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Synthesis, characterization, and antibacterial potential of silver nanoparticles synthesized from *Coriandrum sativum* L.

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ABSTRACT

Introduction: Nanoparticles (NPs) have become very important owing to their various uses. In this research, an environmentally friendly biological technique was used to synthesize silver nanoparticles with *Coriandrum sativum* L. The objective of this research to use the source for the fabrication of silver NPs from *C. sativum* L., and to check the activity of the fabricated silver NPs was determined versus a couple of gram negative and a couple of gram positive bacteria in the presence of antibiotic viz. gentamicin to judge their impact.

Methodology: A silver nitrate solution, which served as the reducing and capping agent, was mingled with coriander leaf extract. The solution's temperature and pH were maintained at 75 °C and 8.6, respectively. The observed mean particle size (z-average) and polydispersity index were 390.2 nm and 0.452, respectively. The synthesized Ag NPs were characterized using different techniques, including scanning electron microscopy (SEM), X-ray diffraction, and Fourier transmission infrared (FTIR) analysis. The globular shape of the silver nanoparticles was depicted in SEM illustrations.

Results: XRD data revealed the mean size of the particles was 11.9 nm. The FTIR analysis showed the existence of various functional groups, including C═O and O—H. When their antibacterial ability was tested, it was found that the fabricated Ag NPs inhibited *Bacillus subtilis*, *Pasteurella multocida*, *Enterobacter aerogenes*, and *Staphylococcus aureus*, with a greater effect against *B. subtilis* and *P. multocida* compared to *E. aerogenes* and *S. aureus*.

Conclusion: It has been concluded small silver NPs benefited from a higher surface area ratio, as shown by the results of experiments where smaller particles had a better bactericidal proficiency than large silver-based NPs. Silver-based NPs infiltrate bacterial cells, as well as interfere with their exterior membrane. Silver ions also have the potential to interact with bacterial DNA, inhibiting the reproductive system of the cell.

Introduction

Nanotechnology is considered an interdisciplinary field of study [1] and basically deals with the formation and use of materials having nanoscale dimensions [2]. Nowadays, research on nanoparticles (NPs) is of immense significance not just because of their uses, but because of their different methods of formulation [3]. Particles with a size in the range of 1–100 nm are considered NPs [4]. The proper characterization of NPs is very important because it is performed to access their porosity, surface area, size distribution, pore size, solubility, orientation, zeta potential, aggregation, crystallinity, adsorption potential, shape, dispersion, and intercalation [5]. Superior properties are also shown by NPs with specific attributes such as distribution, size, and morphology. Nanotechnology is a very useful methodology in molecular biology, and can be used for diagnostics, biosensors, tissue generation, cell culture, and targeted drug therapy [6]. NPs are more reactive than larger particles of the same material because of the important role

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played by the surface area to volume ratio [7]. The preparation of Ag NPs using various physical and chemical methods has been thoroughly studied. In the field of nanotechnology, the most important step is the fabrication of a study methodology to manufacture NPs [1]. The chemicals used in the production of NPs are hazardous and cause acute complications. To reduce the toxic effects of these chemicals, there is an increasing demand for biological approaches because these are free of toxic chemicals. Thus, the interest in green nanotechnology is increasing day by day [8]. Plants and microorganisms such as fungi and bacteria have been used for the green synthesis of silver NPs [9]. NPs prepared from plants are preferred because they are ecofriendly, produced using a one-step procedure, cost less, and protect personnel from health concerns [10]. Various plant components such as the exocarp of fruit [11], callus [12], roots [13], essence [14], and fruit [15] have been evaluated for manufacturing gold, silver, titanium, and platinum NPs in different sizes [3]. Plant extracts contain reducing and antioxidant properties that have been shown to cause the formation of the respective NPs by reducing metal salts [16]. In the manufacture of NPs, temperature is considered to be the most important factor affecting this process. Based on this idea, particles with a size range of 5–300 nm and polydisperse particles were acquired using a low temperature, whereas small ball-shaped particles were derived at a high temperature [17]. The impact of pH has also been examined in relation to the solidity of biofunctionalized Ag NPs. Silver metal has an immense hindering effect on microorganisms such as many bacterial and fungal strains, which are commonly found on industrial and medical implements, where it acts as an antimicrobial agent [18]. Silver NPs have shown anti-inflammatory [19], antifungal [20], and antiviral properties [21]. Because silver NPs show antimicrobial properties, they are receiving much attention [22]. It has been estimated that they will be regarded as an antimicrobial agent group in the future [23]. Silver metal-based NPs possess exceptional bacterial activity against both gram-positive and -negative bacteria, including manifold resistant strains of bacteria [24]. *Coriandrum. sativum* L. is also known as cilantro. It is a Chinese plant that is also called dhania and is an herb that is grown annually. It belongs to the Apiaceae family [25]. As a flavoring agent, it is generally used in traditional medicine and is also utilized in food production and clinics [26]. It is a smooth plant that can attain a height of 50 cm and bears no hair. However, the leaves do not have uniform physical appearance. The genus name is from the Greek word koris, which means bedbug, because its odor is thought to be similar to that of bedbugs [27]. The distinguishing characteristics of coriander include its curative features, with it being used in stimulant, stomachic, fungicidal, antispasmodic, carminative, and digestive treatments. Coriander also helps to soothe the nerves, cure stress, alleviate worry, and treat headaches of the mind, anorexia, sleeplessness, and paroxysm [28]. Oil of coriander has a broad spectrum antimicrobial action, which allows it to be used as an antimicrobial agent [29]. The specific mechanism for the antimicrobial activity of silver NPs is being given much attention, but has not yet been precisely identified. Despite this fact, various facts about the antibacterial activity of silver NPs in relation to microbes have been revealed. Silver NPs have the capacity to grip the bacterial cell wall and can enter into it, where they change the structural components of the cell membrane and cause bacterial death. Bumps appear on the cell surface, and the NPs accumulate [20].

In this research, the source used for the fabrication of silver NPs was *C. sativum* L., and the activity of the fabricated silver NPs was determined versus a couple of gram negative and a couple of gram positive bacteria in the presence of antibiotic viz. gentamicin to judge their impact.

Materials and method

Gathering plant material

Healthy leaves of *C. sativum* L., which from a medicinal perspective means free from disease, were obtained from a regional store.

Formation of extract

A total of 30 g of leaves were cleaned in distilled water, dried in a shady area, and well-ground to obtain a powdery form. Until used for extraction, the prepared sample was preserved in polythene bags. The powdered leaf (10 g) was mixed with deionized water (100 ml) and heated at 75 °C for 20 min. The leaf extract was filtered using the customary method of filtration with filter paper from Whatman [17]. This prepared solution was preserved for future use in a freezer [30,31].

Synthesis of silver NPs

A 1 mM solution of silver nitrate (80 ml) was added to 20 ml of the leaf extract by applying the protocol of [32]. A stirring hot platter was used to raise the temperature of the solution for 25 min at 75 °C [33]. A change in color from yellow to brown specified the production of silver NPs. Sonication of the solution was performed for 1 h at 60 °C, and then the synthesized NPs were collected through centrifugation.

Formation of silver NPs

Zeta sizer

The zeta size was used to observe the development of the silver element. A zeta size analyzer was used to determine the morphology based on the polydispersity index (PI), zeta potential, and average particle size (z-average) of the Ag NPs (Nano ZS 90, Malvern Instruments).

Characterization of silver NPs

The following techniques were applied to characterize the synthesized silver NPs.

Zeta potential analysis

The value of the zeta potential was used to determine the solidity of the particles. A negative value clearly showed the suitability of the NPs and protected against their aggregation [34].

FTIR

The functional group was determined using Fourier transform infrared spectroscopy [35].

SEM

The morphological features of the silver NPs synthesized from the coriander extract were quickly calculated using SEM with a voltage of 20–25 KV.

XRD

The features and size of the manufactured silver NPs were determined using the XRD (PAN analytical)

Antibacterial assay

The disc diffusion/Kirby–Bauer method [36] was used to analyze the antimicrobial vulnerability of the silver NPs with two gram positive bacteria, in addition to two gram negative bacteria, using various quantities of silver NPs manufactured from coriander extract. All of the varieties were collected from the Microbiology

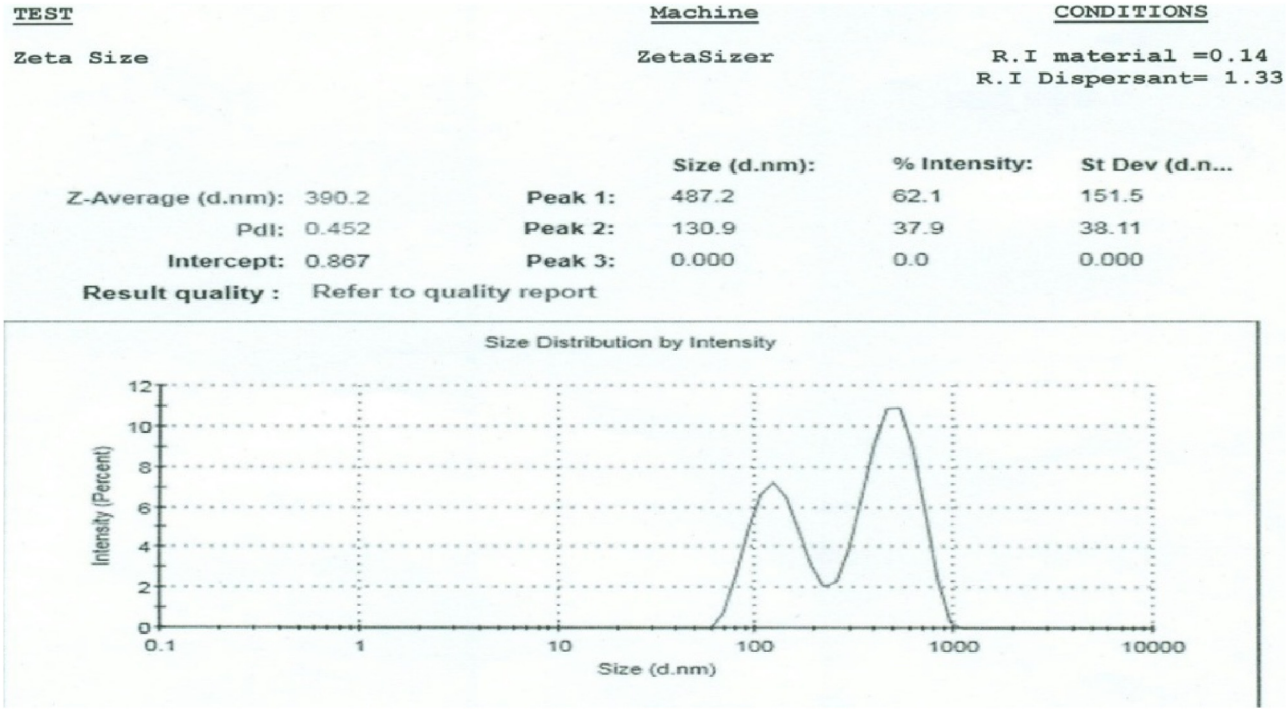

Fig. 1. Zeta analysis results for silver NPs.

Laboratory. The varieties were satisfactorily sub-cultured on agar base plates for 24 h prior to being used for the antibacterial analyses. The outer layer was repeatedly washed with 0.01 ml of the solution and then dried for 5 min at normal temperature, after which the medium was applied to antigerm discs of 6 mm thick Whatman filter paper.

After the addition of various amounts of fabricated silver NPs, the growth hindrance effect was examined after being at normal room temperature for 20 min. Then, the temperature of petri-plates was maintained at 37 °C for 1 day, and the inhibited area (IZD) was magnified.

Results

Synthesis of silver NPs

The silver NPs were a brown color in solution because of the apparent excitation of the plasmon resonance. When the extract was added to an aqueous mixture of the silver complex, a color change from yellowish to brown was observed. Silver NPs were produced upon the reduction of the silver ions.

Characterization of silver NPs

Zeta sizer

The mean diameter of the mixture with the polydispersity property was calculated using the zeta sizer. The findings revealed two peaks at 487.5 nm and 130.9 nm. Conversely, 390.2 nm was the optimum size for the silver based NPs. The observed poly dispersibility index (PDI) was 0.452, with an interception of 0.867 (Figs. 1 and 2).

Zeta potential

The firmness of the silver-based NPs was detected using the zeta potential and found to be −18.6 mV (Figs. 1 and 2). The negative value showed the ability of the silver biomolecules to hinder NP aggregation

FTIR

An FTIR analysis was performed to identify the existence of particles for enveloping, as well as the effectual steadiness of the manufactured metallic NPs. The FTIR analysis of the silver NPs showed the presence of a peak at 3275.64 cm^{-1}, which agreed with that for H-bonded phenols, alcohols, and O—H stretching vibration. The peak found at 1632.43 cm^{-1} showed C═O, with carbonyl extension and -NHCO for protein extensions (Fig. 3). That at 2919.43 cm^{-1} indicated the C—H extension and extension of alkanes with the C—H connection. The existence of C—C showed CH_3 stretching, which occurred at 1398.12 cm^{-1}. The presence of C—O and amine vibrations was revealed by the peak at 1237.86 cm^{-1}, and the peak at 1031.18 cm^{-1} indicated the existence of anhydrides, ethers, and the carboxylic group. The NPs were attached to metabolite terpenoids and protein, forming advantageous clumps, i.e., they enveloped of NPs to prohibit aggregation and therefore reduce the risk.

SEM analysis

The surface features of the manufactured silver NPs were determined using SEM. The result indicated that the fabricated silver NPs had a ball shape (Fig. 4).

XRD

The XRD results showed that the (100) plane of the cubic face-centered silver had different peaks at approximately 38°. In the 2θ spectrum, three high pitched peaks formed with different values fluctuating from 10° to 70°. A comparison of the XRD results with the literature showed that the synthesized silver NPs had a crystalline assemblage, as signified by the peaks at 2θ of 32.775, 44.455, and 52.185 for the (101), (111), and (200) planes of silver, respectively. Moreover, other peaks were also found at 26.774 and 46.2 (Table 1a; Fig. 5).

Scherrer's equation was applied to determine the size of the crystalline NPs from the X-ray enlargement (Table 1b).

In the final appraisal, k was found to be 0.89. The FWHM values were calculated for the (101), (111), and (200) planes to investigate the size of the silver NPs.

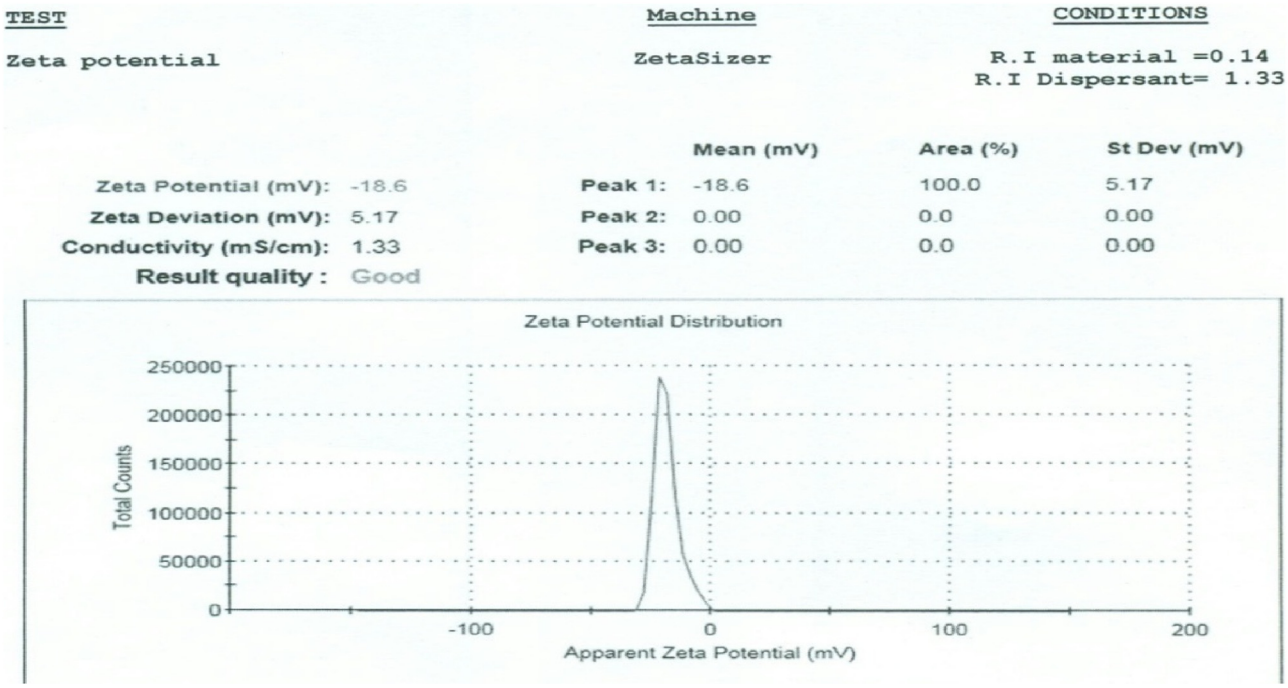

Fig. 2. Zeta potential of silver NPs.

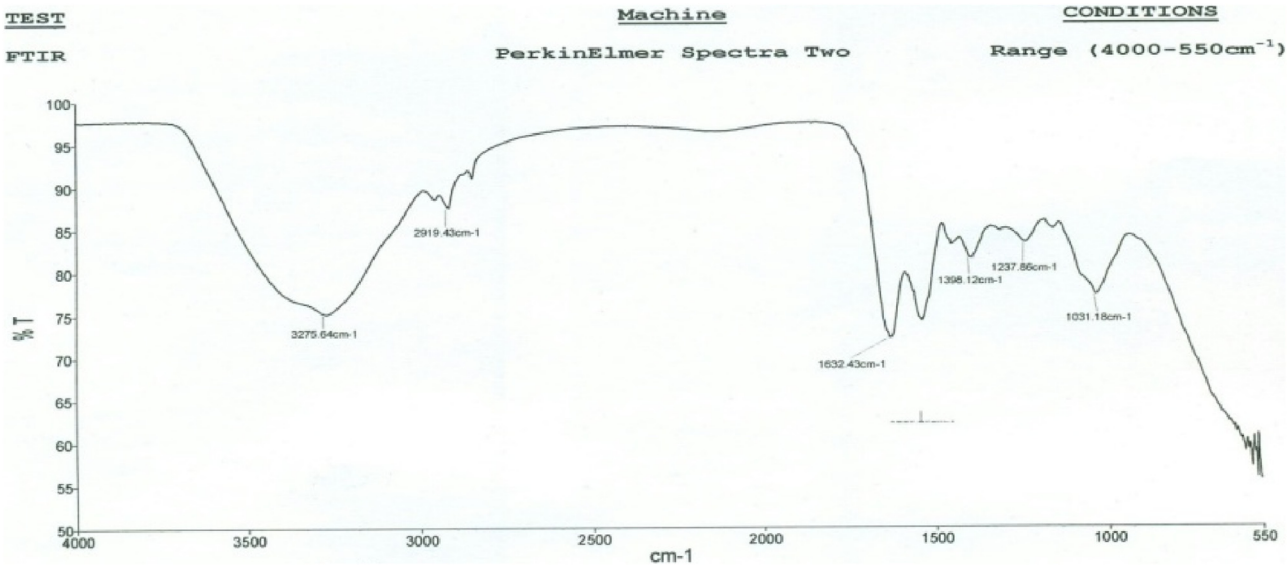

Fig. 3. FTIR results for silver NPs.

Table 1a
Formation of different peaks.

2θ	Intensity	h k l
32.775	95.522	101
44.455	151.097	111
52.185	122.783	200

Table 1b
Average crystallite size by Scherrer's formula.

Size from (101) peaks	Size from (111) peaks	Size from (200) peaks	Average crystalline size (nm)
12.6	15.0	8.2	11.9

The nanoparticle size was investigated using the peaks for the 101, 111, and 200 planes, and values of 12.6 nm, 15.0 nm, and 8.2 nm were found, respectively. The mean size of the fabricated silver NPs was 11.9 nm.

Antibacterial activity

Silver-based NPs synthesized by a green method are of immense importance because of their characteristic antimicrobial effectiveness. The *C. sativum* L. plant has curative properties. In order to obtain satisfactory results, each bacterial growth and viability test was performed three times. The diameter of the inhibition zone was evaluated using various concentrations of NPs (Table 2).

The micro-organism retardation process had the following mechanism. As the silver NPs became attached to the negatively charged exterior of the cell surface, they altered the chemical

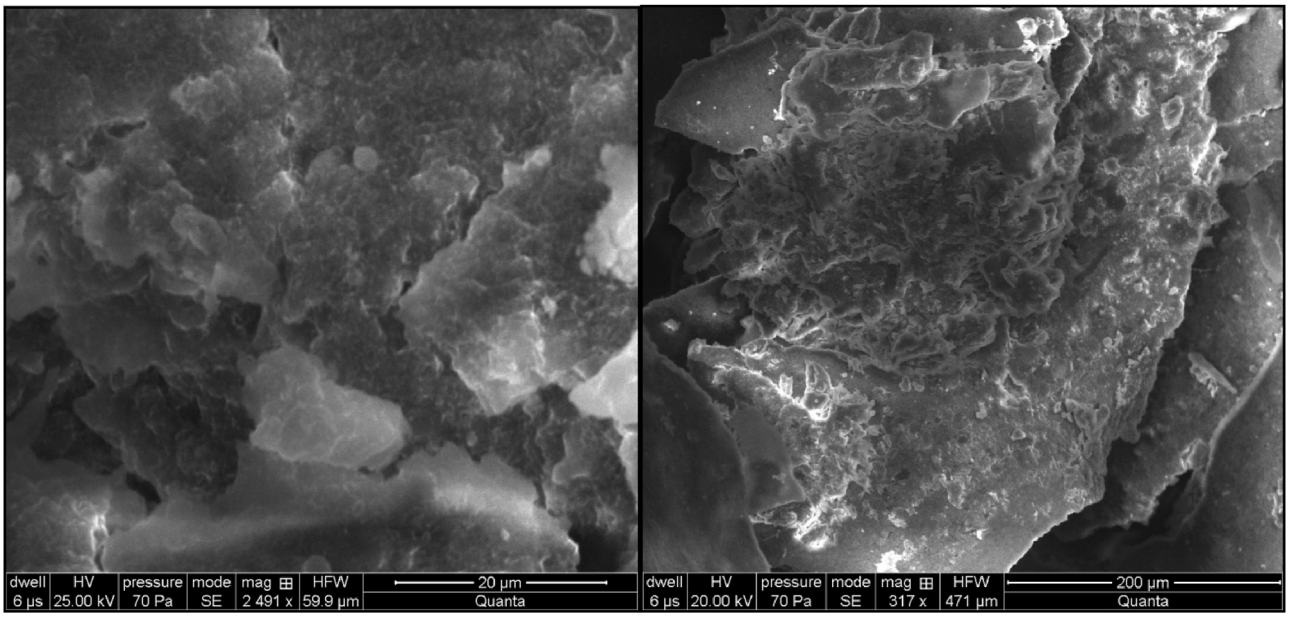

Fig. 4. SEM micrograph of silver-based NPs (1 mM concentration) prepared using extract of *Coriandrum sativum* L. at high field width(HFW) and high vacuum (HV) with SE mode.

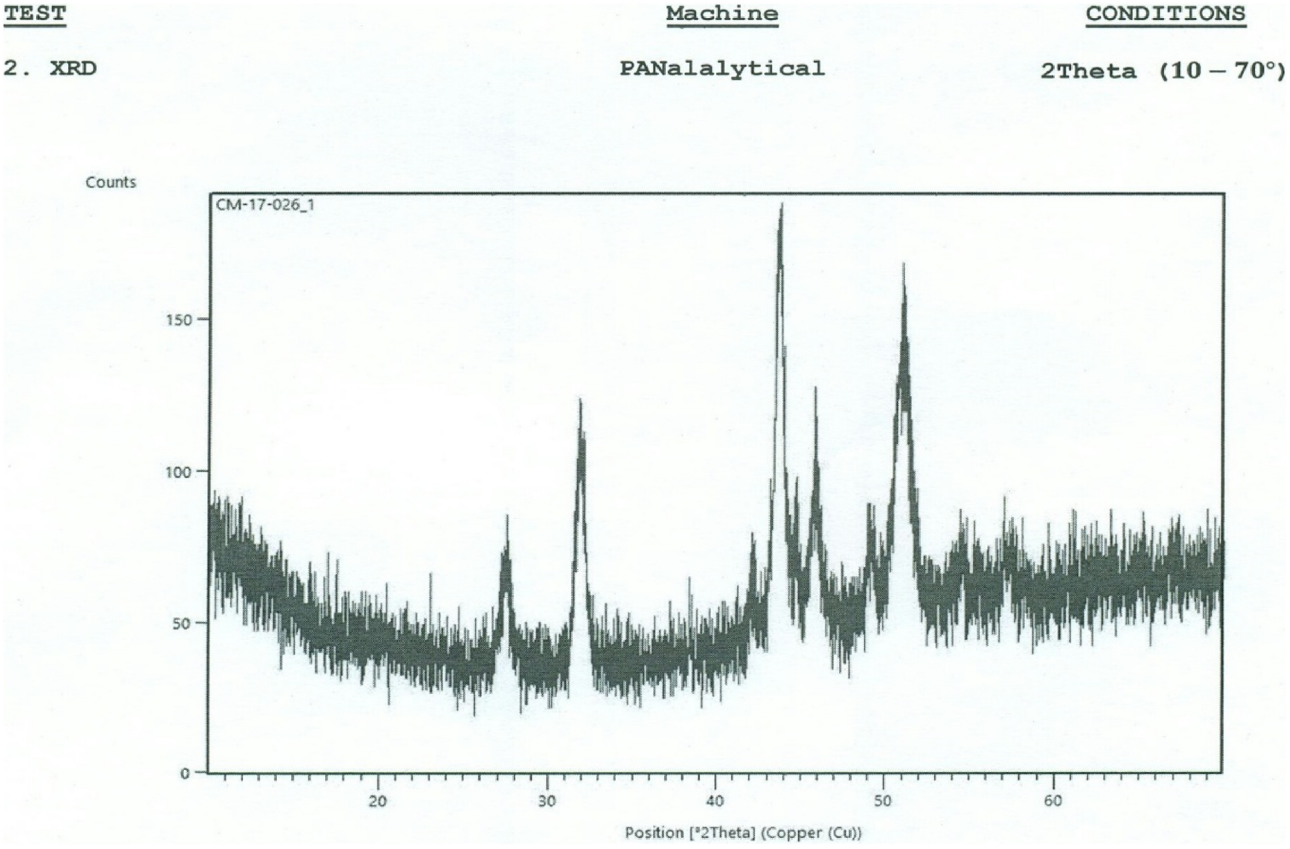

Fig. 5. XRD pattern of Ag NPs at position 2 theta.

Table 2
Inhibition zone (mm).

Bacteria	Gentamicin	50 µL	100 L	150 uL	200 uL
Pasteurella multocida	13	8	8	9	10
Enterobacter aerogenes	18	8	10	11	11
Staphylococcus aureus	13	8	9	11	12
Bacillus subtilis	0	9	11	13	14

and shape characteristics of the cell wall and plasmalemma and terminated functions like permeability, electron transport, and respiration. Bacterial cells were destroyed by the silver NPs as these particles penetrated into them. Once they entered a cell, they interacted with its DNA, phosphorus, and a few proteins. Silver ions were released by the silver NPs, which resulted in reactive oxygen species. *Bacillus subtilis* and *Pasteurella multocida* showed larger

hindrance zones than *Enterobacter aerogenes* and *Staphylococcus aureus* (Table 2). A larger hindrance zone indicated a greater potential for the silver NPs to kill the bacterial organisms. However, no hindrance was indicated in the control test.

Discussion

In this research, we found that *Coriander sativum* could be used as an important source for the synthesis of silver NPs [37]. The silver NPs were fabricated following the procedure reported by [34]. The silver NPs were observed to be brownish in color in solution because of the mobilization of surface plasmons within the NPs [38] a change in the color of the solution was the first indication of the synthesis of these particles, as previously reported [39]. The extensive uses of silver-based NPs have prompted scientists to use them when studying surface-enhanced Raman scattering and antigens [40,41]. The zeta sizer, zeta potential, SEM, XRD, and FTIR results helped in the characterization of these particles [46]. The zeta sizer and mean size measurement results resembled those reported by [42]. The consequences of zeta potential were consistent with those of the silver NPs produced from the leaf extract of *F. religiosa* [43]. The FTIR results indicated various peaks, including those at 3275.64 cm^{-1} related to the O—H extension of the H-bonded phenols and alcohols; 2919.43 cm^{-1} for the extension of the C—H bond with alkanes vibration and aldehyde C—H stretching; 1632.43 cm^{-1} related to C═O with carbonyl stretching and the existence of Amide-1 (-NHCO of amide), where the proteins are bent; 1398.12 cm^{-1} related to the presence of C—C, in which CH3 bending occurred; and 1237.86 cm^{-1} related to the occurrence of C—O for the functionally groups [44]. The XRD investigation confirmed the peaks at 32°, 44°, and 52°. The XRD data indicated that the size of the silver NPs was 11.9 nm [44]. The results of tests showed that significant concentrations of microorganisms were killed by the action of the silver-based NPs. In addition, a smaller amount of silver-based NPs could also hinder the growth of micro-organisms, which resulted in killing a small little concentration of bacteria. However, *S. aureus* and *P. multocida* were more inhibited by the silver NPs than *E. aerogenes*, as has been shown in various studies. Small silver NPs benefited from a higher surface area ratio, as shown by the results of experiments where smaller particles had a better bactericidal proficiency than large silver-based NPs. Silver-based NPs infiltrate bacterial cells, as well as interfere with their exterior membrane. Silver ions also have the potential to interact with bacterial DNA, inhibiting the reproductive system of the cell [45].

Conclusion

It has been concluded small silver NPs benefited from a higher surface area ratio, as shown by the results of experiments where smaller particles had a better bactericidal proficiency than large silver-based NPs. Silver-based NPs infiltrate bacterial cells, as well as interfere with their exterior membrane. Silver ions also have the potential to interact with bacterial DNA, inhibiting the reproductive system of the cell.

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Competing interests

None declared.

Ethical approval

Not required.

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