Journal of Polymers and the Environment (2021) 29:2978–2985
https://doi.org/10.1007/s10924-021-02087-5

ORIGINAL PAPER

Green Synthesis and Investigation of Antibacterial Activity of Silver Nanoparticles Using *Eryngium bungei* Boiss Plant Extract

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Accepted: 1 February 2021 / Published online: 22 February 2021

Abstract

Metal nanoparticles synthesis using plant extracts and the study of their medicinal effects is a relatively new topic. Many chemical techniques have been proposed for the synthesis of silver nanoparticles (AgNPs), but green synthesis has a special place due to its clean and non-toxicity. *Eryngium bungei* Boiss plant was selected for this study due to its reducing properties and medicinal properties. The effect of various factors including concentration of silver nitrate, contact time and pH were investigated to reach optimum conditions. Silver nanoparticles were synthesized by the reaction between extract and silver nitrate after 20 min at room temperature and pH 12. The obtained nanoparticles were analyzed by XRD, UV–Vis, FESEM, EDX analysis to determine the crystals, morphology, identification of constituents, identification of unknown substances and particle distribution, respectively. The absorption of silver nanoparticles at 438 nm was measured using spectrophotometer machine. Particle size, morphology and antibacterial activity against standard strains of *Escherichia coli* (*E. coli*; ATCC® 25922™), *Klebsiella pneumoniae* (*K. pneumonia*; PTCC® 700603™) and *Staphylococcus aureus* (*S. aureus*; PTCC® 16538™) were investigated and the results showed that the synthesized silver nanoparticles have antibacterial properties. Due to the antibacterial results, biosynthesized silver nanoparticles enhanced antibacterial efficiency against *S. aureus*, *K. pneumonia* and *E. coli* bacteria with MIC value of 27.34, 27.34, 6.83 µg/ml and MBC value of 54.68, 109.3 and 13.67 µg/ml, respectively. The results of this study showed that the synthesis of silver nanoparticles can be performed using the extract of *Eryngium bungei* Boiss and the synthesized nanoparticles by this extract have effective antibacterial effects.

Keywords Green synthesis · Silver nanoparticles · *Eryngium bungei* Boiss · Antibacterial activity

Introduction

In the recent years, nanotechnology is growing rapidly and has far-reaching effects in various fields such as agriculture, medicine, pharmacology, environmental and industry [1–4]. In this regard, the use of nanoparticles whose size is in the range of 1 to 100 nm, due to their unique electrical, optical, mechanical and magnetic properties has received more attention in various areas such as environmental health, chemical industry, energy science, optics, electronics, biomedical and optical-electricity sciences [5–10]. The main methods of nanoparticle synthesis include physical, chemical and biological methods which physical and chemical methods have been less used due to high costs, high energy consumption, and use of toxic reducing agents and even production of toxic waste. Biological or green synthesis methods are more important due to their environmental compatibility and cost-effectiveness [11, 12]. Plant extracts, fungi and bacteria are the three main methods for synthesizing nanoparticles biologically [13–17]. It has been proven that there is an inverse relationship between particle size and surface to volume ratio of nanoparticles, so the surface energy of the nanoparticles and the catalytic reaction increase intermittently, causing the biological effect of the nanoparticles to increase proportionally [18].

In the green synthesis method, metal ions can be converted into nanoparticles using plant extracts. Plant extracts contain chemicals such as enzymes, retinoic acid, cyclic peptides, terpenoids, tannins, proteins, amino acids, polysaccharides, ascorbic acid, polyphenols and more. Polyphenols

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in plant extracts have antioxidant properties that play an important role in providing reducing and covering agents in the green synthesis of nanoparticles and also improve the performance of the nanoparticles [19, 20]. Also, due to the prevention of cell culture and extensive storage processes, the use of plants in green synthesis has received more attention than microorganisms [21]. Many studies have been conducted on the green synthesis using plant extracts and the use of metal nanoparticles such as Ag, Au, Zn, Fe and Cu which can be attributed to Suman's research on the green synthesis of gold nanoparticles using *Morinda citrifolia* extracts. In the mentioned study, gold nanoparticles were absorbed at 540 nm and the anti-diabetic effect of nanoparticles was investigated [22]. Also, the green synthesis of silver nanoparticles was performed using the extract of *Annona squamosa* plant by Vivek which the absorption of silver nanoparticles at 444 nm was measured using a UV spectrometer machine and the effect of these nanoparticles on MCF-7 human breast cancer cells has been investigated [23]. Various factors can affect the rate of synthesis and properties of nanoparticles, including plant extract concentration, metal concentration, pH, temperature and contact time [24].

Nowadays, noble colloidal metal nanoparticles such as silver, platinum and gold have received more attention due to their size, shape and tendency to accumulate. Among these, silver nanoparticles are more used due to their antimicrobial properties [25]. Silver can react with skin moisture and wound fluid and ionize, although its antibacterial properties depend on the amount of silver and the amount of silver released. Due to its high reactivity, silver ions can cause changes in the cell wall structure of bacteria and nuclear membranes and eventually lead to cell death [26]. In various studies, the antibacterial effects of silver nanoparticles have been studied, including the research of Nagsh et al. which hat the antibacterial effects of silver nanoparticles have been investigated using *Eucalyptus* plant extract. The effect of silver nanoparticles on *Escherichia coli* was examined at concentrations of 25, 50, 100, 200, 300, 400 and 500 mg/l and it was concluded that the most suitable concentration of silver nanoparticles for the growth inhibitory effect of *Escherichia coli* has been 25 mg/l [27]. Parthiban et al. also investigated the effect of silver nanoparticles on control of *Aedes aegypti* mosquito larvae population and found that a concentration of 20 µg/l of nanoparticles synthesized by *Annona reticulate* leaf extract could kill 100% of this larval population [28].

In the present study, the synthesis of silver nanoparticles was performed in a bio-friendly way without the use of harmful chemicals by methanolic extract of *Eryngium bungei* Boiss plant. This plant belongs to the Apiaceae family, which grows in most of the foothills of South Khorasan Province (Iran). This plant is rich in tannins, alkaloids, saponins and flavonoids. Various extracts of the genus *Eryngium* can have anti-inflammatory, anti-scorpion, anti-glycemic and anti-seizure effects [29]. *Eryngium bungei* Boiss has many properties including enhancing sexual power, digestion, treating flank, chest pain, treating inflammation, controlling blood sugar and crushing kidney stones. The leaves of this plant are also used to treat colds, asthma, cough, sinusitis and rheumatism. Therefore, this study was performed to investigate the antibacterial effect of silver nanoparticles synthesized by the extract of *Eryngium bungei* Boiss plant against Gram-positive and negative bacteria.

Materials and Methods

Materials

In the present study, silver nitrate for synthesis of nanoparticles and methanol (Merck Co. German) with 99.9% purity for preparation of plant extract was used. Also sodium hydroxide solution was used for pH adjustment. For antibacterial experiments, Mueller Hinton Broth and Mueller Hinton Agar (Merck Co. German) culture mediums were used.

Methanolic Plant Extract

In order to synthesize silver nanoparticles, *Eryngium bungei* Boiss plant was collected in spring from around the Birjand city (the capital of South Khorasan province, Iran) and transferred to laboratory. After rinsing with double distilled water, place at room temperature to dry. 20 g of dried *Eryngium bungei* Boiss was contacted with 400 ml of methanol for three days to prepare the extract. Then the obtained solution was passed from the Whatman paper No. 42 and a rotary apparatus was used to concentrate methanol and separate the extract.

Biosynthesis of Silver Nanoparticles

For synthesis of silver nanoparticles, 10 ml of extract with a concentration of 10 g/l was mixed with 10 ml of 15 mM silver nitrate ($AgNO_3$) solution and the sample was placed at room temperature for 20 min on a shaker at 200 rpm (Fig. 1). The color of mentioned solution changed to dark brown, which was a sign of the formation of silver nanoparticles ($Ag^+ \rightarrow Ag^0$) [30]. To optimize the concentration of silver nitrate, concentrations of 5, 10, 20 and 30 mM with 10 ml of *Eryngium bungei* Boiss plant extract were placed at constant temperature and pH for 20 min, respectively.Forevaluation of the optimum pH, 10 ml of silver nitrate solution with optimized concentration with 10 ml of *Eryngium bungei* Boiss plant extract was brought to the pH of 10, 12 and 14 using a solution of sodium hydroxide (2 N) and was tested for

Fig. 1 Synthesis of silver nanoparticles (Ag-NPs) by *Eryngium bungei* Boiss extract

20 min at a constant temperature. Optimally, 10 ml of silver nitrate solution with optimized concentration with 10 ml of *Eryngium bungei* Boiss plant extract was placed on the shaker at 5, 20, 60 and 120 min at a constant temperature and pH. Finally, the absorption spectrum was taken using a two-beam spectrophotometer machine for all samples in the range of 200 to 500 nm. To obtain the nanoparticle precipitate, the optimized solution was placed in a centrifuge at 20,000 rpm for 20 min. The precipitate was washed twice with distilled water and methanol to wash the nanoparticles thoroughly four times, and the supernatant was discarded. The precipitate was placed in an oven at 60 °C for 24 h.

Antibacterial Activity

In this research, antibacterial activity of synthesized silver nanoparticles against gram-positive bacteria such as *Staphylococcus aureus* (*S. aureus*; PTCC®16538™) and Gram-negative bacteria such as *Klebsiella pneumoniae* (*K. pneumoniae;* PTCC®700603™) and *Escherichia coli* (*E. coli*; ATCC®25922™) were determined. To prepare the 0.5 McFarland standards: some bacterial colonies were first removed after 24 h by sterile looping near the flame and then dissolved in Muller Hinton Broth medium and incubated at 37 °C for 2 h. 96-well micro plate was used to determine the minimum inhibitory concentration (MIC) by dilutionin liquid medium (Micro Broth dilution). All wells of the microplate were filled with 100 µl of Mueller–Hinton Broth including diverse concentrations of silver nanoparticles (200 µl) at ambient temperature. Then, 100 µl of microbial suspension with a concentration of 10^6 CFU/ml was added to each well. These biological experiments were performed in triplicate. MIC assay was determined visually as the lowest concentration without visible growth. To obtain the minimum bactericidal concentration of biosynthesized silver nanoparticles, we discharge 10 µl of the well that reported as MIC along with three higher wells (higher concentration) on the blood agar medium. At that concentration where no growth of bacteria was observed, we declare it as the minimum bactericidal concentration (MBC).

Results and Discussion

Determination of Nanoparticle Characterization

The following methods were used to determine the properties of synthesized silver nanoparticles:

UV–Vis Analysis

Results of the UV–Vis spectra analysis of green synthesized silver nanoparticles (colored solutions) are shown in Figs. 2, 3 and 4. Characteristic peaks originating from surface plasmon resonance of AgNPs solutions confirmed the preparation of silver nanoparticles (about 420 nm). Different parameters like pH (10, 12 and 14), $AgNO_3$ concentration (5, 10, 20, and 30 mM) and temperature (5, 20, 60, and 120 min) have significant effect on shape and size of products. So, the morphology and grain size of samples were optimized and observed by UV–Vis spectrum. The UV–Vis absorption spectra of the silver nanoparticles with various concentrations of silver nitrate solution of 5, 10, 20, and 30 mM are recorded and shown in Fig. 2. When the concentration of Ag solution increased (5 mM to 10 mM), the intensity of the SPR bands increased and the absorption band shifted

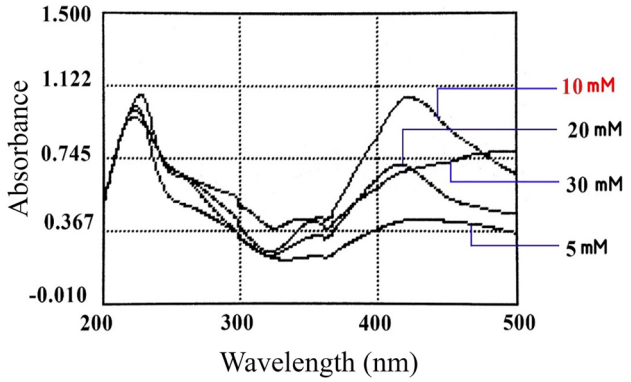

Fig. 2 UV–Vis absorption spectra of AgNPs: optimization of $AgNO_3$ concentration

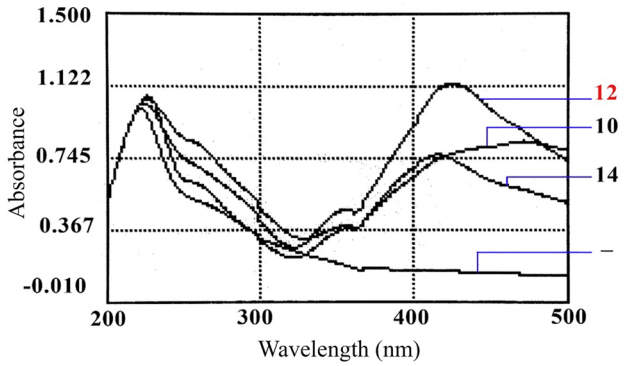

Fig. 3 UV–Vis absorption spectra of AgNPs: optimization of pH

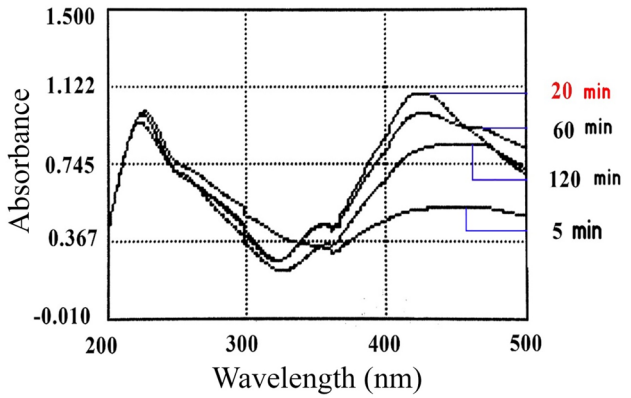

Fig. 4 UV–Vis absorption spectra of AgNPs: optimization of time (min)

to shorter wavelengths (blue shift). This displacement can be due to the small size of biosynthesized silver nanoparticles. In contrast, when molar concentration of silver solution increased to 30 mM, the intensity of SPR band decreased. This decline could be owing to aggregation of synthesized nanoparticles [31, 32]. Past studies have shown that hat SPR bands intensity and reaction solution color were pH-dependent. Figure 3 illustrates the influence of pH on the absorption spectra of green synthesized silver nanoparticles. The SPR band intensity improved with increasing of pH from 10 to 12. Due to the UV–Vis results, the optimum pH reaction condition was pH 12. At this pH, low aggregation and small size were features of green synthesized silver nanoparticles. As the pH increased (to pH 14), the intensity of the adsorption band decreased, which could be due to the accumulation of particles. The reaction among silver ion and *Eryngium bungei* Boiss extract as capping, reducingand stabilizing agents was followed at various times (5, 20, 60 and 120 min). Figure 4 illustrates the UV–Vis spectra of synthesized silver nanoparticles after different reaction times. The UV–Vis absorption spectrum recorded (after 60 and 120 min) illustrated a sharp decrease in the SPR absorption which indicating the silver nanoparticles synthesis reaction tended towards aggregation. So, best time for the synthesis of silver nanoparticles being 20 min. As the results showed, the size and aggregation of the synthesized nanoparticles were reduced (from 5 to 20 min).

X-ray Diffraction (XRD)

XRD is a method of studying the structure of crystalline materials. X-ray diffraction (Philips X'pert PRO, The Netherlands) was used for fuzzy analysis and to study the grain size and nanomaterials. This technique can be performed by processing and analyzing the reflected X-ray from the sample surface. The diffraction peaks related to the (111), (200), (220) and (311) crystallographic planes that are relevant to 2θ values of 38.3°, 44.7°, 64.4° and 77.2°, respectively (Fig. 5). This illustrates that the biosynthesized AgNPs are faced centered cubic in nature. Three extra weak peaks at $2\theta = 28.18°$, 32.24° and 46.57° were recognized to AgCl impurity as depicted at the diagram. These impurities were related to the presence of chlorine ions in the solution, which reacted with silver nitrate, leading to the formation of silver chloride precipitate. Our result was in agreement with previous studies [33].

Energy Dispersive X-ray spectroscopy (EDS)

The elemental analysis (EDS) recorded from the synthesized silver nanoparticles in presence of *Eryngium bungei* Boiss are shown in Fig. 6. The energy dispersive X-ray spectroscopy analysis illustrates a strong silver signal along (3 keV) with weak oxygen and carbon peaks. O and C are most likely associated with the organic compounds from the *Eryngium bungei* Boiss extract absorbed on the surface of silver nanoparticles.

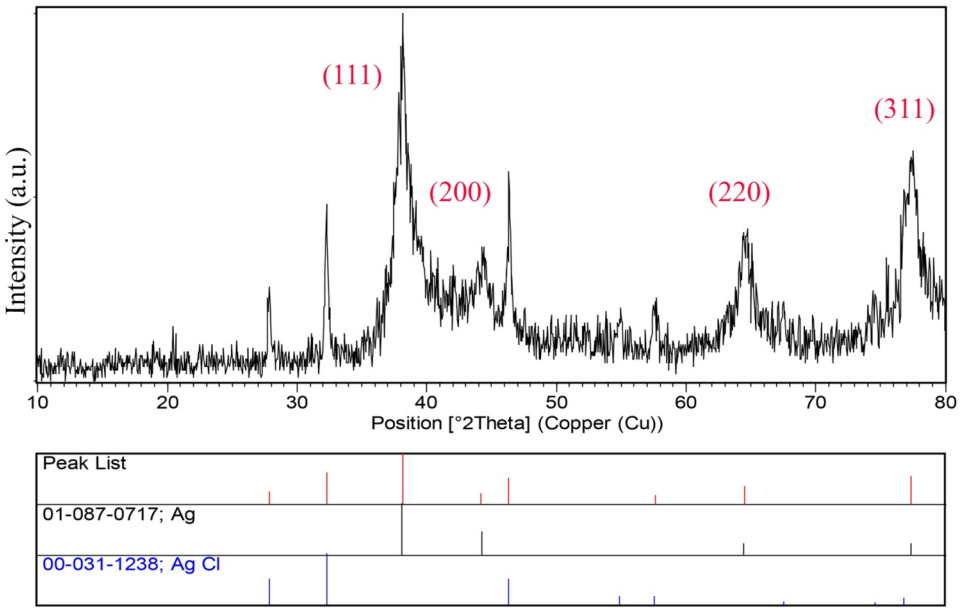

Fig. 5 XRD pattern of biosynthesized silver nanoparticles

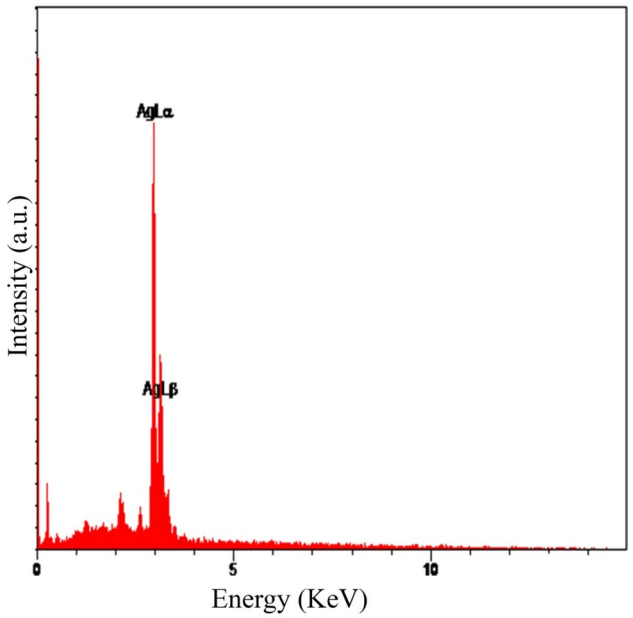

Fig. 6 EDS spectrum of AgNPs from *Eryngium bungei* Boiss extract

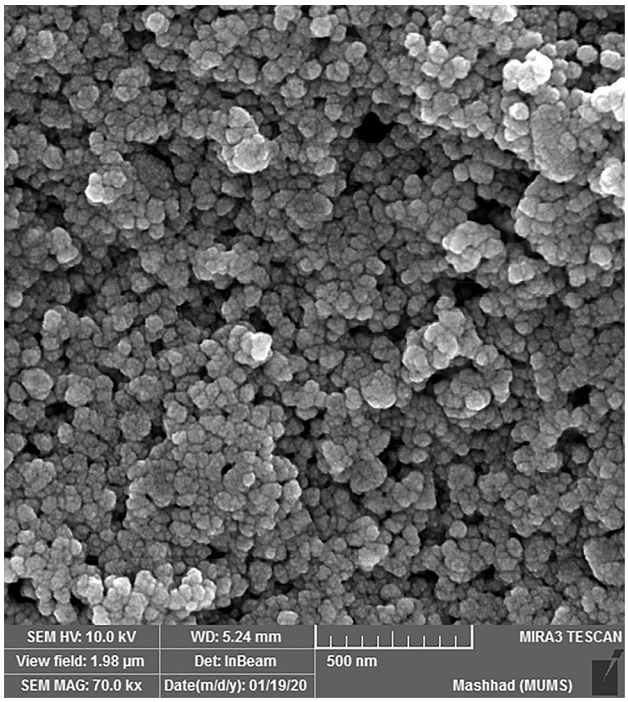

Fig. 7 Surface morphology of synthesized silver nanoparticle from the aerial extracts of *Eryngium bungei* Boiss

Field Emission Scanning Electron Microscopy (FESEM)

The grain size and morphology of the green synthesized silver nanoparticles in presence of natural extract was performed by FESEM technique (operated at 10.0 kV; JSM 6380 A Jeol, Japan). The FESEM results of the biosynthesized silver nanoparticles are shown in Fig. 7. The image obtained by the SEM demonstrated oval-like and spherical-like shape of silver nanoparticles from aerial extracts of *Eryngium bungei* Boiss being applied as stabilizing, capping and reducing agents. In the present study, the particles size of the as-obtained silver nanoparticles was found to be in the range of 60–80 nm.

Antibacterial Activity

In present study three series of ATCC strains including Gram positive and Gram negative bacteria were selected to

Table 1 Results of MIC and MBC of bacteria for silver nanoparticles synthesized from *Eryngium bungei* Boiss extract

Bacteria	MIC $\left(\frac{\mu g}{ml}\right)$	MBC $\left(\frac{\mu g}{ml}\right)$
Escherichi coli	6.83	13.67
Klebsiella pneumoniae	27.34	109.3
Staphylococcus aureus	27.34	54.68

examining their susceptibility against synthesized AgNPs (Table 1). The biosynthesized silver nanoparticles from *Eryngium bungei* Boiss extract were analyzed for antibacterial activity against *S. aureus, K. pneumoniae* and *E. coli* strains. In continue of work, MIC three bacterial for ATCC strains with broth dilution method was determined. The antibacterial activity of AgNPs has demonstrated that as the concentration of AgNPs was increased the MIC for strains of bacteria decreased parallel. The study showed that high antibacterial activity was revealed against ATCC strains at very low concentration of AgNPs (in µg/ml). The antibacterial effects of the extract which tested separately no significant inhibition of this extract and consequently the bacterial growth has occurred in all wells. The MIC and MBC values in this research are listed in Table 1. The greater antibacterial activity could be due to the amount of silver. The results of antibacterial activity showed that higher antibacterial activity was revealed against *E. coli* with MIC value of 6.83 µg/ml, while intermediated antibacterial activity was observed against *S. aureus, K. pneumoniae* with MIC values of 27.34 and 27.34 µg/ml, respectively. In addition, minimum bactericidal concentration values for *S. aureus, K. pneumoniae* and *E. coli* were 54.68, 109.3 and 13.67 µg/ml, respectively (Fig. 8). In our opinion, the possible mechanism for killing bacteria can be as follows: In the first stage, silver ions enter the bacterial cell (via cell wall destruction). In the next step, the DNA is converted to a concentrated form which in turn prevents DNA replication. This process finally leads to cell death.

Conclusion

In this research, a eco-friendly and inexpensive method for green synthesis of silver nanoparticles using *Eryngium bungei* Boiss extract as reducing and capping agents were carried out. The nature of biosynthesized silver nanoparticles was characterized with various techniques including FESEM, XRD, EDS and UV/Vis. FESEM image showed the formation of silver nanoparticles with a mean diameter of 60–80 nm. Biosynthesized AgNPs illustrated high antibacterial activity against *E. coli*, *S. aureus* and *K. pneumoniae* microorganisms with MIC vales of 6.83, 27.34 and 27.34 µg/ml, respectively.

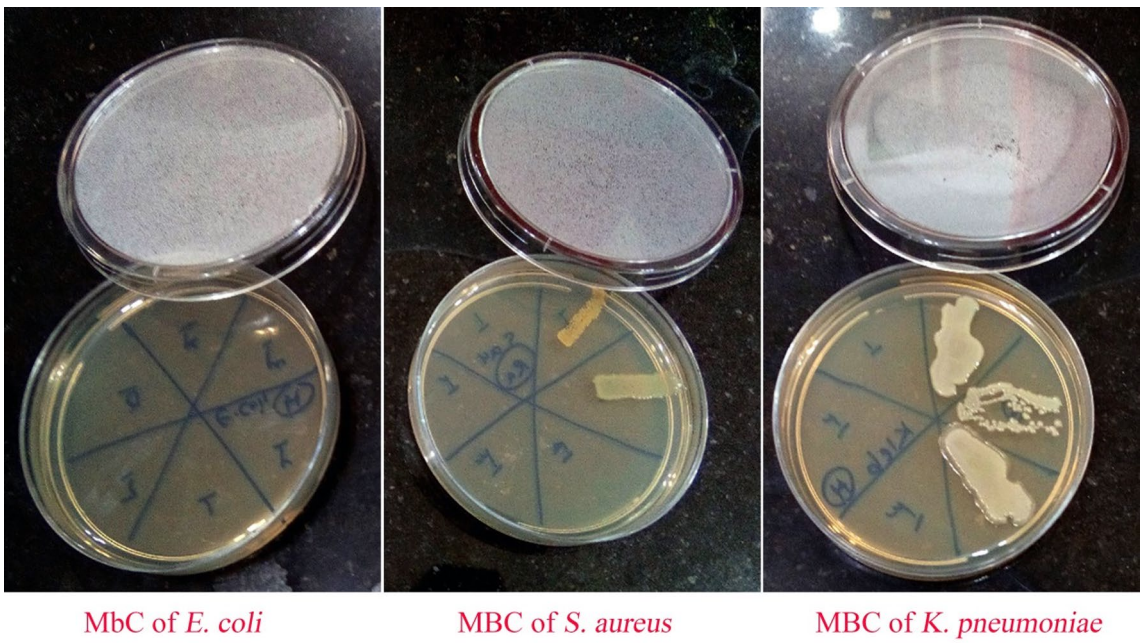

Fig. 8 Photographs of MBC tests of various bacteria

Acknowledgements In this investigation, the entire procedures were conducted according to the Helsinki Declaration and ethical standards of the institutional research committee. The ethics code was taken from Birjand University of Medical Sciences (Grant No. IR.BUMS.REC.1399.205).

References

1. Sinsinwar S, Sarkar MK, Suriya KR, Nithyanand P, Vadivel V (2018) Use of agricultural waste (coconut shell) for the synthesis of silver nanoparticles and evaluation of their antibacterial activity against selected human pathogens. Microb Pathog 124:30–37
2. Mohammadi-Aghdam S, Valinezhad-Saghezi B, Mortazavi Y, Qhoreishi SM (2018) Modified Fe_3O_4/HAP magnetically nanoparticles as the carrier for ibuprofen: adsorption and release study. Drug Res 69:93–99
3. Mohammadzadeh P, Ardestani MS, Mortazavi-Derazkola S, Bitarafan-Rajabi A, Ghoreishi SM (2019) PEG-citrate dendrimer second generation: is this a good carrier for imaging agents in vitro and in vivo? IET Nanobiotechnol 13:560–564
4. Ardestani MS, Bitarafan-Rajabi A, Mohammadzadeh P, Mortazavi-Derazkola S, Sabzevari O, Azar AD, Kazemi S, Hosseini SR, Ghoreishi SM (2020) Synthesis and characterization of novel 99mTc-DGC nano-complexes for improvement of heart diagnostic. Bioorg Chem 96:103572
5. Femi-Adepoju AG, Dada AO, Otun KO, Adepoju AO, Fatoba OP (2019) Green synthesis of silver nanoparticles using terrestrial fern (Gleichenia Pectinata (Willd) C. Presl.): characterization and antimicrobial studies. Heliyon 5:e01543
6. Ebrahimzadeh MA, Naghizadeh A, Amiri O, Shirzadi-Ahodashti M, Mortazavi-Derazkola S (2020) Green and facile synthesis of Ag nanoparticles using *Crataegus pentagyna* fruit extract (CP-AgNPs) for organic pollution dyes degradation and antibacterial application. Bioorg Chem 94:103425
7. Khojasteh H, Safajou H, Mortazavi-Derazkola S, Salavati-Niasari M, Heydaryan K, Yazdani M (2019) Economic procedure for facile and eco-friendly reduction of graphene oxide by plant extracts; a comparison and property investigation. J Cleaner Prod 229:1139–1147
8. Jorge de Souza TA, Rosa Souza LR, Franchi LP (2019) Silver nanoparticles: an integrated view of green synthesis methods, transformation in the environment, and toxicity. Ecotoxicol Environ Saf 171:691–700
9. Orooji Y, Mortazavi-Derazkola S, Ghoreishi SM, Amiri M, Salavati-Niasari M (2020) Mesopourous Fe_3O_4@SiO_2-hydroxyapatite nanocomposite: green sonochemical synthesis using strawberry fruit extract as a capping agent, characterization and their application in sulfasalazine delivery and cytotoxicity. J Hazard Mater 400:123140
10. Ebrahimzadeh MA, Mortazavi-Derazkola S, Zazouli MA (2020) Eco-friendly green synthesis of novel magnetic Fe_3O_4/SiO_2/ZnO-Pr_6O_{11} nanocomposites for photocatalytic degradation of organic pollutant. J Rare Earths 38:13–20
11. Roy P, Das B, Mohanty A, Mohapatra S (2017) Green synthesis of silver nanoparticles using *Azadirachta indica* leaf extract and its antimicrobial study. Appl Nanosci 7:843–850
12. Girón-Vázquez NG, Gómez-Gutiérrez CM, Soto-Robles CA, Nava O, Lugo-Medina E, Castrejón-Sánchez VH, Vilchis-Nestor AR, Luque PA (2019) Study of the effect of *Persea americana* seed in the green synthesis of silver nanoparticles and their antimicrobial properties. Results Phys 13:102142
13. Mathur P, Saini S, Paul E, Sharma C, Mehtani P (2021) Endophytic fungi mediated synthesis of iron nanoparticles: characterization and application in methylene blue decolorization. Curr Res Green Sustain Chem 4:100053
14. Ameen F, AlYahya S, Govarthanan M, Aljahdali N, Al-Enazi N, Alsamhary K, Alshehri WA, Alwakeel SS, Alharbi SA (2020) Soil bacteria *Cupriavidus* sp. mediates the extracellular synthesis of antibacterial silver nanoparticles. J Mol Struct 1202:127233
15. Ebrahimzadeh MA, Mortazavi-Derazkola S, Zazouli MA (2019) Eco-friendly green synthesis and characterization of novel Fe_3O_4/SiO_2/Cu_2O–Ag nanocomposites using *Crataegus pentagyna* fruit extract for photocatalytic degradation of organic contaminants. J Mater Sci 30:10994–11004
16. Ebrahimzadeh MA, Naghizadeh A, Mohammadi-Aghdam S, Khojasteh H, Ghoreishi SM, Mortazavi-Derazkola S (2020) Enhanced catalytic and antibacterial efficiency of biosynthesized *Convolvulus fruticosus* extract capped gold nanoparticles (CFE@AuNPs). J Photochem Photobiol 209:111949
17. Mortazavi-Derazkola S, Ebrahimzadeh MA, Amiri O, Goli HR, Rafiei A, Kardan M, Salavati-Niasari M (2020) Facile green synthesis and characterization of *Crataegus microphylla* extract-capped silver nanoparticles (CME@Ag-NPs) and its potential antibacterial and anticancer activities against AGS and MCF-7 human cancer cells. J Alloys Compd 820:153186
18. Padalia H, Moteriya P, Chanda S (2015) Green synthesis of silver nanoparticles from marigold flower and its synergistic antimicrobial potential. Arab J Chem 8:732–741
19. Ezealisiji KM, Noundou XS, Ukwueze SE (2017) Green synthesis and characterization of monodispersed silver nanoparticles using root bark aqueous extract of *Annona muricata* Linn and their antimicrobial activity. Appl Nanosci 7:905–911
20. Alharbi FA, Alarfaj AA (2020) Green synthesis of silver nanoparticles from *Neurada procumbens* and its antibacterial activity against multi-drug resistant microbial pathogens. J King Saud Univ Sci 32:1346–1352
21. Gomathi M, Prakasam A, Rajkumar PV, Rajeshkumar S, Chandrasekaran R, Anbarasan PM (2020) Green synthesis of silver nanoparticles using *Gymnema sylvestre* leaf extract and evaluation of its antibacterial activity. S Afr J Chem Eng 32:1–4
22. Suman TY, RadhikaRajasree SR, Ramkumar R, Rajthilak C, Perumal P (2014) The green synthesis of gold nanoparticles using an aqueous root extract of *Morinda citrifolia* L. Spectrochimica Acta Part A 118:11–16
23. Vivek R, Thangam R, Muthuchelian K, Gunasekaran P, Kaveri K, Kannan S (2012) Green biosynthesis of silver nanoparticles from *Annona squamosa* leaf extract and its in vitro cytotoxic effect on MCF-7 cells. Process Biochem 47:2405–2410
24. Dwivedi AD, Gopal K (2010) Biosynthesis of silver and gold nanoparticles using *Chenopodium album* leaf extract. Colloids Surf A 369:27–33
25. Kumar B, Smita K, Cumbal L, Debut A (2017) Green synthesis of silver nanoparticles using Andean blackberry fruit extract. Saudi J Biol Sci 24:45–50
26. Castellano JJ, Shafii SM, Ko F, Donate G, Wright TE, Mannari RJ, Payne WG, Smith DJ, Robson MC (2007) Comparative evaluation of silver-containing antimicrobial dressings and drugs. Int Wound J 4:114–122
27. Naghsh N, Soleymani S, Torkan S (2013) Inhibitory effect of alcoholic eucalyptus extract with nanosilver particles on *E. coli* growth. J Gorgan Univ Med Sci 15:2
28. Parthiban E, Manivannan N, Ramanibai R, Mathivanan N (2019) Green synthesis of silver-nanoparticles from *Annona reticulata* leaves aqueous extract and its mosquito larvicidal and anti-microbial activity on human pathogens. Biotechnol Rep 21:e00297
29. Fatemi M, Shomali T, Nazifi S, Fazeli M (2019) *Eryngium bungei* Boiss extract has hepatoprotective effect against liver damage induced by acetaminophen in rats: novel antioxidant and anti-inflammatory effects. Iran J Toxicol 13:11–16

30. Bahrami-Teimoori B, Nikparast Y, Hojatianfar M, Akhlaghi M, Ghorbani R, Pourianfar HR (2017) Characterisation and antifungal activity of silver nanoparticles biologically synthesised by *Amaranthus retroflexus* leaf extract. J Exp Nanosci 12:129–139
31. Arya G, Kumari RM, Gupta N, Kumar A, Chandra R, Nimesh S (2018) Green synthesis of silver nanoparticles using Prosopis juliflora bark extract: reaction optimization, antimicrobial and catalytic activities. Artif Cells Nanomed Biotechnol 46:985–993
32. Nayak RR, Pradhan N, Behera D, Pradhan KM, Mishra S, Sukla LB, Mishra BK (2011) Green synthesis of silver nanoparticle by *Penicillium purpurogenum* NPMF: the process and optimization. J Nanopart Res 13:3129–3137
33. Shirzadi-Ahodashti M, Mortazavi-Derazkola S, Ebrahimzadeh MA (2020) Biosynthesis of noble metal nanoparticles using *Crataegus monogyna* leaf extract (CML@X-NPs, X= Ag, Au): antibacterial and cytotoxic activities against breast and gastric cancer cell lines. Surf Interfaces 21:100697