg²⁺ ions due to the interaction of Sm-AgNPs with Hg²⁺ ions resulted in a visible color change of Sm-AgNPs from yellow to colorless at high concentrations more than 10 μmol/L (Fig. 8(b)). Further studies at lower concentrations did not produce a visible color change, but an optical change was measured by the UV–Vis spectrophotometer. The disappearance of the characteristic absorption peak of Sm-AgNPs was observed, resulting in a clear solution with zero or nearly zero absorbance intensity. Similar results were observed in starch-functionalized AgNPs which were used to detect Hg²⁺ ions in tap water [50]. Another previous study revealed that cysteine-modified AgNPs can also act as a probe for the selective colorimetric detection of Hg²⁺. Most studies reported that surface coated or modified AgNPs were used in the colorimetric detection and reduction of Hg²⁺. In this study, we used unmodified green Sm-AgNPs directly for the colorimetric detection of Hg²⁺.

Unmodified nanoparticles are rarely reported [52]. Therefore, we reported that unmodified green Sm-AgNPs were very efficient in the colorimetric sensing of Hg²⁺. In future studies, these green Sm-AgNPs can be used as colorimetric probes for sensing different lethal metal ions in environmental samples.

**Paper-based sensor detection of Hg²⁺ ions using green Sm-AgNPs**

In this study, a Sm-AgNP probe with application to Hg²⁺ sensing was investigated to improve detection in the field. We developed a Whatman filter paper-based sensing strip, and the photographic image shown in Fig. 8(c) exhibited the disappearance of the yellow spots of Sm-AgNPs (sensing line) in contrast to the control sample (control line). Different mercury solution concentrations of 100, 50, 10, 1, 100, 50, 10, and 1 μmol/L were used for the discoloration of Sm-AgNPs. The discoloration was dependent on the Hg²⁺ solution concentrations. Sm-AgNPs spots were colorless after the addition of 5 μL (100 mmol/L), 12 μL (50 mmol/L), 18 μL (10 mmol/L), and 24 μL (1 mmol/L) in the first reaction on Whatman paper, as shown in Fig. 8(c). In addition, a larger volume of Hg²⁺ solution was required at lower concentrations; specifically, 40, 80, 120, and 240 μL volumes required concentrations of 100, 50, 10, and 1 μmol/L, respectively, in the second reaction on Whatman paper (Fig. 8(c)). All the control samples exhibited no visible change in the yellow color of Sm-AgNP spots. Finally, as the concentration of mercury decreased, the required sample volume and discoloration time increased. This result is due to the decreased availability of mercury ions, which decreases the

![Fig. 7 Antibacterial activity of Sm-AgNPs.](image-url)
reaction rate. The paper-based sensor strip could detect 100 mmol/L of mercury ions within 45 min. A lower concentration of 1 mmol/L required 2 h. Thus, visible detection was easily achieved in the present experiment. Similar results were reported by Nain et al. [16] and Han et al [53]. There are few comparable studies, but a recent study was carried using Achillea wilhelmsii extract-mediated silver nanoparticles (Aw-AgNPs) in Hg\(^{2+}\) sensing in solution and on a paper substrate [54]. The development of simple paper-based tools will decrease the complexity of sensors and cost of assays, leading to lethal metal samples decreasing to parts per million and parts per billion levels.

**Conclusion**

In this study, we report a simple and rapid method for the green synthesis of AgNPs using the bark extract of *S. mahagoni*. The results reveal that the green synthesized Sm-AgNPs have important biomedical and industrial applications. The green Sm-AgNPs were characterized by different spectroscopic methods and evaluated in antimicrobial and toxicological applications like dual sensing of Hg\(^{2+}\) ions and toxic Cr(VI) reduction. The SPR spectra of Sm-AgNPs were obtained at 430 nm and FTIR analysis revealed that various bioactive molecules of the bark extract actively participated in the reduction and stabilization of Sm-AgNPs. The SEM analysis revealed that Sm-AgNPs were roughly spherical in shape, and EDS data revealed that Sm-AgNPs were completely reduced to elemental silver. The particle size analysis revealed that the green synthesized Sm-AgNPs were polydisperse with an average particle of 41.3 nm, a Z average of 37.7 nm, and a PDI of 0.169. The zeta potential of Sm-AgNPs was −19 mV, which
indicates stable colloidal nanoparticles. Furthermore, the green synthesized Sm-AgNPs were evaluated in biomedical and industrial applications, and these materials had a very good antibacterial activity against both Gram-positive and Gram-negative bacteria. These nanoparticles were also useful in the colorimetric detection of Cr(VI) by reduction with Sm-AgNPs. Green Sm-AgNPs proved to be an effective dual sensing agent of Hg\(^{2+}\) ions using both optical and paper-based biosensor methods. Finally, Sm-AgNPs can be very useful in the development of novel, simple, and low cost biosensors for the efficient detection of mercury and reduction of chromium.

**CRediT Author Statement**

**Hema Gunti:** Methodology, experimental studies, and writing, and editing.  
**Susmila Aparna Gaddam:** Design and plan of study, review, and editorial.  
**Ramamurthy Nadipi:** Experimental studies and results analysis.  
**Venkata Subbaiah Kotakadi:** Conceptualization, supervision, final manuscript writing, and editing.

**Conflict of Interest**

The authors declare that no competing interest exists.

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