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Full Length Research Article

Role of *Bambusa bambos* in Nanoparticle Assisted Phytoremediation of Cadmium from Tannery Effluent in Tiruchirappalli Region of Tamil Nadu

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Abstract

Cadmium levels have increased recently as a result of the rapid development of the industrial sector. Cadmium exposes people to long-term health risks and a series of medical issues. Phytoextraction is the most successful method of phytoremediation among the various approaches since it removes heavy metals effectively and completely from the contaminated site. For sequestering carbon and perhaps influencing the phytoremediation of soils contaminated with heavy metals, some bamboo species have been identified as the most promising species. Through experiments, the ability of *Bambusa bambos* to phytoextract Cadmium from tannery effluent contaminated has been proven. In modern field of science, nanotechnology is one of the most active fields of research. Nanoparticles have interesting properties due to their small size and suitable for providing a matrix for any chemical reaction, such as pollution clean-up. Today, the synthesis of these nanoparticles is done by green synthesis using plant extract in many industries and scientific research. Green synthesis plays a significant role in the synthesis of nanoparticles as the cost of production is low and less time consuming as compared to chemical methods. The potential of silver nanoparticles made from *Bambusa bambos* was evaluated for removal of heavy metals from tannery effluent. The silver nanoparticles ssynthesized from *Bambusa bambos* (0 (control), 0.1, 0.5, and 1 mg) were applied to treat tannery effluent at different concentrations (0%, 5%, 10%, 15%, and 100%) for different periods (15, 30, and 45 days). The results suggested that the green synthesis of silver nanoparticles from *Bambusa bambos* will be a useful and ecofriendly biotechnological tool for treating tannery effluents, before getting discharged into water bodies, thus making the soil environment clean and preventing the human population from the ill effects of heavy metals like Cadmium that enter through food chain.

Key words: *Bambusa bambos*, Phytoextraction, Nanoparticle, Heavy metal, Tannery

Tannery effluent is one of the most destructive industrial pollutants. The approximate quantity of tannery effluent produced is 75,000 m^3/day in Tamil Nadu. 4,00,000 tons of chemicals are required to process 7,00,000 tons of hides and skins annually. The leather used in the tanning process primarily absorbs around 20% of the chemicals, and the rest dissolves in the wastewater [1]. The most polluted wastewater comes from tanneries and contains significant levels of suspended particles, proteins, chlorides, trivalent chromium, nitrogen, sulfate, and sulfides and higher BOD and COD levels [2]. Wastewater from beam house activities like soaking, liming, deliming, bathing, etc., is alkaline and contains hair, lime, TSS, TDS, sulfides, and BOD, which is mainly due to excess usage of calcium hydroxide without sufficient monitoring. Heavy metal contamination affects the quality of food, drinking water, and the natural environment [2]. The usage of sewage water for crop irrigation results in the build-up of several heavy metals in soil in most developing nations [3]. These heavy metals, including Cr, Ni, and Cd, are absorbed by plants, raising the likelihood that they will build up in human cells [4]. Since they harm living things, heavy metals at higher concentrations are defined as environmental pollutants [5]. One of the main hazardous substances created by leather tanneries is Cadmium [6]. Cadmium is carcinogenic and particularly harms the kidneys, liver, and lungs and also cause DNA damage [7].

When compared to other methods of removing heavy metals from the soil, phytoremediation is a new process that is far less expensive and calls for less technical expertise. The ability of plants to collect heavy metals, their tolerance to higher concentrations of heavy metals, their ease of harvest, and composition growth all have a role in the selection of plants for phytoremediation. These plants are well adapted to ingest hazardous trace metals in contaminated soils and grow rapidly [8]. In addition to other nutrients, some plants called

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"hyperaccumulators" have the capacity to take up and absorb heavy metals from the soil. A phenomenon known as Phytoextraction also referred to as phytoaccumulation, photoabsorption, or phytosequestration, occurs when plant roots absorb pollutants and move to shoots or other above-ground biomass such as stems, leaves, and fruits [9]. As *Bambusa bambos* (Poaceae) is available in abundance in India and is also an eco-friendly and multifunctional plant, the leaves and stems of the plant have been used in agriculture and medicine for thousands of years. Chemical constituents include silica, potash, lime, alumina, choline, betaine, hydrate of silicic acid, nuclease, urease, a proteolytic enzyme, cyanogenetic glucoside, and an alkaloid [10].

The field of nanotechnology has great promise for the dependable and economical treatment of wastewater pollutants. Due to their extensive surface area, strong thermal resistance and capacity, extremely small size, self-assemblage, and high chemical reactivity, nanoparticles are recognized as effective materials in the disciplines of environmental science and technology [11]. They exhibit a considerable shift in their atomic structure and magnetic properties due to their small size. According to Lowry [12], several nanoscale materials have substantial surface areas, sizes between 1 and 100 nm, and physicochemical properties that significantly reduce the concentration of contaminants, particularly heavy metals from wastewater. Plants may produce nanoparticles, which are a viable biosorbent as well as a quick, inexpensive, and easy way [13]. The primary use of nanotechnology is to clean up contaminated water. In order to separate heavy metals from contaminated water, a variety of nanomaterials, such as metal oxide nanoparticles (NPs), nano-sensors, magnetic nanoparticles, and nanotubes are used [14]. Metallic ions are very well-adsorbed by the charged functional groups on the surface of nanoparticles. When compared to other traditional physicochemical procedures, the green synthesis of silver nanoparticles is time and energy efficient, cost-effective, and environmentally benign. A farmland that receives wastewater irrigation on a regular basis has a consistently increasing concentration of harmful contaminants. Due to cadmium's toxicity in maize, the protein content reduces by 16.4% to 68.4% [15]. Additionally, it affects how much nitrogen is present in various plant tissues. These pollutants have a severe negative impact on the soil's microbial community, disrupt ecological processes, and eventually lead to stunted growth and lower agricultural yields [16]. This study aimed to synthesize silver nanoparticles from the native *Bambusa bambos* of Indian origin and to evaluate its phytoextraction capacity in treating the heavy metal from tannery effluent collected from Trichy region, Tamil Nadu.

MATERIALS AND METHODS

Plant authentication and voucher reference

The native Indian bamboo species (*Bambusa bambos*) is collected from Mannampandal (latitude 11.1021361 and longitude 79.6941161), a village located in the Nagapattinam District of Tamil Nadu State in India. Mrs. Philomina, Department of Botany, St. Joseph's College, (Autonomous), Tiruchirappalli, authenticated the selected plant species. A voucher specimen of the plants has been deposited in the Rapinat Herbarium of the Department of Botany, St. Joseph's College, (Autonomous), Tiruchirappalli. The entire experimental portion of this work was completed in a controlled setting. Three pots with varying concentration of tannery effluent along with control (tap water) are taken for growing the target bamboo sp. (*Bambusa bambos*) designated for this study to examine their adaptability, contamination level, and efficiency in removing Cadmium from soils and roots, rhizomes, stems, and leaves. Each pot measures D = 30 cm in diameter and h= 24 cm in height. For a single volume of 10 L, each pot has a horizontal surface area of 490 cm^2. The soil's density (D) was equivalent to 0.25 kg/l, and it had a mixture of blond, brown peat, natural vegetable conditioner, and humified organic matter, with a pH of 6.9 and a C(org) content of about 20% dry weight (DW) and 1% DW. Each container contained a total of 4 kilograms of soil.

Soil preparation

At 75 °C, the soil is air-dried to a constant weight before being used to plant the bamboo species. Before chemical digestion, the samples were homogeneously mixed, and to eliminate coarse particles, they were sieved through a 2-mm sieve. The same amount of prepared soil (2 kg) was put into each pot. Each bamboo plant is then thoroughly rinsed with deionized water after being properly cleaned with water to eliminate any remaining soil and debris. After that, the soil in the pot was filled with plant materials. Then, the tannery effluent was applied to pot soils to develop cadmium contamination levels. To prevent overflow from the pots, the effluent was applied gradually. Finally, the pots were coated with effluent, left undisturbed for a few days, and then uniform amounts of water were poured into the pots to contaminate the soil with cadmium evenly.

Measurement of bamboo growth

To assess growth performance every week, the heights of the bamboo species planted in pots were measured (Table 1). After each measurement, a computer-aided drawing that showed the development of bamboo stems emerging from a shared subsurface rhizome system was updated. Additionally, any indication of abnormal plant growth was documented.

Determination of physicochemical parameters of tannery effluent

The tannery effluent gathered from the tanneries in Tiruchirappalli region was characterized for fundamental parameters in the current investigation (Table 2). The effluent was gray with an unpleasant odor, acidic in pH, and high in electrical conductivity (EC), total dissolved solids (TDS), hardness, chlorides, and sulfates due to high organic and inorganic load levels. The values of Biological Oxygen Demand and Chemical Oxygen Demand ranged between 420 mg/L and 1123 mg/L in the current study. The physicochemical characteristics were established by the requirements set forth by the Bureau of Indian Standards (BIS).

Plant species and experimental design

A phytoremediation study was conducted on native bamboo species such as *Bambusa bambos* in earthen pots. This species was chosen due to its ease of availability and fast pace of growth. The experiment had four treatments, and three replications were created for each. A pot study is used to assess the ability of *Bambusa bambos* to remediate cadmium levels in tannery effluent, even at lower concentrations.

Seedlings transplantation and experiment duration

Each container received a transplant of healthy seedlings of uniform height. Each pot was irrigated with a tiny amount of water after transplantation. For 45 days, the target bamboo sp. (*Bambusa bambos*) is cultivated on contaminated soils. After the experiment, all the plants were removed from the pots, and their cadmium uptake was examined.

Determination of bioconcentration

BCF and TF were calculated to identify the phytoremediation potential of plants. BAF is the ratio of metal in plant parts with the metal in the effluent, i.e., BCF = metal concentration in plant part/metal concentration in the effluent. It is the efficiency of plants to accumulate metals in their tissues from tannery effluent. Plants exhibiting high BCF and TF values >1 are phytoextractors, while those with BCF and TF values <1 are Phyto stabilizers [17].

Translocation factor

The primary criterion for assessing and choosing plants for phytoremediation is the translocation factor [18]. TF measures how much heavy metals have moved from the roots to the vegetative portion of the plant including leaves, shoots, and flowers. The following equation was used to determine TF for cadmium concentrations in the bamboo species that were selected for analysis.

Analysis of total cadmium levels

Air-dried soil and plant samples were ground, sieved, and exposed to acid digestion for heavy metal analysis. Nitric acid and perchloric acid (9:4) are used for soil decomposition, and nitric acid is used for plant parts (US Environmental Protection Agency 1996, 1998). Following digestion, filtered samples were subjected to inductive coupled plasma-optical emission spectroscopy (ICP-OES 6000, iCap 6300 DUO, Thermo Fisher, England). The concentration of the target heavy metal (Cadmium) present in the samples was reported using the following equation:

$$(V/M)\ \text{mg kg}^{-1}$$

Where;
V = final volume of sample in a volumetric flask (100 ml) and
M = dry mass of digested sample.

Green synthesis of silver nanoparticles from Bambusa bambos
Preparation of bamboo leaves extract

20 g of bamboo leaves were properly cleaned with distilled water before being dried for 24 hours at room temperature to create the bamboo leaf extracts. The extract solution was made by heating dried leaves in an Erlenmeyer flash for 10 minutes at 100°C with 100 ml of distilled water.

Synthesis of silver nanoparticles

For synthesis of nanoparticles, 5 ml of fresh leaf extract was introduced to a conical flask that already contained 5 ml of a 3 mM aqueous $AgNO_3$ solution. The conical flask was then heated to 65 °C while being continuously stirred. The bamboo leaf extract quickly converted the silver ions into silver nanoparticles. The colour of the extract changes from colourless to yellowish-brown, revealing the synthesis of silver nanoparticles.

Antibacterial assay

Silver is said to be a universal antimicrobial substance for centuries. However, to use silver against microorganisms, it is essential to prepare it with environmentally friendly and cost-effective methods. Besides, it is also important to enhance the antimicrobial effects of silver ions [19]. In this study, the antibacterial effects of the bio reduced silver nanoparticles from bamboo leaves were investigated against two bacterial strains, *S. aureus* / ATCC-25923 (gram-positive) and *E. coli* / ATCC-25922 (gram-negative). The agar petri dishes for antibacterial activity were prepared by boiling 12.5 gm of LB (Luria-Bertani) agar (10 gm of Tryptone, 5 gm of Yeast Extract and 10 gm of NaCl) in 100 ml of water till it melted down completely. The agar solution was inoculated for 30min. After inoculation, the bacterial strains (*E. coli* and *S. aureus*) were poured with different concentrations of AgNPs (20, 40, 60 and 80 µg/mL) in agar plates and spread evenly. The prepared agar plates with bacterial strains and AgNPs were then kept at 37 °C for 24 hours. For the antimicrobial evaluation of synthesized AgNPs, the disc MIC and MBC method was used.

Characterization of BbAg-NPs by UV-Vis spectrum

A double beam UV-Vis Spectrophotometer was used to track colour changes caused by the reduction of AgNO3 in the bamboo extract/$AgNO_3$ solution mixture at wavelengths between 200 and 800 nm. By centrifuging the bio reduced silver nitrate at 12000 rpm for 30 minutes, it was made pure enough for subsequent characterisation tests [20]. To remove any biological molecules that may have been present in the bamboo extract, the pellet was collected and thoroughly cleaned in sterile double-distilled water.

Characterization of BbAg-NPs by FTIR

By using FT-IR analysis, the functional groups found in green synthesized BbAg-NP were examined. A disc was loaded with 0.5 g of BbAg-NP powder under high pressure. At a wavelength of 500–4000 cm^{-1}, the FT-IR spectra were scanned at a resolution of 4.0 cm^{-1}. In order to examine the functional groups, present in the bamboo leaf extract that are involved in the reduction and stabilization of BbAg-NPs [21].

Treatment of wastewater with nanoparticles

Three replicates along with control (no effluent) were used for the treatment of tannery effluent with synthesized silver nanoparticles. The experiment was carried out in 250 mL of jars with three replicates (R1, R2, and R3), and each were analyzed at different time intervals i.e., 15, 30, and 45 days respectively. Three different concentrations along with control (0%) were prepared using distilled water for the tannery effluent according to the requirement of the experiment: 0% (contained only distilled water), 5% (5 mL of effluent in 95 mL of dH_2O), 10% (10 mL of effluent in 90 mL of dH_2O), 15% (15 mL of effluent in 85 mL of dH_2O), and 100% (pure industrial wastewater).Then the prepared concentrations of the tannery effluent were treated with the four concentrations of nanoparticles 0 (control), 0.1, 0.5, and 1.0 mg, respectively, along with the control.

Evaluation of the bioremediation potential of bamboo silver nanoparticles

To evaluate the phytoremediation potential of silver nanoparticles synthesized from *Bambusa bambos* leaf extract,5 mL of HNO_3 and 15 mL of perchloric acid was added in 25 mL of tannery effluent in the ratio of 3:1. The final volume was raised up to 100 mL with distilled water. Then, the solution was filtered with filter paper. Finally, the filtrate solution was used for the determination of heavy metal concentration in sample [22] with the help of Atomic Absorption Spectrophotometer (GBC, Australia) and compared with the concentration of heavy metals present in the effluent before the application of synthesized silver nanoparticles.

RESULTS AND DISCUSSION

Measurement of bamboo growth

Table 1 Effect of tannery effluents at various levels on the growth of *Bambusa bambos*

Character	Plant parts	Control	50 ml	100 ml	150 ml
45 days treatment	Shoot	37.41±0.46	35.83±0.55	35.21±0.39	34.61±0.17
Length (cm)	Root	12.67±0.51	11.54±0.67	10.78±0.16	10.02±1.16
	Shoot	17.07±0.33	15.86±0.44	14.65±0.19	14.06±0.66
FW (g)	Root	2.0±0.42	1.74±0.28	1.21±0.47	0.97±0.38
	Shoot	12.11±0.64	11.54±0.49	10.43±0.35	9.84±0.44
DW (g)	Root	0.88±0.23	0.61±0.52	0.45±0.27	0.21±0.57

Determination of physicochemical parameters of tannery effluent

Table 2 Physicochemical parameters of tannery effluent compared with BIS limits

Parameters	Observed values	BIS limits
Colour	Brownish	-
Odor	Disagreeable	-
pH	8.02	5.5-9
BOD (mg/l)	420	30
COD (mg/l)	1123	250
TDS (mg/l)	12315	2100
TSS (mg/l)	7017	100
Conductivity (moles/cm)	1.108	10
Turbidity (NTU)	78	-
Total chromium (mg/l)	37	2.0

Assessment of growth of Bambusa bambos (Pot method)

Fig 1 Pot experiment done with *B. bambos* containing varying concentrations of tannery effluent

Determination of translocation factor

The translocation factor evaluates the rate at which heavy metals are moved from roots to leaves and shoots. The main criteria for assessing and choosing plants for phytoremediation are BCF and TF [23]. With low cadmium concentrations, the translocation rate is approximately 1.3. It remained steady at the next concentration, 100 ppm, but gets significantly increased at 150 ppm. Furthermore, it remained above 1.3 and steady for 150, 200, and higher concentrations. If the translocation factor exceeds 1, the metal has moved from the root to the above-ground portion [24]. Only plant species with BCF and TF values larger than 1 have the potential to be employed for phytoextraction [25].

Table 3 BCF and TF of *Bambusa bambos* grown on effluent-treated soil

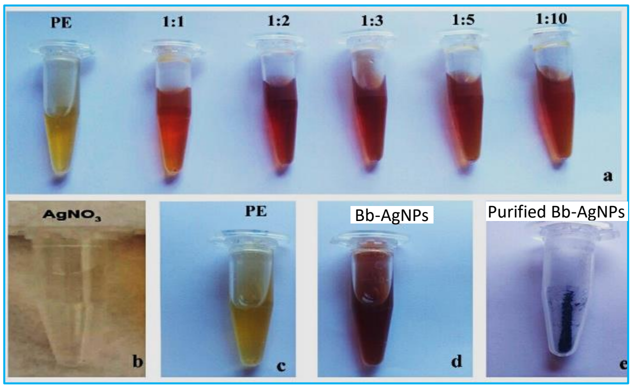
Species	No. of days	BCF and TF of heavy metal (Cd)	
		BCF	TF
Bambusa bambos	15	3.22±0.116	2.00±0.054
	30	3.45±0.108	1.9±0.057
	45	3.83±0.12	2.06±0.04

Analysis of total cadmium level in various tissues of Bambusa bambos

Table 4 Accumulation of various heavy metals on *Bambusa bambos* after 45 days of effluent treatment

Heavy metal	Treatment of effluent (ml)	Leaves (µg/g DW)	Stem (µg/g DW)	Root (µg/g DW)
Cadmium	0 (Control)	1.23	1.32	1.79
	50	2.88	4.26	7.34
	100	4.89	5.37	7.89
	150	7.48	7.90	9.59

Synthesis of bamboo-silver nanoparticles



a. Different ratio of plant extract (PE) with silver nitrate ($AgNO_3$) solution (1mM)
b. Silver nitrate (AgNO3) solution (1mM)
c. Plant extract (PE)
d. Biosynthesized silver nanoparticle (BbAgNPs)
e. Purified Silver Nanoparticle powder (BbAgNPs)

Fig 2 Synthesis of bamboo-silver nanoparticles

Characterization of bamboo-silver nanoparticles

UV-Vis spectroscopic sstudies confirmed the bio reduction of aqueous silver ions to silver nanoparticles which can easily be followed by UV-Vis spectrophotometer at first. UV-vis absorption spectrum was observed by Lambda 900 UV-vis spectrophotometer (Perkin Elmer, USA). The most important feature of optical absorbance spectra is surface Plasmon band among metal nanoparticles, which is due to the electron oscillations that collectively gather around the surface of metal particles. Bioreduction of silver ions to AgNPs mediated by bamboo leave extracts was observed by recording the absorption spectra. The yellowish-brown color of silver nanoparticles became visible due to the excitation in surface Plasmon vibrations by absorbance in between 420 and 450 nm (Fig 3f).

The bamboo leaves (*B. bambos*) used in this investigation is native to India, and the bamboo leaves are known to be rich in various phytochemicals like flavonoids, phenolic acids. Due to these diverse constituents of bamboo leaves bio reduction of silver nanoparticles became significantly possible [26]. Bamboo leaves are also a common source of derivative compounds of phenolic acids, coumaric lactones and flavonoids like; homoorientin, orientin, isovitexin, vitexin, naringin7-rhamnoglucoside, rutin, quercetin, luteolin, tricin, caffeic acid, chlorogenic acid and phydroxy coumaric acid [27]. Flavonoids play an important role in the reduction process for biosynthesis AgNPs (Egorova EM,2000). Accordingly, the high content source of flavonoids and phenolic acids in bamboo leaves extract (BLE) supports the potential bio reduction of Ag^{+} to Ag^{o}.

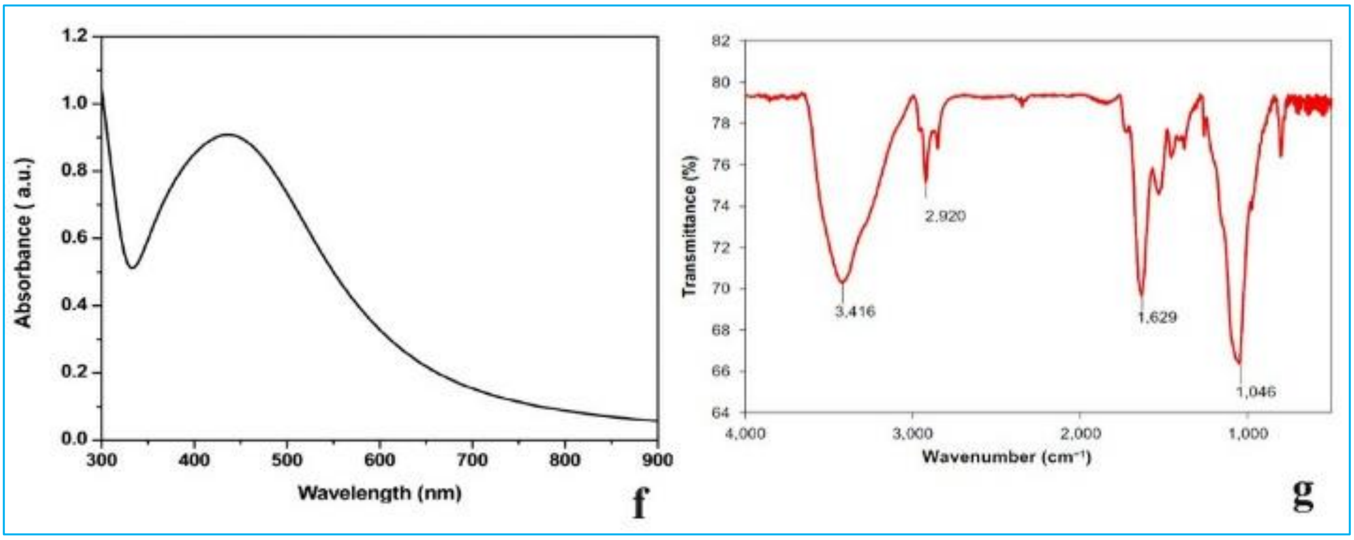


Fig 3 (f) UV-Visible absorption spectra of biosynthesized silver nanoparticles
(g) FTIR spectra of biosynthesized silver nanoparticles

Antibacterial Activity

In this study, the antibacterial effects of the bio reduced silver nanoparticles from bamboo leaves were investigated against two bacterial strains, *S. aureus* / ATCC-25923 (gram-positive) and *E. coli* / ATCC-25922 (gram-negative). For the antimicrobial evaluation of synthesized AgNPs, the disc MIC and MBC method was used. In this study, the lowest concentration of AgNPs 20 µg/mL shows measurable cell growth on agar plates counting 1 × 108 CFU/mL (Fig 6). The cell growth gradually decreased to none as the concentrations increased, ranging from 1 × 107 to 1 × 10^{3} CFU/mL representing bactericidal properties of AgNPs. In MIC/MBC study, the lowest concentration of AgNPs 20 µg/mL was found to be effective in killing the bacteria up to 1 × 10^{7} CFU/mL concentrations, as there was no cell growth seen on plating after incubation at 37 °C for 24 hours. The analysis of MIC/MBC study states that these ratios are responsible for inclusive killing of bacteria up to mentioned concentrations.

Nanotechnology is a promising and advanced field of science particularly for treating wastewater effluents. Green synthesis of nanoparticles from *Bambusa bambos* native of Indian origin is cost-effective due to their high surface area, high reactivity, and strong mechanical properties that are highly efficient and effective for wastewater treatment related to tannery effluents.

The synthesis of nanoparticles was observed by the initial color change from light green to pale yellow. Physicochemical parameters such as pH, EC, TDS, chlorides, BOD, COD, and heavy metals (Cr, Cd, and Pb) were also monitored, along with different treatments. Although in this study, the pH levels began to lower down with time, the lowest values were recorded after 45 d of incubation at 5% and under the treatment of 1 mg NPs. It is also suggested that increases in chemical treatment may differentially influence physiochemical parameters such as pH, EC, and COD [28]. Using different doses of $AgNO_3$ the present study showed an effective reduction in EC burden from different concentration of effluents. Precisely, the application of 1 mg NPs at 15%, reduced the EC value from 17.58 mg/L to 13.09, 8.71, and 5.37 mg/L after 15, 30, and 45 d, respectively [29]. Our results suggest that biosynthesized silver nanoparticles efficiently reduced the EC content compared to the chemical approach. The bioremediation potential of silver nanoparticles toward the reduction in TDS content was good enough. In the present study, 53% of removal efficiency for TDS content was found at 100% concentration for the leather tanning industry, with a significant reduction in values from 11.54 mg/L to 8.72, 6.73, and 6.17 mg/L after 15, 30, and 45 d, respectively, at 1 mg nanoparticle treatments. A further 5% reduction in TDS content was observed before and after the experiment. Moreover, a significant reduction in chloride content was achieved at 5% effluent concentration and 1 mg of silver nanoparticles. At 10%, the effluent load of the chloride reduction was within permissible limits (about 1000 mg/L Cl) but at 15% and 100% the values were higher than the permissible limits. The precipitation method was applied at a pH range of 6–11 and a temperature of 30 °C. The amount of biochemical oxygen demand (BOD) was reduced at the 1 mg treatment and 5% effluent concentration (65, 53, and 41 mg/L) after 15, 30, and 45 d of treatment, respectively, and a further reduction in BOD was recorded at 10% and 15%. In the current study, the reduced COD content at the 1 mg treatment and 100% was 801, 612, and 521 mg/L after 15, 30, and 45 d of treatment, respectively. Similar reduction in chemical oxygen demand was observed in other concentrations of leather industrial effluents. The results showed that the nanoparticles effectively remove Cd^{2+}, Cu^{2+}, Ag^{1+}, and Pb^{2+} and exhibit a lower efficiency of removing Cr^{4+}, Mn^{2+}, and Ni^{2+} from the effluent sample. In the current research, green synthesized silver nanoparticles showed maximum adsorption for Cd, Cr, and Pb in a similar sequence. Chromium was reduced to 60.9, 52.5, and 26.1 mg/L after 15, 30, and 45 d, respectively, at 5% effluent concentration. In the present investigation, the reduction in Cd content was ~42, 40.5, and 23.5 mg/L at 5%; 98.4, 83.3, and 42.4 mg/L at 10%; and 127.1, 113.2, and 57.4 mg/L at 15% after 15, 30, and 45 d, respectively. Pb concentration was reduced from 25.3 mg/L to 17.8, 16.4, and 9.9 mg/L at a concentration of 5%. At 100%, the content was reduced to 57.3, 51.2, and 25.7 mg/L. These findings indicate that the biologically mediated synthesis of nanoparticles could become a useful resource in removing pollutants. The phytochemicals present in plant extracts may also increase the antibacterial, antifungal, and anticancer properties of green-synthesized nanostructures, by generating a synergetic nanostructure that combines the antimicrobial properties of both the plant extract and the NPs themselves [30]. In the present study, heavy metals were significantly reduced in all industrial effluent concentrations, and the removal efficiency for all parameters was optimized after 45 d of treatment with 1 mg nanoparticles. The green synthesis of silver nanoparticles showed effective bioremediation against leather industry effluents. The removal percentages of tannery effluents may be attributed to the adsorption of heavy metals onto the adsorption sites present on the NPs surface [31]. Nanomaterials are utilized as adsorbents that depend upon structural qualities including good specificity for the use of eliminating heavy metal ions from wastewater at low concentrations. Agglomeration of nanoparticles with the passage of time may be ideally helpful for the adsorption of toxic substances or other pollutants, as they could elevate the surface-region to volume proportion [32]. The adsorption processes are governed by the diffusion of metals to the pores fixed on the adsorbent surface, which reacts with the surface-active sites. The high adsorption of BbAg-NPs could also be attributed to the liberation of OH^- from $AgNO_3$ [31]. In the case of heavy metal adsorption, absorbents such as silver nanoparticles (Ag-NPs) have been investigated, which selectively interact with Cadmium. This mechanism is based not only on electrostatic interaction but also on metal coordination and complexation, which interact with and provide synergetic effects that result in enhanced adsorption and finally increased removal efficiency. Metal coordination and especially complexation strongly depend on the pH. The pH also influences the precipitation of metals. Our findings showed that application of the silver nanoparticle could help with reducing toxic substances in the tannery effluent to safe levels and at a reasonable cost, as the conventional methods of remediation may cost a lot. Hence the synthesized silver nanoparticles could be effective in treating tannery effluent and can be strongly suggested for routine application.

CONCLUSION

The present study highlights the capability of silver nanoparticles synthesized from *Bambusa bambos* for reducing the pollution load from tannery effluents. The study indicates that the silver nanoparticles adsorp heavy metals at a higher rate and alter some other physicochemical parameters of the tannery effluent after 45 d of treatment, particularly at low concentrations. Owing to the efficacy of NPs, it could prove to be a cost-effective and eco-friendly process. The trend of nanomaterials for water-pollutant treatment is rapidly increasing in this modern era, due to the limited water supply at the global level. Nanotechnology for water purification is an alternative approach for the availability of fresh water, though it requires digital monitoring techniques. There is a need to synthesize modified nanomaterials that should be effective, with high efficiency, and be easy to handle and eco-friendly. In this study, a simple approach was attempted to obtain a green eco-friendly way for the synthesis of silver nanoparticles using aqueous bamboo leaves extracts. The silver ions in an aqueous solution were exposed to the bamboo leaves extracts (BLE), the biosynthesis of AgNPs were confirmed by the rapid colour change of plant extracts. The natural benign AgNPs were confirmed further by using UV-Vis spectroscopy. Phenols and flavonoids were present in the leaves, and they serve as an effective reducing agent. AgNPs biosynthesized from bamboo leaves also exhibits great antimicrobial activities against the sample bacterial cultures. Hence, we conclude that innovative techniques such as the use of BbAg-NPs could provide good quality water for irrigation purposes, besides removing pollutants from tannery effluents.

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Conflict of interest

The authors declare no conflict of interest.

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