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ORIGINAL ARTICLE

Study of antimicrobial activity of *Thespesia populnea*-coated nanozirconium on cotton gauze fabrics

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Abstract

Indian traditional medicinal plants are important sources of phytotherapeutic agents. Plants with antimicrobial properties have been involved in the treatment of infectious diseases and also, in mitigating the side effects produced by the synthetic antimicrobial agents. Hence, the present work has been focused on the study the antimicrobial activity of *Thespesia populnea* extract-coated nano-zirconium on cotton gauze fabrics. UV–Vis spectroscopy showed the strong peaks produced by Zr nanoparticle after 200 nm, which indicated that *T. populnea*-coated Zr nanoparticles would possess antimicrobial activity. The crystalline nature of the nanoparticles was confirmed by XRD analysis and the smaller size of the nanoparticles about 10 nm was observed using TEM analysis. The antimicrobial activity of *T. populnea* extract-coated Zr nanoparticles was studied by well diffusion against pathogens such as *E. coli, Bacillus subtilis, Staphylococcus aureus* and *Pseudomonas aeruginosa* and the Zr nanoparticles showed a high toxicity against the bacterial species studied. The antimicrobial activity suggests that the synthesized nanoparticles can be used in wounds dressings.

Keywords Zr nanoparticles · Green synthesis · *Thespesia populnea* · Antimicrobial agent · Gauze fabrics

Introduction

Infectious diseases are more common in both developing as well as developed countries all over the world and are the most important global problems, leading to the death of several people (Nair et al. 2017; Vu et al. 2015). They are caused by pathogenic microorganisms such as bacteria, virus, fungi, parasites, protozoans, etc. Wound is the one of the easiest routes for the microorganisms to invade the host. The inflammatory response is a protective mechanism that aims to neutralize and destroy any toxic agent at the site of an injury and restore tissue homeostasis (Collier 2003). Wound infection is the deposition and multiplication of bacteria in tissues with an associated host reaction. Wound infection continues to be a challenging problem and represents a considerable healthcare burden.

In accordance with World Health Organization (WHO), 80% of human population depend on traditional medicine for curing their health care problems (Nair et al. 2005). Among the 2,58,650 species of plants, 10% are used for therapeutic purposes. In view of the recent reports, metabolites from plants are a great source for controlling microbes and microbe-related diseases (Ribeiro et al. 2018; Samoilova

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et al. 2014). Hence, plants and plant extracts have become alternate sources of antimicrobial agents to treat various illnesses (Ameya et al. 2017; Rahim et al. 2015; Walter et al. 2011). Drugs from plant sources are the treasure of Indian traditional medicine because of their antimicrobial property to cure microbial diseases (Saranraj and Sivasakthi 2014; Govindappa et al. 2021). In this context, researchers and pharmaceutical companies are in search of new antimicrobial agents from plants. At present, nanomaterials have received great attention regarding antimicrobial property because of their beneficial physical and chemical features and high surface to volume ratios (Butler et al. 2015; Durán and Marcato 2013; Rai and Ingle 2012).

Nano-bioscience and nanotechnology encompass various techniques including physics, chemistry, engineering, and medicine. Nanoparticles can be metal or metal oxide nanoparticles, organic and inorganic nanoparticles, polymeric nanoparticles, etc. In recent days, metal nanoparticles are used as ingredients in complementary medicine for curing various ailments in the traditional medicinal practices (Fathima et al. 2017; Prakashkumar et al. 2021). 80% of the world population prefers plant-based ayurvedic treatment and it is encouraged by WHO because of its less side effects. The World Health Organization (WHO) shows great interest towards the promotion of utilizing medicinal plant resources in the developing countries to provide effective health care for the people. In the field of medicine, pathogen-induced toxicity has become a major problem, which paves the way for the application of nanotechnology. Hence, the use of traditional method of biosynthesis of nanoparticles using plants and plant extracts has been increased for controlling microbial diseases because of its safety and lack of phytotoxic side effects (Gardea-Torresdey et al. 2003; Savithramma et al. 2012).

The antimicrobial activity of nanoparticles is determined by their size, shape, morphology, surface charge, stability, concentration in the growth medium and surface coating (Siegel et al. 2013). Textile materials can be easily affected by microbes and the microbes produce odour, cause damage to the clothing, strength loss, staining, discoloration, which lead to skin diseases. However, antimicrobial-coated fabrics are hygienic and prevent infections caused by pathogens in hospitals, nursing homes, homes, hotels, supermarkets, schools, colleges and overcrowded areas (Gao and Cranston 2008). The production of nanoparticle-based cotton fabrics has attained major importance with antibacterial, wound healing and hygienic applications, especially, in the field of medicine. Nanoparticles with antimicrobial property control the growth of microbes by preventing cell reproduction, blocking enzyme activity, cell wall destruction and cell poisoning (Schindler and Hauser 2004). Various requirements of these finishes in textiles are durability of cloth washing, dry cleaning, increased usage by the user, compatibility with chemical treatment and so on (Schindler and Hauser xxxx; Dhiman and Chakraborty 2015; Thiry 2010). Chemically synthesized textile fabrics are reliable but they also produce some side effects such as allergy to fabrics, toxicity on continuous usage, costlier and not biodegradable.

Thesperia populnea is an Indian indigenous plant, also known as tulip tree and it is most commonly used in traditional medicine. It is used in the treatment of hepatitis, ulcers, wounds, psoriasis, scabies, leprosy, urinary tract infections, diabetes, cholera, asthma, swollen joints and guinea worm infections (Akhila and Rani 1993). According to Shekshavali and Shivakumar (Shekshavali and Hugar 2012) *T. populnea* possesses antimicrobial and antifungal properties against infectious microbes. Hence, the present work has aimed to develop the cotton gauze fabrics with *T. populnea* extract coated nanozirconium and investigate the antimicrobial activity.

Materials and methods

Chemicals and preparation of Thespesia populnea leaf extract

Chemicals and reagents used in the present study were procured from Himedia, India and were of analytical grade. The leaves of *T. populnea* were collected and were washed with distilled water. The dry powder of leaves was soaked in 100 mL of double distilled water and vacuum evaporated at 60–70 °C for 10–12 h. After evaporation, a semisolid mass (2.435 g) of *T. populnea* extract was obtained. The percentage of extract yield was 24.35% w/w. The extract obtained was stored in a sterile container and refrigerated till the commencement of experiments.

Green synthesis of zirconium nanoparticles

Zirconium nanoparticles were prepared by green synthesis. Zirconyl chloride (1 mM, 80 mL) was taken and added with 20 mL of *T. populnea* leaf extract. The mixture was stirred for 2 h at 80 °C and the solution was left undisturbed for overnight for the formation of nanoparticles. The particle sediment was vacuum evaporated in a hot air oven at 200 °C for 1–2 h to get Zr nanoparticles.

Characterization of nanoparticles

The green synthesized nanoparticles underwent characterization procedures for the evaluation of their size, shape, surface area, and homogeneity. Major techniques of characterization included UV–visible spectroscopy, X-ray diffraction (XRD), transmission electron microscopy (TEM) and Fourier transform infrared spectroscopy (FTIR). The colloidal nanoparticle solution was analyzed to monitor the bioreduction of Zr using a UV–Visible spectrophotometer (Shimadzu Corporation, Kyoto, Japan) in the wavelength range of 200–800 nm at a resolution of 1 nm. The morphology of the Zr nanoparticles was observed using TEM analysis (EOL JEM-2100, Japan). XRD spectrum of Zr nanoparticles were obtained with X-ray diffractometer (JEOL, JDX 8030, DX-MAP2, Tokyo, Japan) using Ni-filtered CuK-alpha radiation (40 kV, 20 mA) to determine the nature of the synthesized Zr nanoparticles. The chemical structure and functional groups of Zr nanoparticles were characterized by FTIR spectroscopy.

Antimicrobial activity of *T. populnea*-coated nanozirconium treated and untreated fabrics

For the evaluation of antimicrobial activity, the bacterial strains including *E. coli, Bacillus subtilis, Staphylococcus aureus*, and *Pseudomonas aeruginosa* were selected and exposed to cotton gauze fabrics treated with and without *T. populnea*-coated Zr nanoparticles. Bacterial species were cultured in Muller Hinton broth. The antimicrobial activity of *T. populnea* leaf extract coated Zr nanoparticles was studied by well diffusion method on cotton gauze fabrics. Nutrient agar petri plates were prepared and after complete solidification, the plates were inoculated with the selected strains and allowed to dry. Finally, cotton gauze fabrics treated with *T. populnea* leaf extract-coated nano-Zr and untreated cotton gauze fabrics were placed on the medium and kept in an incubator at 37 °C for 24 h and after the incubation period, the zones of inhibition were measured in millimeters and the results were recorded.

Results and discussion

UV–visible spectroscopy

UV–visible absorption spectroscopy is used to confirm the synthesis of the nanoparticles. UV–visible absorption spectrum was observed at the wavelength of 200–800 nm. There was no peak between 400 and 800 nm indicating non-aggregations of the nanoparticles. The strong peaks produced by Zr nanoparticles at 250 nm confirmed the synthesis of *T. populnea* coated Zr nanoparticles (Fig. 1). Similar absorption spectra for the Zr nanoparticles have been reported earlier (Jalill et al. 2017).

FTIR studies

The FTIR analysis was used to investigate surface characteristics and confirmed the presence of functional groups

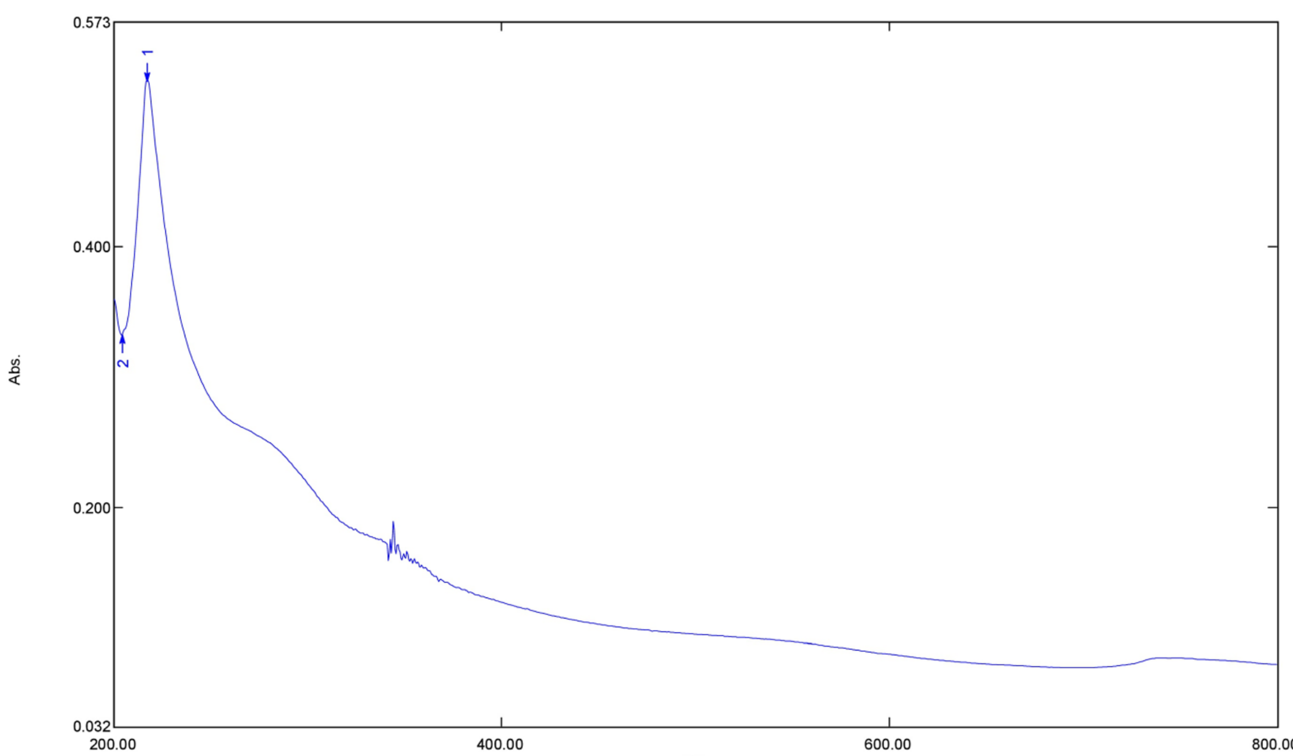

Fig. 1 UV–visible spectrum of Zr nanoparticles synthesized using *Thespesia populnea* leaf extract

that were responsible for the stable production of zirconium nanoparticles (Ali et al. 2020). The peaks were recorded between 4000 and 400 cm^{-1}. The absorption bands at 3220.28, 2921.01 and 1608.02 to 698.94 cm^{-1} were due to the asymmetric vibration stretch produced by the O–H group of the absorbed water. The weak bands between 2900 and 1700 cm^{-1} might have been due to the presence of C–H and C–O groups. The strong peaks between 500 and 400 cm^{-1} were attributed to the stretching of O–H group indicating the stretching and bending of water absorbed by the Zr nanoparticles (Fig. 2). Similarly, Kumaresan et al. (2018) reported that *Sargassum wightii* mediated capping proteins would be important for the long-term stabilization of ZrONPs and for providing protection from oxidation.

XRD studies

The crystalline nature of the nanoparticles was studied by an X-ray diffractometer (XRD) using CuKβ radiation at the wavelength of 40 kV and 30 mA of X-ray. The results showed the diffraction peaks at 28.472°, 31.8486°, 40.595°, 45.563°, 56.585°, 66.332° and 75.398°, which were in accordance with the standard diffraction data of (JCPDS card number 79–1769). The highest peak was observed at 31.8486° (Fig. 3). The average crystallite size of the Zr NPs was 12.13 nm as determined by employing Scherrer Debye's equation.

$D = 0.9\lambda/\beta \cos \theta$.

where D crystal size, λ wavelength of X-ray, θ Braggs angle in radians, β full width at half maximum of the peak in radians.

The amorphous nature of the particles was indicated by the broad peaks while the sharp peaks indicated the crystalline nature. The XRD pattern obtained in the current study confirmed that the synthesized nanoparticles were crystalline in nature.

TEM studies

The size and dispersion of the *T. populnea* leaf extract-coated Zr nanoparticles were confirmed through TEM analysis. There was no aggregation of particles as shown in Fig. 4 and the particles were well distributed. The nanoparticles were very small in size with an average diameter of 10 nm and were spherical. Similar results have been reported in an earlier study where TEM imaging showed that the ZrONPs had spherical shapes with size around 5 nm (Kumaresan et al. 2018). These results were in accordance with the particle size obtained by XRD analysis. The nanoparticles were well isolated on TEM grid, confirming the good dispersion of the nanoparticles in the aqueous medium.

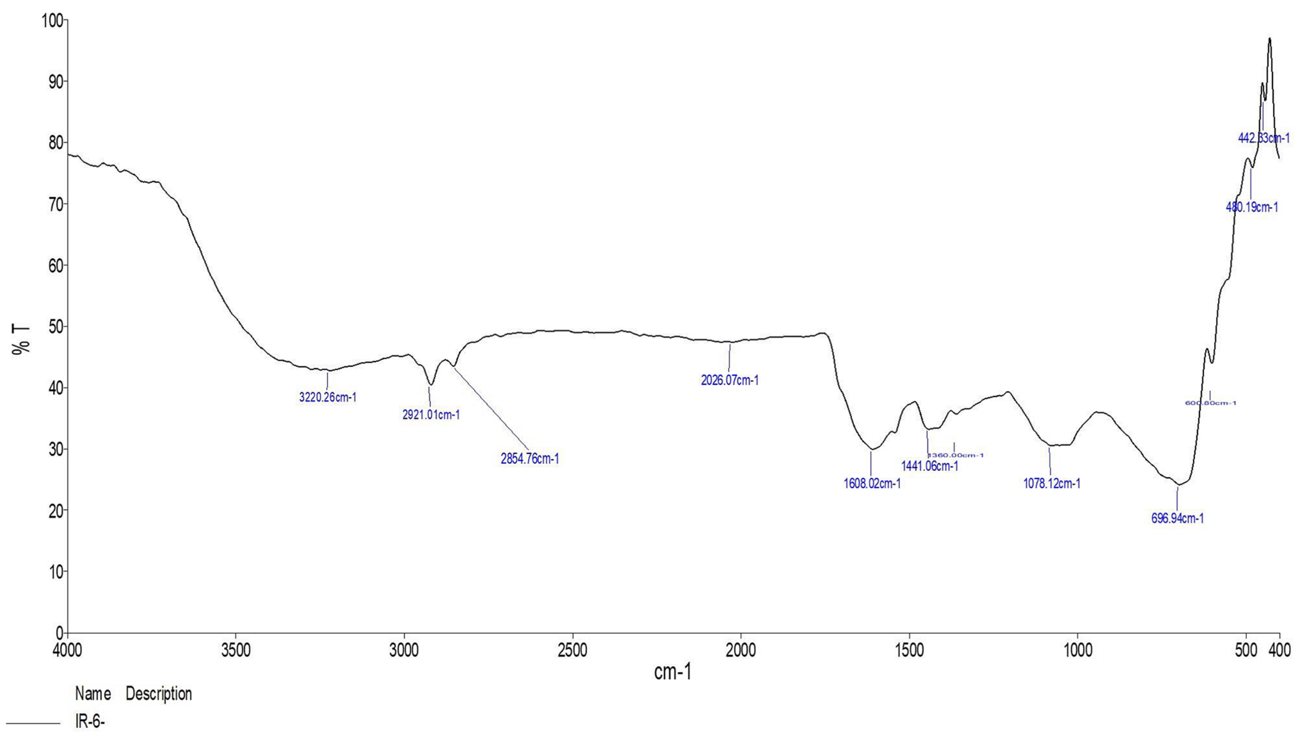

Fig. 2 FTIR spectrum of Zr Nanoparticles synthesized using *Thespesia populnea* leaf extract

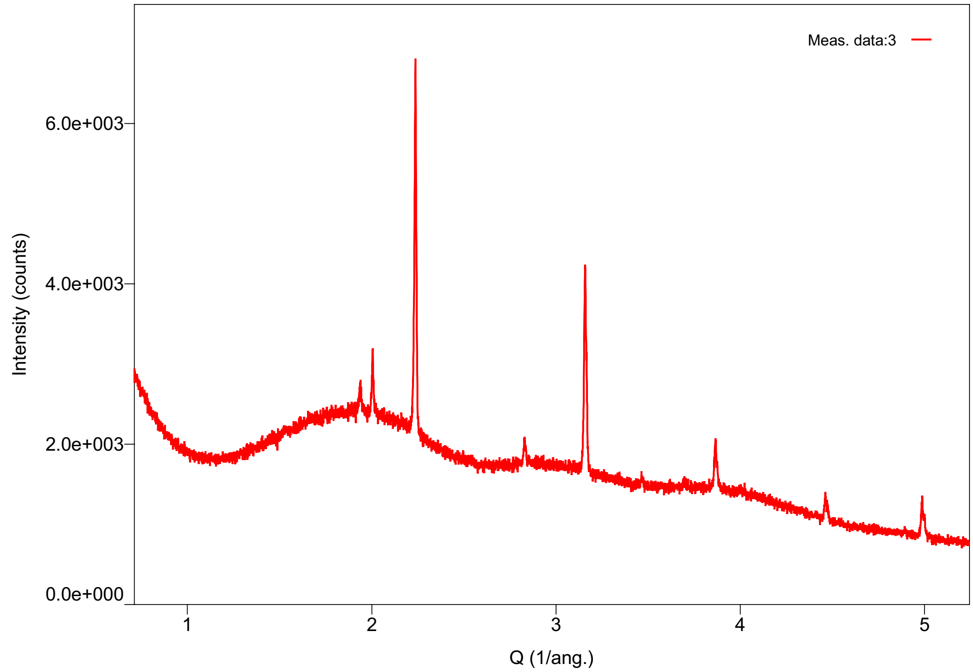

Fig. 3 X-ray diffraction pattern of the Zr nanoparticles synthesized using *Thespesia populnea* leaf extract

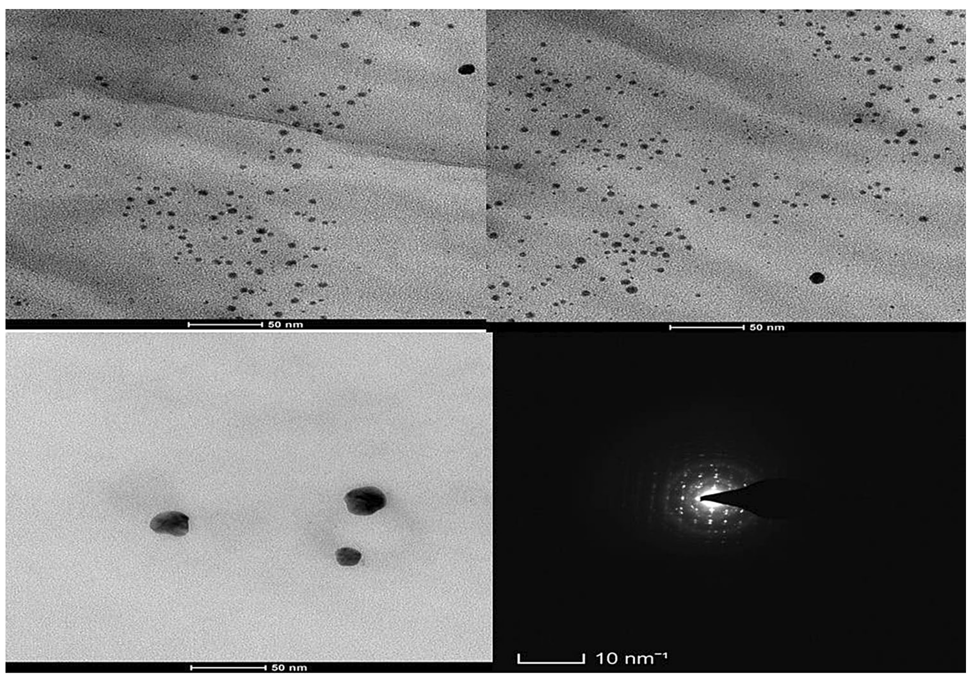

Fig. 4 TEM images of the Zr nanoparticles synthesized using *Thespesia populnea* leaf extract

Antimicrobial activity

The antimicrobial activity of the *T. populnea* leaf extract-coated Zr nanoparticles was studied by well diffusion against various pathogens such as *E. coli, Bacillus subtilis, Staphylococcus aureus* and *Pseudomonas aeruginosa*. Cotton fabrics not treated with Zr nanoparticles did not exhibit zone of inhibition again the bacterial species tested. The maximum zone of inhibition obtained against *E. coli* (26 mm) followed by *S. aureus* (25 mm), *B. subtilis* (11 mm), and *P. aeruginosa* (8 mm) as shown in Fig. 5. The Zr nanoparticles showed the minimal zone of inhibition observed against *Bacillus subtilis*. The results indicated that the nanoparticles synthesized using plant sources would be highly toxic to microbes than other nanoparticles. Bacterial contamination at wound sites leads to several impairments including unbearable pain and delayed wound healing. The application of herbal extracts and their nanoparticles is fascinating

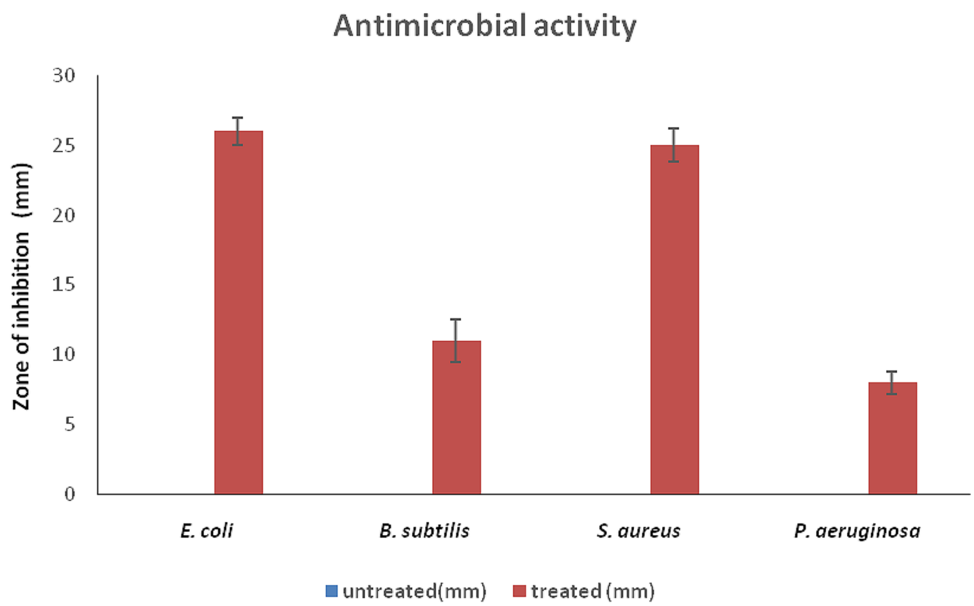

Fig. 5 Antimicrobial activity of cotton fabrics treated with and without Zr nanoparticles

in medical and textile fields for producing cotton fabrics. According to Gowtham et al. (Gowtham et al. 2019). *T. populnea* flower crude extract produced significant antimicrobial activity against pathogenic microbes than chemical drugs. Similarly, the present results found that the cotton fabrics treated with Zr nanoparticles established the highest antimicrobial activity, which would play a key role in wound dressings.

Conclusion

A complete safer and ecofriendly synthesis of zirconium nanoparticles has been achieved using *T. populnea* leaf extract. The synthesized zirconium nanoparticles were spherical and crystalline in nature with 10 nm in size. Green synthesized zirconium nanoparticles have also been analyzed for antimicrobial properties. The cotton gauze fabrics treated with the synthesized nanoparticles demonstrated a strong antimicrobial activity against both gram positive and Gram-negative bacteria. The outcome of this study could be useful for the development of value-added products from the indigenous medicinal plants for nanotechnology-based biomedical applications.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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