Antibacterial activity of green gold and silver nanoparticles using ginger root extract

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Abstract

Background

Recent studies demonstrated that the speed of synthesis, biocompatibility, and antimicrobial activity of gold (Au) and silver (Ag) metals is enhanced when biosynthesized in nano-sized particles. In the present study, Au NPs and Ag NPs were synthesized *via* a biological process using aqueous Ginger root extract and characterized by various spectroscopic methods.

Methods & Results

The NPs were found to be in hexagonal and spherical shapes. The average particle size for Au and Ag NPs was found to be 20 nm and 15 nm, respectively. The dynamic light scattering (DLS) method has shown that the zeta potential values of synthesized NPs were found to be 5.7 mv and 7.11mv, respectively. Gas chromatography-mass spectrometry (GC-MS) analysis of Ginger root extract revealed 25 compounds. The synthesized NPs showed significant activity against *Staphylococcus aureus* and *Escherichia coli* in vitro with IC50 and IC90 values for Au and Ag NPs, respectively, noted to be 7.5 and 7.3 µg/ml and 15 and 15.2 µg/ml for both bacterial strains. The protein leakage level was high and morphological changes occurred in bacteria treated with biosynthesized NPs.

Conclusion

These results suggest that the biosynthesized metallic NPs show potential for application as antibacterial agents with enhanced activities.

Background

Biofilms are microbial populations enclosed in a matrix. Those grow in three steps, (i) initial adhesion, (ii) proliferation, and (iii) detachment. Bacterial cells bind together by extracellular polymeric substances and are connected to a substrate surface, involved in each cell-cell interaction and cell surface as a part of the developmental process. Biofilms show high resistance towards toxicants if compared to planktonic cells [1, 2]. They can cause of lead to infections in humans and animals and serious problems in the environment. Infectious diseases are one of the health threats on human society. The use of antibacterial drug for the control and treatment of infectious disease are common worldwide. However, continued use from the antibacterial drug leads to drug resistance [3]. In this condition use of the drug for control and treat of infectious diseases don't be effective. Eliminating this problem requires a new therapeutic agent for control and treatment of the infectious disease [4].

Nowadays, silver (Ag) and gold (Au) nanoparticles (NPs) are used in a wide range of medicine. There are several methods including laser ablation, gamma irradiation and use of the chemical agent as a reducing and capping agent, for the synthesis of the Au and Ag NPs [3]. The important problems with these methods are expensive, and use of toxic chemical agents that are not safe for human health and the

environment [5]. The green synthesis of the NPs, also known as photosynthesis, is one of the emerging fields in nanotechnology. Green synthesis NPs have shown high activity against the primary biofilm. Plants are used for the synthesis of NPs and have advantages over physical and chemical processes [6]. In recent years, NP synthesis using plant extracts has been increasing because, these are available, environmentally friendly, and easy to use, and have a wide range of secondary metabolites that act as a reducing agent [7].

Ginger (Zingiber officinale), Roscoe belonging to the family Zingiber aceae, is a perennial herb with thick tuberous rhizomes. Ginger extracts have antibacterial activity. Malu and co-workers show that material such n-hexane, ethyl acetate and soxhlet which are in the ginger extract solution, have antibacterial effects. In the fact this material in addition to having bactericidal activity, inhibition of bacterial growth [8]. *E. coli* (gram-negative bacteria) and *S. aureus (*gram-positive bacteria) have an important role in human infectious diseases. *E. coli* through penetration to lymphocytes and an inflammatory reaction with the host, by causing bloody diarrhea [9]. *S. aureus* is the main cause of food poisoning and surgical wounds infection which together with epidermidis syndrome, causes infections associated with medical equipment [10].

In this research, gold and silver nanoparticles were synthesized with green and chemical synthesis methods. For this purpose, Ginger root extract and citrate were used as reducing agents, respectively. The synthesized metal NPs were characterized by dynamic light scattering (DLS), transmission electron microscope (TEM), ultraviolet-visible spectroscopy UV-Vis, Atomic absorption spectroscopy (AAS), and Fourier transforms infrared spectroscopy (FTIR). The antibacterial activity of green and chemical synthesized Au and Ag NPs were investigated with *E. coli* and *S. aureus* strains in vitro.

Materials And Methods

2.1. Microorganisms

Standard strains of *S. aureus* (ATTC 25923) and *E. coli* (ATTC 25922) were purchased from the Iranian Research Organization for Science and Technology (IROST). These strains were cultivated in the nutrient broth medium and were incubated at 37 °C for 24h. For further experiments, small amount of bacterial colonies was stored in Tripticas soy broth containing glycerol at -70 °C.

2.2. Preparation of ginger extracts

Roots of ginger were purchased from the local market, the Islamic Republic of Iran, and washed frequently with ultra-pure deionized water. After shredding the ginger root, dried and crashed into powder by the steel hammer. After that, 2 gr of powder was mixed with 80 ml of ethanol and incubated at 40 °C for 24 hours. Then for obtaining ginger extract, the solution was filtered with Whatman No.1 filter paper.

2.3. Green and chemical synthesis of gold and silver nanoparticles

For the green synthesis of Au NPs, 1 mL ginger root extract was added to a 50 mL boiling solution of $HAuCl_4 \cdot 3H_2O$ (1mM) and the boiling continued for 5 min. Then, the solution was kept undisturbed at room temperature until the colorless solution converted to a wine red color which indicated the formation of Au NPs. For the chemical synthesis of Au NPs, $HAuCl_4$ solution is boiled and then trisodium citrate dehydrate was added slowly into the boiling solution under stirring. A few minutes later, the color of the solution from light yellow converted to wine red.

For green synthesis, like above, 1 ml of ginger extract was added to with 100 ml of silver nitrate (2mM) boiling solution. The reaction mixture was kept undisturbed at room temperature until the colorless solution converted to reddish brown color which indicated the formation of Ag NPs. For the chemical synthesis of silver nanoparticles, silver nitrate solution and citrate of sodium were used as a metal ion source and reduction agent, respectively. Also, citrate of sodium was used as a reducing agent. When the citrate sodium was added to the silver nitrate the color of the solution converted from pale yellow to pale brown color. And the final silver nanoparticle was purified by centrifugation.

2.4. Gas chromatography-mass spectrometry analysis (GC-MS)

Ginger extract was analyzed by a mass scientific trace 2200 (gas chromatography) system with a thermalSaturnmass selective detector (Varian Company). The machine was equipped with a TG-5MS (mass spectroscopy) column (30 * 0.25 mm (5% phenyl) -methylpolysiloxane capillary column, film thickness * 0.25 micrometer), 220 centigrade temperature injector and 250 centigrade temperature transfer line. The temperature of the oven was programmed as follows: initial temperature; 50 centigrade for 5 min and then increase 4 °C/min up to 250 centigrade. The gas carrier used was He at a flow rate of 1.0 ml/min. 1microliter sample was injected and the ionization energy was 70 eV. The base of the identification of individual components was based on their retention time and by comparison of their mass spectral pattern with standard library data. (National Institute of standards and technology).

2.5. Characterization of gold and silver nanoparticles

The reduction of gold and silver ions was monitored by a UV-Vis spectrophotometer (SPECTOR 250, Analytic Jena) in the 350-800 nm wavelength range. Due to the evaluation of concentration of green and chemical synthesized NPs, a solution of synthesized NP was diluted, and then the amount of Au and Ag NPs were measured by atomic absorption spectroscopy (AAS) (NovaAA400, Analytic Jena Co). Also for determination of shape and size of the nanoparticle were used from Transmission electron microscopy (TEM) (Zeiss Leo q06) operating at 200 kV accelerating voltage. For the preparation of the sample; 10

microliter of aliquots of NPs solution was drop-casting onto a carbon-coated copper grid and then was placed on a piece of paper to get rid of excess solvent. For determination of the average particle size, distribution, and stability of the gold and silver NPs were used from ELSZ-1000 zeta-potential and particle sizer (Mastersizer 2000, Malvern, USA). For FTIR analysis, the powdered gold and silver NPs were recorded by FTIR spectrometer (Tensor 27, Bruker Co) over the 4000-400 cm^{-1} frequency with 4 cm^{-1} resolutions by using a KBr pellet method.

2.6. Antibacterial assay

The antibacterial activity of chemical and green synthesizedAu and Ag NPs were performed by well diffusion agar method. Standard strains of bacteria were subculture on plates containing Muller Hinton agar using the pour plate method. Then the wells which have 6mm diameter were punctured onto the agar plates and 25µg/ ml of Au and Ag NPs solution and aqueous plant extract were loaded into the wells. After 24 hours of incubation, the inhibition of zone diameter around of wells was measured. For comparison of the effectiveness of Au and Ag NPs and ginger extract against tested bacteria, we used Streptomycin (30 µg/ml). For evaluation of the minimum inhibitory concentration (MIC) was studied using a two-fold dilution method with the first test concentration of 30 µg/ml [11]. The minimum inhibitory concentration was calculated as the minimum dose of the NPs inhibiting the visual growth of the test cultures on the agar plates. The culture tests were conducted in triplicates.

2.7. Intracellular protein leakage

30 microgram/ml of NPs for 8 h at 37 centigrade, were used for a treat of the bacteria cultures. After incubation, the bacteria were centrifuged at 5000 rpm for 10 min and then supernatants were collected. For evaluation of the intracellular protein leakage, the supernatants were assayed according to the method of Bradford (1976). The assay consisted of 1 ml of supernatant, 0.5 M NaOH (2 ml), and 0.1 N folin (0.1 ml) phenol reagent; absorbance of the solutions was read at 550 nm after 10 min.

3. Statistical analysis

Standard deviation (SD) was measured for antibacterial and protein leakage assays. For differences between treat and control group data in protein leakage assay were carried out by Student's t-test. $P < 0.05$ was significant.

Results

4.1. Phytochemical analysis

GC-MS analysis for ginger extract was showed that 101 compounds (**Table 1**). The result showed that major compounds were Coronene (13.5%), trans-Caryophyllene (12.2%), Chavicol (11.9%), ACETONITRILE (11.8%), and EPOXYSPIRO (5.36%).

4.2. Characterization of biosynthesized nanoparticles

The visual examination or color change test was used to indicate the green and chemic synthesis of Au NPs (**Figure 1**) and Ag NPs (**Figure 2**), which confirmed that the reduction of metal ions to metal NPs results in a color change of the solution.

Thereafter, the UV-Vis spectrum was used to find out the stability and bioreduction of metal NPs in the solution. In the present study, UV-Vis analysis revealed the maximum absorption peaks of green synthesized Au NPs and Ag NPs were at 523 and 432.5 nm, respectively (**Figure 2**). Also, the Au and Ag NPs amount were measured by atomic absorption spectroscopy (AAS), results show that the amounts of those are 1.531 and 2.025 mg/L, respectively.

DLS method indicated that the average particle size for green synthesized Au and Ag NPs are 314 and 225 nm respectively (**Figure 3**), also average particle size for chemical synthesized Au and Ag NPs are 42 and 27 nm respectively. Zeta potential values give information about the stability of the NPs that for green synthesized Au and Ag NPs value were -7.11 and 4.83 mv, respectively, which confirm the high stability of biosynthesized NPs.

TEM techniques were used for studying the morphology and sizes of Au NPs and Ag NPs (**Figure 4**). TEM images of NPs showed the particles distributed individually in different shapes, such as hexagon and spheres, with sizes ranging from 15-25 nm for Au green synthesized nanoparticles and less than 15 nm for Ag green synthesized NPs. Also, TEM study was shown that sizes ranging for chemical synthesized Au nanoparticles from 15-25 and 20-70 nm for Ag NPs.

FTIR spectrum (**Figure 5**) of ginger root extract shows the band at 3441 cm^{-1} which is assigned to O–H stretching of phenolic compounds, water, and fatty acids. The band 2933 cm^{-1} is assigned to C–H stretching of methylene group in esters, fatty acids, and aliphatic hydrocarbons, 1738 cm^{-1} is assigned to C=O stretching of aldehyde, esters, fatty acid, and ketones, 1620 cm^{-1} is assigned to (H–O–H) bending of water, 1517 cm^{-1} is due to C=C stretching of aromatic elements, 1462 cm^{-1} is assigned to C–O–H in-plane bending of fatty acids and other compound's, 1269 cm^{-1} is assigned to C–O stretching of ester and fatty acid and 1044 cm^{-1} is due to C–O stretching of alcohols, phenols.

By comparing the infrared spectra of plant extract and green synthesized NPs (**Figure 5**) it is observed that the intensity of the peaks at 3450 cm^{-1} for Ag, and 3435 in Au, 2928 cm^{-1} for Ag and 2928 cm^{-1} in Au NPs, 1735 cm^{-1} in Ag and 1738 cm^{-1} in Au, 1460 cm^{-1} in Ag and 1384 cm^{-1} in Au, and1108 cm^{1} in Au and 1107 cm^{-1} in Ag in compare with plant extract spectrum has decreased/increased and then shifted to

higher/lower wavenumbers. The band at 3450 cm^{-1} is assigned to O–H stretching of water, 2928 cm^{-1} is assigned to methyl C–H stretching of esters, 1620cm^{-1} is assigned to H–O–H bending of water, 1383 cm^{-1} is assigned to methyl symmetrical C–H bending of esters and band at 1107 cm^{1} is assigned to C–O stretching of carbohydrates, ester. The peak of 2928 cm^{-1} which is related to C-H stretch of aliphatic fatty acids, esters, and hydrocarbons in the plant root extract became less intense and shifted to 2923 cm^{-1}. The band at 1620 cm^{-1} assigned to H–O–H bending of water became less intense and shifted to 1628 cm^{-1}. The band at1517 cm^{-1} which is assigned to C=O stretching of esters, aldehyde, ketones, and fatty acid disappeared. Further, the peak at 1383 cm^{-1} which is assigned to methyl symmetrical C–Hbending of esters became sharp.

4.3. Antibacterial activity

Due to prove the antibacterial activity of the roots extract, in this study at the first we evaluated the antibacterial activity of ginger extract root (**Table 2**). Better than chemically synthesized once, the green synthesized Au and Ag NPs have shown acceptable bacterial growth inhibitory and also shown a mean zone of inhabitation of *S. aureus* and *E. coli* (**Table 3**). The IC_{50} and IC_{90} values for Au NPs and Ag NPs were noted to be 7.5 and 7.3 µg/ml and 15 and 15.2 µg/ml for both bacterial strains, respectively (**Figures 6,** and **Figure 7**).

4.4. Protein leakage

The total amount of protein leakages upon treatment with green synthesized AuNPs and Ag NPs were quantified. The result showed that protein leakage for treated bacterial cells with green and chemical synthesized NPs was higher when compared to the untreated groups, but the amount of that for Ag NPs was higher than from Au NPs (**Table 4**). This indicates that NPs disrupted the bacteria cells membrane and enhanced the protein leakage.

Discussion

Earlier studies were showed that the ginger extract contains n. hexane, ethyl acetate, and soxhlet which those compounds have an antibacterial effect and also inhibit the growth of the bacterial biofilm [12]. In the present study chemical composition of ginger root extract is made up of gingerol, shogaols, zingerone, paradol, and starch. The rhizome, consisting of 6-gingerol and 6-shogaol, is the principal source of gingerol and shogaol, as previously reported were found in high levels in the ginger extract [13, 14].

The key compounds responsible for the reduction of Au and Ag ions to NPs are water-soluble ingredients present in the *ginger* root extract. Ginger holds chemical compounds like oxalic acid, ascorbic acid, phenylpropanoids, and zingerone. The Au NPs and Ag NPs can be reduced by the ascorbic acid and/or

oxalic acid present in the *ginger* root extract. The possible stages of the formation of NPs from ginger extract during the chemical reaction include nucleation, condensation, surface reduction, and stabilization as previously described [15, 16].

Results indicated that during NPs synthesis, the biodegradable components of root extract can act both as reducing and capping agents, thus promoting the formation of NPs while inhibiting their aggregation via increasing their stability [17]. This finding also presents the potentials of plants root extract as biological “nano-factories” providing non-toxic reducing-capping agents and offering a clean, highly tunable, and environmentally benign method for producing desired NPs [18]. Although the idea of utilizing living plants is revolutionary; nevertheless, the difficulty of purification of the intracellularly formed NPs directed studies to utilize the extracts of plants for extracellular syntheses of NPs [19].

The UV-Vis analysis-peaks indicate that green NPs were synthesized and consistent with the results of previous studies that have shown the range of 400–450 nm for Ag NPs and in the range of 500–550 nm in case of Au NPs [20].

According to Zeta potential data, the surface charge of Ag NPs is more positive than Au NPs, which might potent them for better binding to the outer membrane of Gram-negative bacteria with a negative charge and thereby modulate their activity [21]. Also, Zeta potential for chemical synthesized Au and Ag nanoparticles values are 0 and -10.1mv, respectively. Elia et al. synthesized the Au nanoparticle from P. granatum and characterized them with using DLS spectroscopy which particle size range was 34-312 nm [22]. Inconsistency with our study, Sujitha et al. [23] reported that the lower concentration of the plant extract leads to Au NPs with a lower ZP value. These findings reveal that biological extracts from plants' roots provide the method for producing NPS with a broad range of sizes [3], and since they are also originally naturals, so covering the NPs surface improves their biocompatibility for in vivo applications [18].

Addressing the TEM results, as previously studied , the ratio of plant extract, type of components, and the initial metal salt in the reaction medium affected the Au NPs' size and the shape [24]. Similarly, a study showed that the synthesis of NPs using a marigold flower, where TEM analysis showed spherical and hexagonal shape particles in the range between 10 to 90 nm [25]. Thus, the TEM and DLS studies gave similar results for the size range of the NPs.

The FTIR analysis indicated the presence of phenolic groups which are suggested responsible for the reduction of silver ions [26]. The presence of other FTIR-assocated peaks confirmed that the NPs were covered by ginger root extract with functional groups such as carboxylic acid, ketone, aldehyde, and other functional groups. The presence of these functional groups is due to the biostability of the NPs. It confirms that NPs synthesized from the ginger root extracts are stabilized by phytoconstituents through functional groups [27, 28].

Prakash Patil groups synthesized Ag NPs using flower extract of Madhucalongifolia as a reduction agent and synergic effect. Green synthesized NPs show potential antibacterial activity against Gram-negative

and Gram-positive bacteria. Madhucalongifolia flower is a good source for NPs synthesis. According to obtained data, synthesized Ag NPs are applicable as an antibacterial agent in therapeutics. This was explained by the fact that the antibacterial activity was due to the change in membrane permeability [29]. After entering the cytoplasm, Ag NPs induce reactive oxygen species (ROS) production and by binding the phosphate group of effector molecules disturbing the protein synthesis and thus, causes bacterial growth inhibition or killing [30]. Due to the high prevalence, antibiotic resistance and pathogenicity of *S. aureus* and *E. coli* we studied them. These two pathogens are the causative agents for several infections, such as endocarditis, urinary tract infection, osteomyelitis, and septicemia [31, 32].

Metal NPs especially once having a relatively large size/surface ratio or smaller than 20 nm act as destroyers of the cell membrane through binding to cells, causing structural alterations and eventually the loss of the semi-permeability of the membrane [6]. Studies have shown that bacterial cells membrane disruption by Psidiumguajava leaf extracts is in agreement with the result of this study [33].

Overall, the synthesized NPs exhibited pronounced antibacterial activities on S. aureus and on E. coli. Similar to these findings, Janaki et al showed that zinc oxide nanoparticle (ZnO NPs) which was synthesized using ginger extracted root has an efficient antimicrobial activity [34]. In the other study, Kumor and co-workers utilized ginger extract green synthesized gold NPs and evaluated of blood compatibility of them. The result showed that biosynthesized NPs are suitable vectors for medical applications [13]. These findings explain the possible antibacterial actions of green synthesized NPs: (i) may be due to DNA damage, (ii) protein synthesis inhibition and denaturation, and (iii) formation of free radicals causing cell wall damage [35] (**Figure 8**).

Conclusion

The present study reports the chemical and green synthesis of Au and AgNPs using citric acid and aqueous root extract of ginger, respectively. Biosynthetic NPs were characterized that are spherical and hexagonal shapes with an average size ≤ 100 nm. The biosynthesized Au and AgNPs showed an excellent antibacterial effect against *S. aureus* and *E. coli* in comparing chemical synthesized NPs. Further, the possible anti-bacterial mechanisms were studied by protein leakage. The Result of this study proves that biosynthesized Au and Ag NPs could be used as an alternative therapy to control and eliminate the infection caused by E. coli and S. aureus.

Abbreviations

FTIR, Fourier transforms infrared spectroscopy; MIC, minimum inhibitory concentration; NPs nanoparticles; ROS, reactive oxygen species; TEM, Transmission electron microscopy

Declarations

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Availability of data and materials

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

Contributions

MY was a significant contributor to doing and writing the manuscript. MA, HDM and MM collaborated in doing the thesis that results in the paper. AA and MMD designed and supervised the manuscript. All authors read and approved the final manuscript.

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. Compounds of ginger extract analyzed by GC-MS.

NO:	Type of Component	Area (%)	Time (min)
1	Chavicol	11.9%	27.13
2	Isopropyl	2%	26.52
3	ACETONITRILE	11.8%	26.41
4	Coronene	13.5%	26.33
5	Pentenamide	2.22%	26.23
6	Phosphine	1.27%	26.07
7	trans-Caryophyllene	12.2%	25.55
8	Benzoic acid	1.10%	25.42
9	Homobrend	4.49%	25.24
10	Benzaldehyde	1.10%	25.11
11	Tricyclo	3.26%	25.02
12	EPOXYSPIRO	5.36%	24.73
13	Longiverbenone	3.34%	24.57
14	Phenanthrenecarboxylic acid	3.18%	24.38
15	Seneciphylline	1.91%	23.21
16	Cyclohexene	4.06%	22.36
17	TETRAHYDROQUINOLINE	5.03%	22.1
18	Benzopyran	0.55%	9.35
19	1H-Benzimidazole	0.79%	8.14
20	2,3-Dimethylbenzofuran	0.63%	8.08
21	7-Methyl-1-indanone	0.48%	7.89
22	Benzimidazole	0.56%	7.8
23	Triazolo	0.09%	3.81
24	Quinoxaline	0.37%	3.55
25	5-ethyl-5-fluorobarbituric acid	0.61%	2.92

Table 2. Antibacterial activity of ginger root extract.

The pure ginger root extract (µg/ml)								
Concentration	500	250	125	62.5	31.25	15.62	7.81	3.90
S. aureus	-	-	-	-	+	+	+	+
E. coli	-	-	+	+	+	+	+	+

Table 3. Antibacterial activity of green and chemical synthesized Ag/Au NPs.

Ag (µg/ml)								
Concentration	**27.72**	**13.86**	**6.93**	**3.46**	**1.73**	**0.86**	**0.43**	**0.21**
S. aureus	-	-	-	+	+	+	+	+
E. coli	-	+	+	+	+	+	+	+
Green-Ag								
S. aureus	-	-	-	-	-	+	+	+
E. coli	-	-	-	-	-	-	-	+
Au (µg/ml)								
Concentration	**17.95**	**8.97**	**4.48**	**2.24**	**1.12**	**0.56**	**0.28**	**0.14**
S. aureus	-	+	+	+	+	+	+	+
E. coli	+	+	+	+	+	+	+	+
Green-Au								
S. aureus	-	+	+	+	+	+	+	+
E. coli	+	+	+	+	+	+	+	+

Table 4. Quantification of protein leakage level in NPs treated bacterial species.

Bacteria	**Control (%)**	**G-AgNPs treated cell (%)**	**G-AuNPs treated cell (%)**
S. aureus	7.18 ± 2.5	10.23 ± 1.77[a]	10.07 ± 1.71[a]
E. Coli	11.01 ± 0.69	15.41 ± 0.37 [a]	13.19 ± 0.23 [a]
[a] P<0.05, Experiment performed in triplicates and statistical analysis using a student-t-test.			

Figures

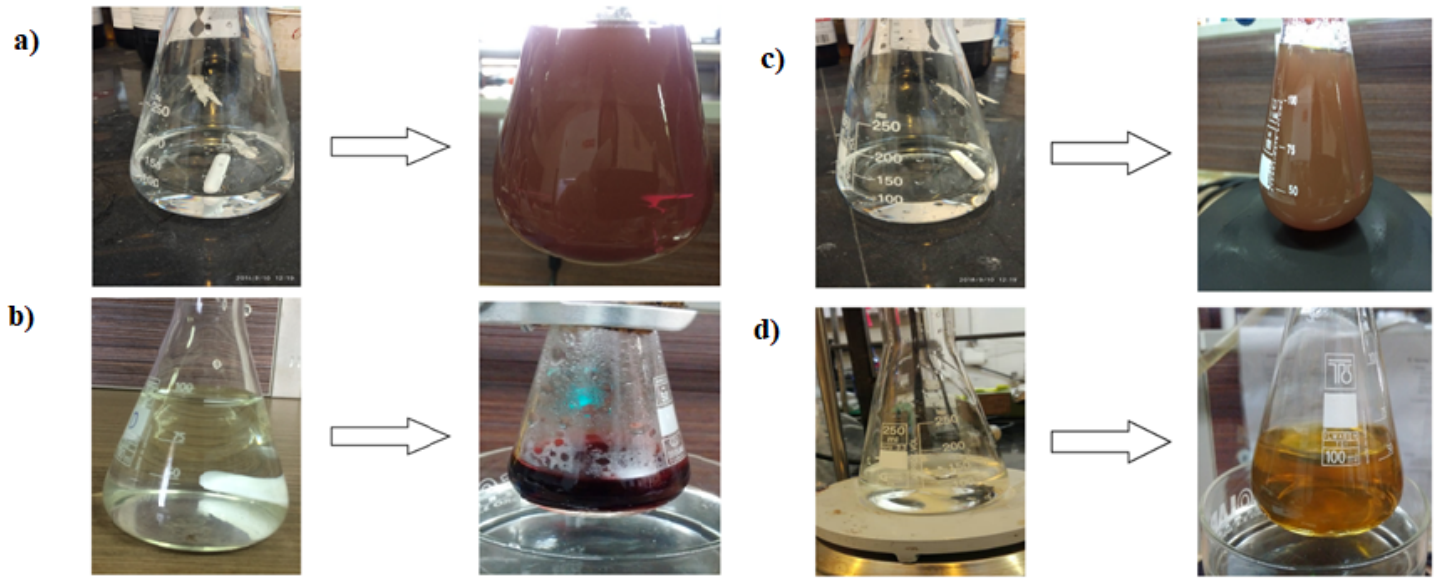


Figure 1

Schematic representation of the synthesis of Au and Ag NPs using ginger root extract and Trisodium Citrate. **a**) Green synthesis of Au NPs using Ginger root extract. **b**) Chemical synthesis of Au NPs with use of Trisodium Citrate. **c**) Green synthesis of Ag NPs using Ginger root extract. **d**) Chemical synthesis of Ag NPs using trisodium citrate.

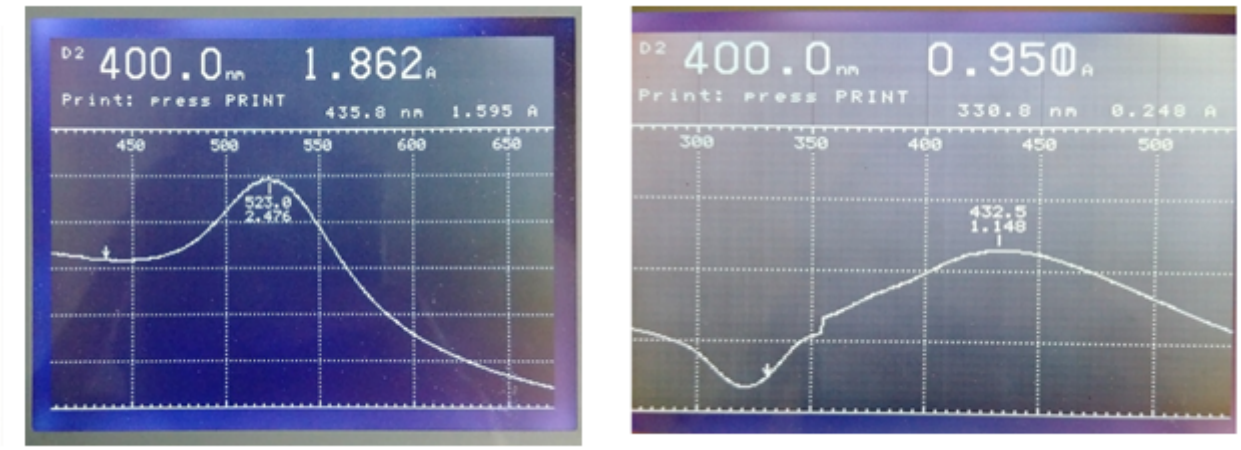


Figure 2

UV-vis spectra of green synthesized Au (right) and Ag (left) NPs.

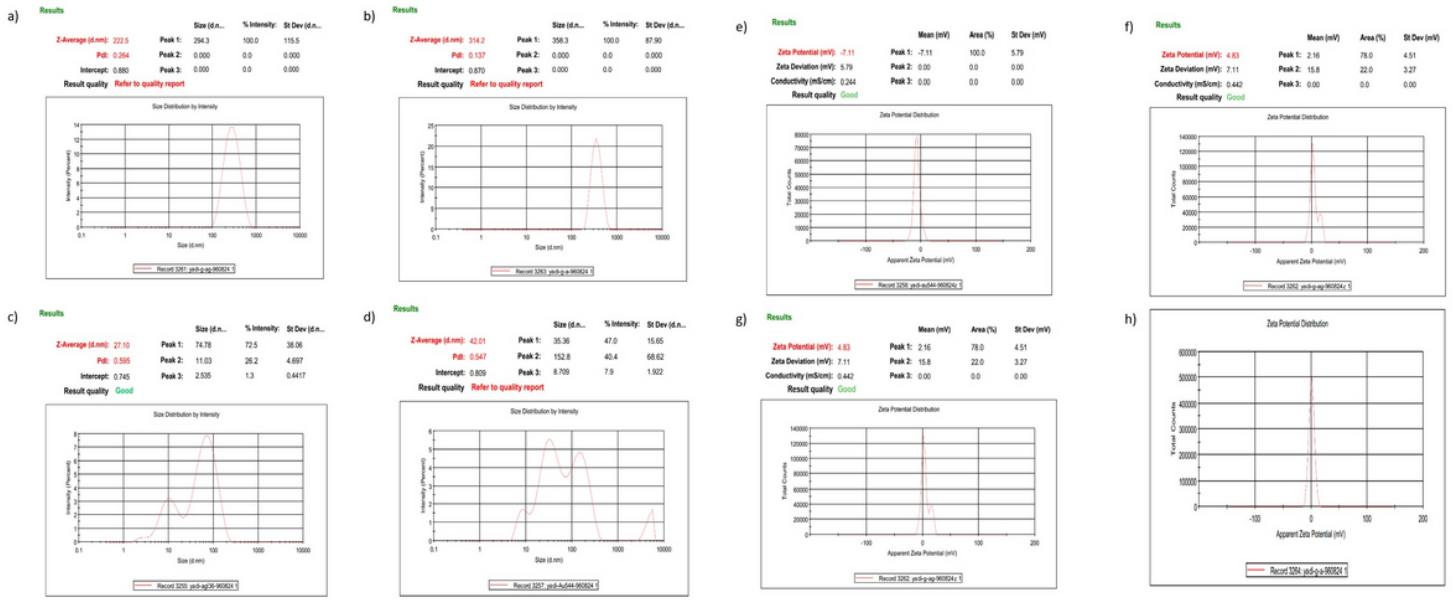


Figure 3

DLS profile and zeta potential analysis of green and chemical synthesized NPs. **a**) size of biosynthesized Ag, **b**) size of biosynthesized Au, **c**) size of chemical synthesized Ag and D) size of chemical synthesized Au NPs. E) zeta potential of biosynthesized Au, F) zeta potential of biosynthesized Ag, **g**) zeta potential of chemical synthesized Ag, and **h**) zeta potential of chemical synthesized Au NPs.

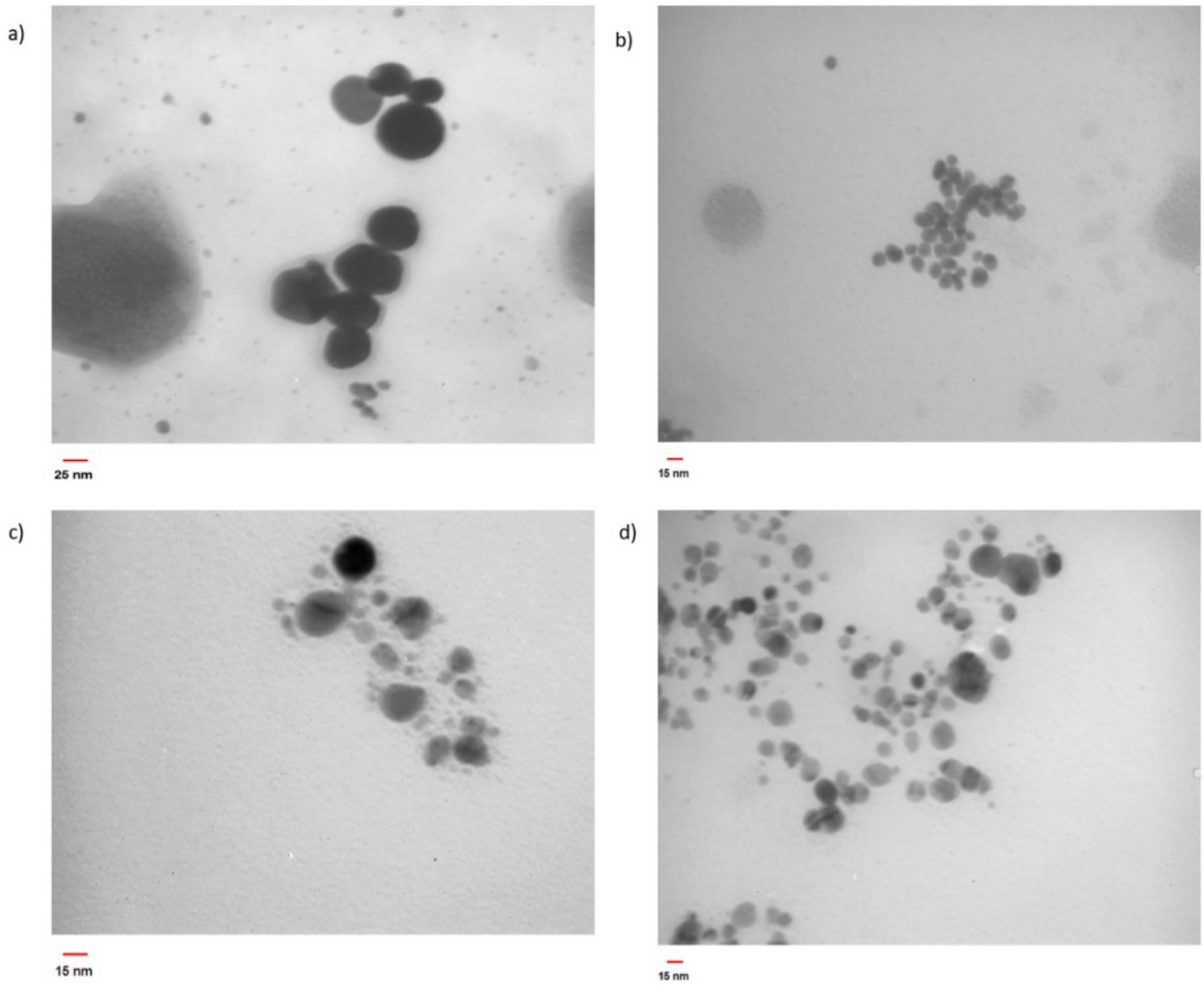


Figure 4

TEM image of NPs biosynthesized and chemical using ginger root extract and citrate. A) TEM imaging of biosynthesized Au NPs, B) TEM imaging of chemically synthesized Ag NPs, C) TEM imaging of biosynthesized Ag NPs, and D) TEM imaging of chemically synthesized Ag NPs.

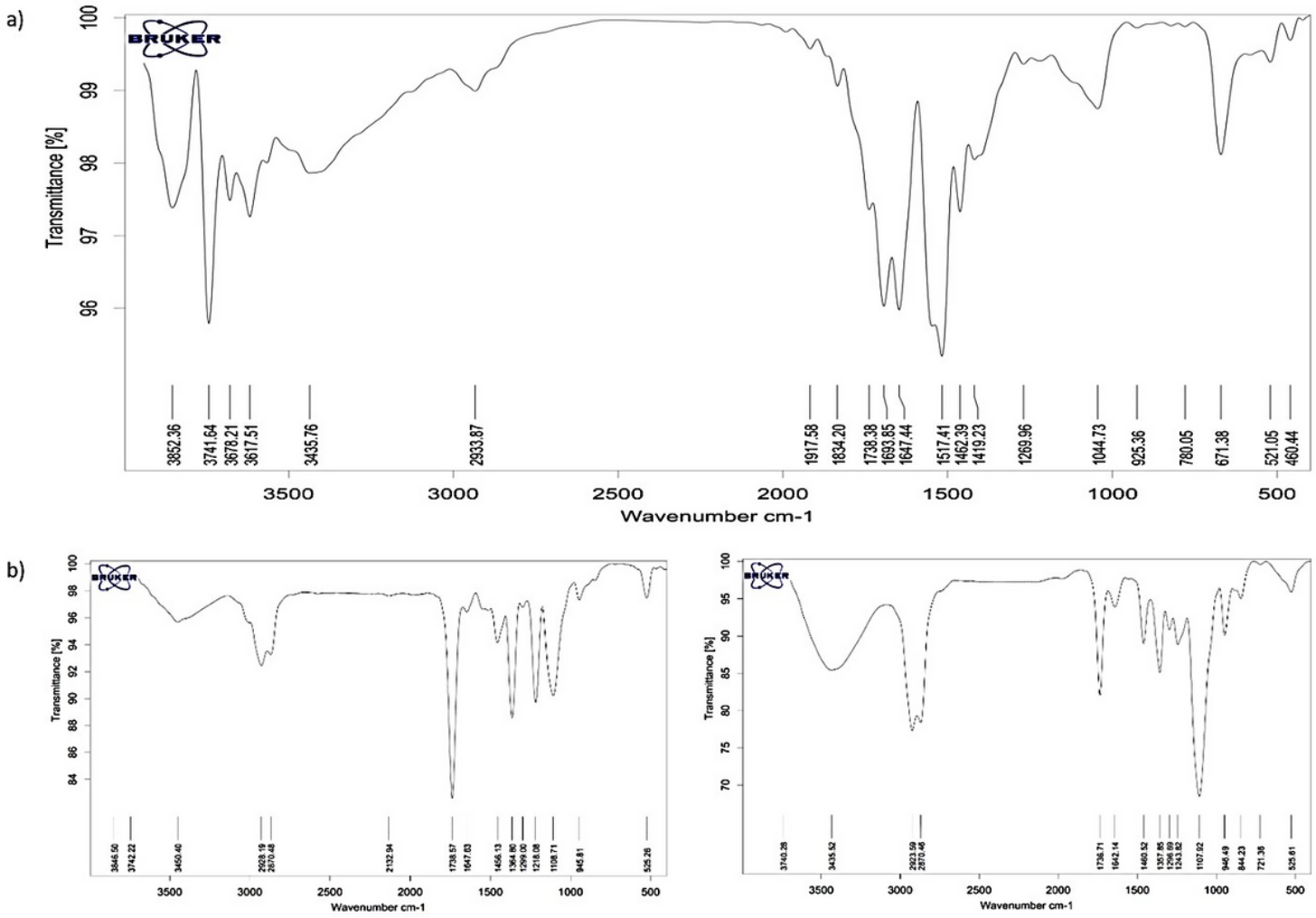


Figure 5

FTIR spectra of (a) ginger root extract and (b) capped reducing phytoconstituents responsible for the synthesis of Au (left) and Ag (right) NPs.

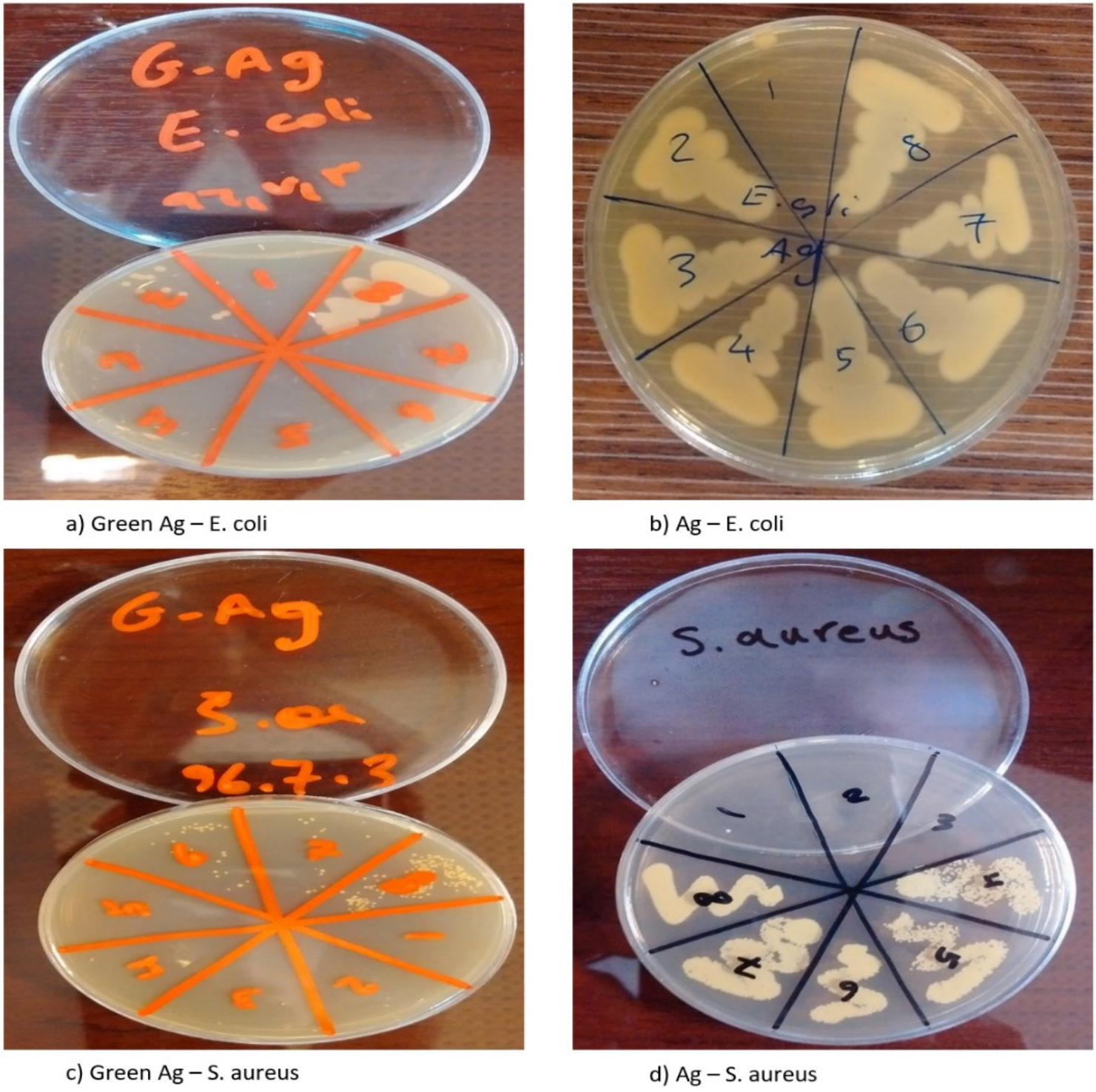
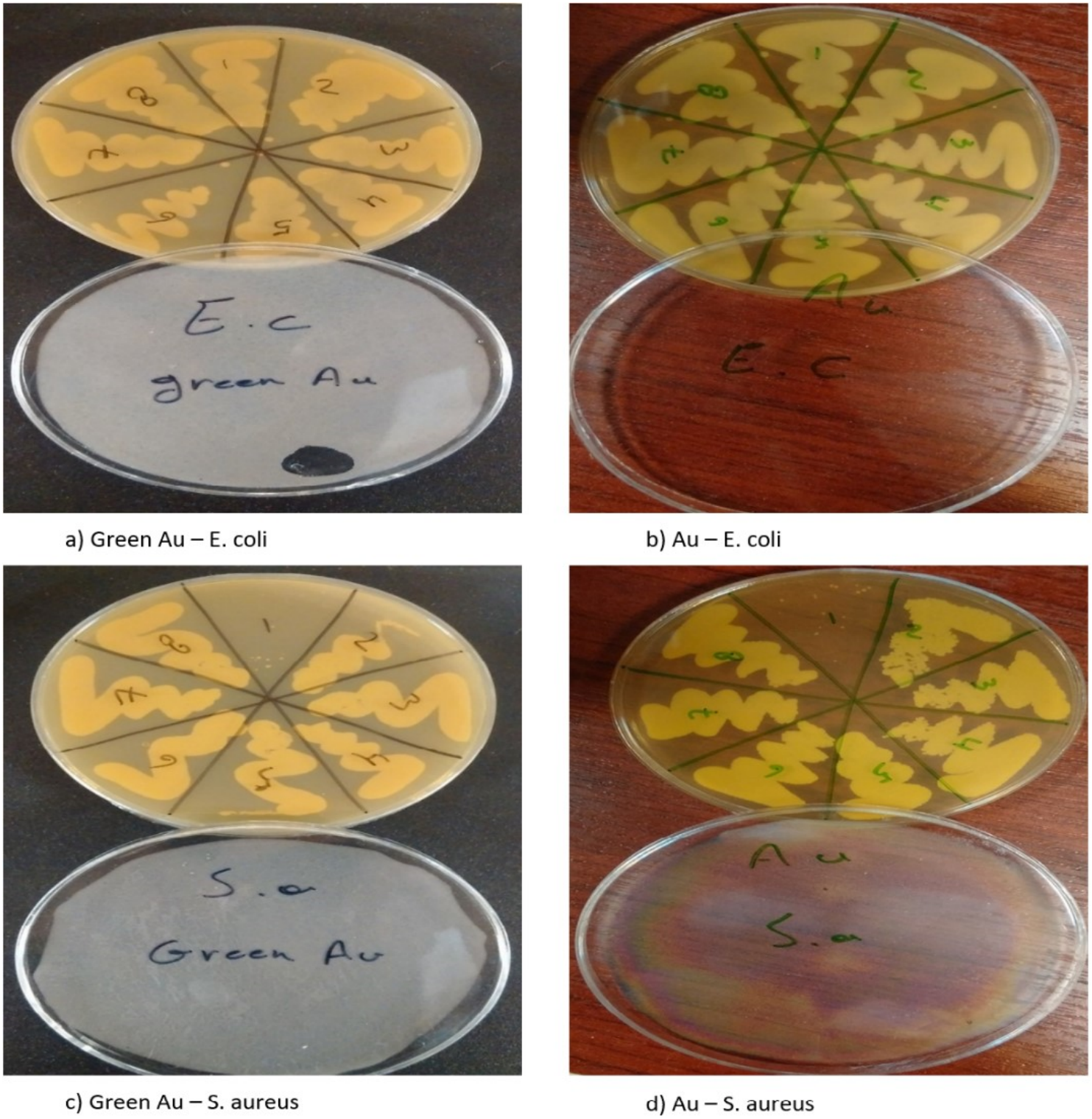


Figure 6

Antibacterial activity of chemical and biosynthesized silver NPs.



a) Green Au – E. coli

b) Au – E. coli

c) Green Au – S. aureus

d) Au – S. aureus

Figure 7

Antibacterial activity of chemical and biosynthesized gold NPs.

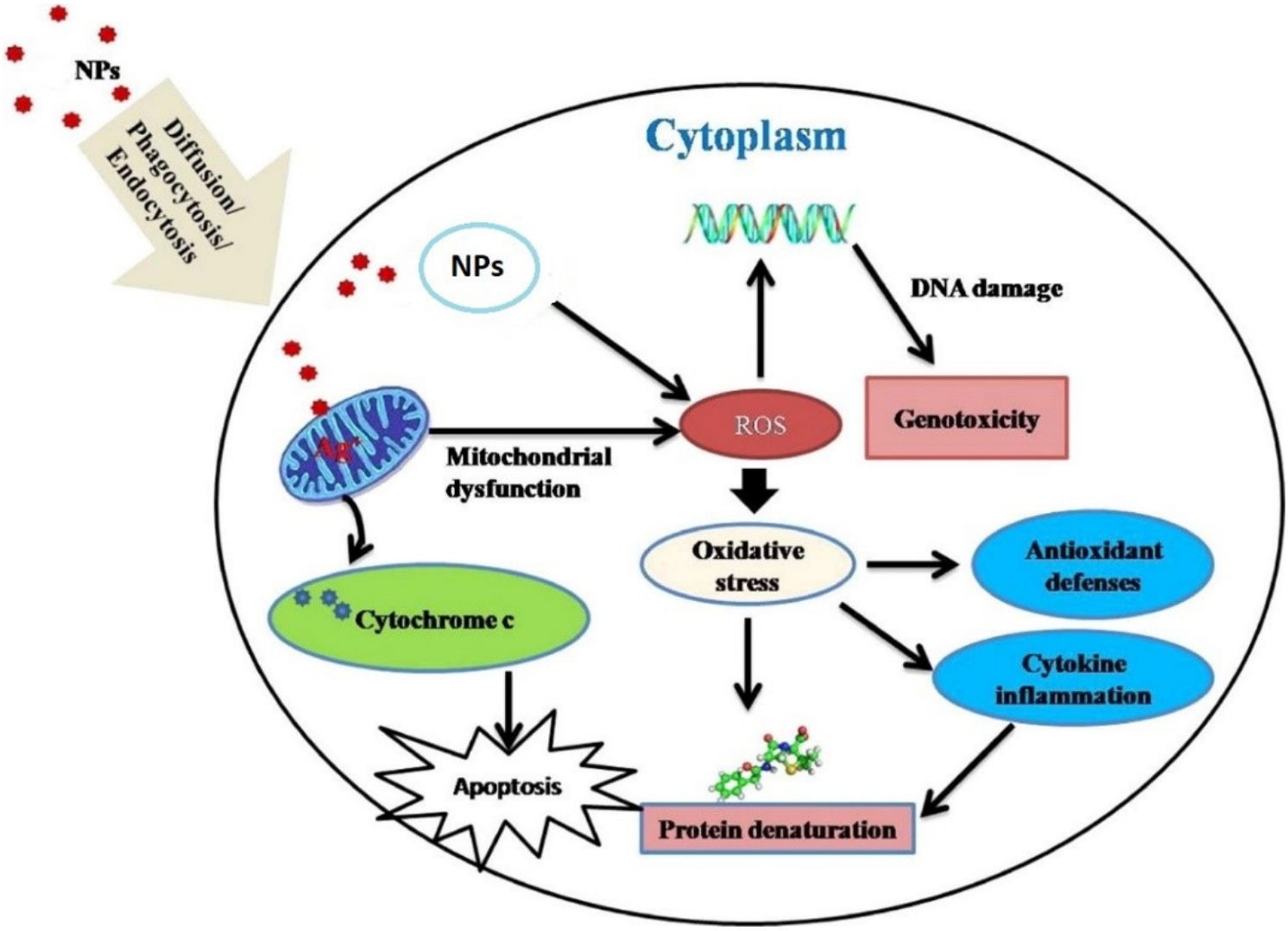


Figure 8

A possible mode of antibacterial action of green synthesized NPs.