Chemical Papers (2024) 78:473–481
https://doi.org/10.1007/s11696-023-03103-9

ORIGINAL PAPER

Biogenic synthesis of silver nanoparticles using *Sambucus nigra* leaves: elucidation, antimicrobial, antioxidant activities and quantification of phenolics

Tunay Karan[1] · **Ramazan Erenler**[2,3] · **Zafer Gonulalan**[4] · **Ugur Kolemen**[5]

Received: 5 June 2023 / Accepted: 17 September 2023 / Published online: 4 October 2023
© The Author(s), under exclusive licence to the Institute of Chemistry, Slovak Academy of Sciences 2023

Abstract

Biogenic production of silver nanoparticles (sn-AgNPs) was accomplished by *Sambucus nigra*. The identification of structures was performed by a wide spectroscopic study. Ultraviolet–visible (UV–Vis) spectroscopic study indicated the maximum absorption of nanoparticles at 480 nm. Scanning electron microscopy (SEM) presented the nanoparticles as spherical shapes. X-ray diffraction (XRD) signals (2θ) at the degrees of 38.20°, 44.40°, 64.61°, 77.61°, and 81.76° corresponded to [111, 020, 202, 131, and 222] facet, respectively, confirming the nanostructure as face-centered cubic structure. The size of the nanoparticles was determined as 28.6 nm and 27.4 nm by SEM and TEM images, respectively. Zeta potential presented the stability of the product (− 51.3 mV). Furthermore, the histogram of dynamic light scattering (DLS) displayed the particle size of the nanostructure as 31.01 nm. HPLC analysis was used to determine the phenolics in *S. nigra* aerial part quantitatively and chlorogenic acid was the main product (10.76 mg/g extract). sn-AgNPs showed the substantial antioxidant effect as 12.1 ± 0.19 (µg/mL, lC_{50}) and 3.1 ± 0.1 (lC_{50}) for $DPPH^{\bullet}$ and $ABTS^{\bullet+}$ assays, respectively. Antibacterial activity of extract and sn-AgNPs was executed. Both extract and Sn-AgNPs exhibited considerable activity.

Keywords Nanotechnology · Natural products · Bioactive compounds · Quantitative analysis · Green synthesis

Introduction

Nanotechnology attracts a lot of attention due to its significant application area (Sahin Yaglioglu et al. 2022). Due to the high surface area, nanoparticles have distinctive properties providing them to be used widely in fields such as optoelectronics, biomedicine, and biosensing (Karan et al. 2022). Mostly, nanoparticle synthesis is carried out using physical and chemical techniques containing toxic chemicals (Genc et al. 2021). The green approach in nanoparticle synthesis has emerged as the most popular topic in recent years (Geetha et al. 2013). Natural products including vegetable waste, algae, arthropods, microorganisms, panchakavya, and plants have been applied for the production of nanostructures. Among them, plant-based materials are hopeful substrates for nanoparticle synthesis since the procedure is simple to scale up (Ameen et al. 2019).

Natural products have been applied for food and remedy for years (Zerrouki et al. 2022). Owing to their secondary metabolite contents, plants display a lot of biological effects, and they are utilized effectively in drug discovery processes (Yaglioglu et al. 2022). Plants synthesize compounds called primary and secondary metabolites. The former is essential for the survival of plants, and they execute physiological functions in the body (Eser et al. 2022). They involve in growth, development, and reproduction. However, secondary metabolites are derivatives of primary metabolism and play a role in ecological functions (Elmastaş et al. 2015). Moreover, secondary metabolites derived from plants were

✉ Tunay Karan
tunay.karan@bozok.edu.tr

✉ Ramazan Erenler
rerenler@gmail.com

1 Department of Genetics, Faculty of Veterinary, Yozgat Bozok University, Yozgat, Turkey

2 Department of Chemistry, Faculty of Arts and Sciences, Tokat Gaziosmanpasa University, Tokat, Turkey

3 Faculty of Health Sciences, Igdir University, Igdir, Turkey

4 Department of Food Hygiene and Technology, Faculty of Veterinary, Erciyes University, Kayseri, Turkey

5 Department of Physics, Faculty of Arts and Sciences, Tokat Gaziosmanpasa University, Tokat, Turkey

reported to display noteworthy biological effects including anti-inflammatory, anticancer, antimicrobial, antioxidant, anticonvulsant, antidepressant, antifungal, antiviral, etc. (Elmastas et al. 2016).

Natural products have been used extensively for nanoparticle synthesis. Aromatic and medicinal plants mediated synthesis of silver nanoparticles were reported to display considerable biological activities (Zhang et al. 2020).

Sambucus genus belonging to the Adoxaceae family contains 30 species. *S. nigra* known as elderberry consists of natural products such as flavonoids and terpenes. The main natural compounds in *Sambucus* species were determined as chlorogenic acid, isorhamnetin-3-glucoside, neochlorogenic acid, isorhamnetin-3, cryptochlorogenic acid, isorhamnetin, quercetin, rutin, astragaline, isoquercitrin, kaempferol-3-rutinoside, kaempferol-3-glucoside (Dawidowicz et al. 2006). In addition, it was reported that *S. nigra* fruits include minerals (vitamin C, amino acids, fiber, magnesium, and calcium) and organic acid (citric acid, malic acid, fumaric acid, tartaric acid, and shikimic acid) (Uzlasir et al. 2021). Due to the flavonoid content, elderberry has a high commercial value and is beneficial as a colorant in food such as jam, jelly, yogurt, fruit juice, and syrup production. In addition, it has been used in making waffles, pancakes, candies, and muffins due to its flowers, fragrance, and taste. *S. nigra* has been utilized effectively in folk medicine for the remedy of different ailments such as skin diseases, constipation, urinary tract disorders, respiratory tract diseases, viral infections, colds, and flu (Ferreira et al. 2022).

Superoxide, hydroxyl, nitric oxide, and peroxynitrite are reactive oxygen species produced in the mammalian body during metabolism (Yaman et al. 2022).

Human has many oxidative stress protection mechanisms. Exposure to factors such as bad lifestyle, smoking, UV radiation, and alcohol leads to insufficient natural antioxidants, and excess free radical damages the cells and their function. As a result, it causes degenerative diseases and conditions. Many drug-based antioxidants have been used to inhibit and remedy complex illnesses. Recently, natural antioxidants have been utilized in food, perfumery, and medical substances to substitute synthetic ones which are being banned owing to their carcinogenic effects. Antioxidants, especially natural constituents existed in edible plants, have an essential effect in the inhibition of human ailments (Guzel et al. 2017; Elmastas et al. 2018).

In the present work, sn-AgNPs were produced utilizing *Sambucus nigra* leaves, and antioxidant and antibacterial activities were assessed. Moreover, the quantification of phenolics in plants was defined.

Materials and methods

Plant

S. nigra was obtained from Murgul (Göktaş) district in Artvin province in June 2021 and elucidation was accomplished by Ozgur Eminagaoglu (Ph.D.), a voucher specimen was deposited in the Artvin Coruh University Herbarium (ARTH 6049).

Silver nanoparticles synthesis

S. nigra leaves (4.0 g) were added to a flask with deionized water (100 mL). The extraction was carried out by heating the flask at 40 °C for 1.5 h. After the filtration with Whatman filter paper, the solution was divided into two parts. One part was applied to the reduced pressure to yield the crude extract. Another part (50 mL) was treated with silver nitrate (1.0 mM, 50 mL) at 50 °C for 2 h to yield the desired product. After the centrifugation and lyophilization, the silver nanoparticles were obtained in black solid form (Ameen et al. 2019).

Characterization

The identification of sn-AgNPs was performed by advanced methods. The maximum absorption of sn-AgNPs was determined by ultraviolet–visible spectrophotometry with the model of Shimadzu UV-2600. The functional groups of bioactive constituents acting as capping stabilizing and reducing agents were displayed by Fourier transform infrared spectroscopy (Jasco, FTIR 4700). The crystalline structure of sn-AgNPs was determined by X-ray diffraction (XRD, Empyrean). Scanning electron microscopy (SEM) with EDX and transmission electron microscopy (TEM) displayed the morphology of sn-AgNPs. Zeta potential and dynamic light scattering were accomplished by Zetasizer Nano ZSP to display the stability and average diameter of sn-AgNPs.

DPPH assay

DPPH assay for nanoparticles and extract was carried out. At first stock solution of extract and nanoparticles (1.0 mg/mL) was prepared. Then, the treatment of the each extract and nanoparticles at different concentrations (3.0 mL, 2–40 µg/mL) with 1.0 mL DPPH$^{\bullet}$ (0.26 mM) was executed. The incubation of the mixture was continued for 30 min at room temperature. The absorbance was measured at 517 nm with a spectrophotometer. The results were presented as IC_{50} that was calculated by absorbance values at different

concentrations. The following equation was used for activity (1).

$$\text{DPPH}^{\bullet}\text{scavenging activity } (\%) = \left[(Ax - Ay)/Ay\right] \times 100 \quad (1)$$

in which Ax is the control and A2 is the absorbance of the extract and nanoparticles. Butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and Trolox were used for standards (Demirtas et al. 2011).

ABTS assay

The $ABTS^{\bullet+}$ radical cation solution was prepared by the reaction of ABTS solution (100 mL, 2.0 mM) with sodium persulfate (2.45 mM, 0.20 L) for 6 h at room temperature. The extract and sn-AgNPs solutions were prepared (1.0 mg/mL, in MeOH). The phosphate buffer (0.1 M, pH 7.4) was added to each extract and sn-AgNPs solution (80 µL) up to 1.25 mL. The different concentrations of sn-AgNPs and extract (3.0 mL, 2–40 µg/mL) were treated with 1.0 mL $ABTS^{\bullet+}$ solution (1.0 mL). BHA, BHT, and Trolox were used for standard compounds. A spectroscopy (734 nm) was used for the evaluation of activity with given Eq. (2).

$$ABTS^{\bullet+}\text{scavenging effect } (\%) = \left[(Ax - Ay)/Ay\right] \times 100 \quad (2)$$

in which Ax is the initial concentration of $ABTS^{\bullet+}$ and A2 is the remaining concentration (Gecer et al. 2021).

Reducing power activity assay

The reducing power capacity of nanoparticles and leaf extract was evaluated by ferric ions reduction assay. The samples (10–90 µg/mL, 100 µL) were treated with the potassium ferric cyanide, $[K_3Fe(CN)_6]$ (1.25 mL) in the presence of buffer (0.20 M); then, the reaction mixture was incubated for 30 min at 50 °C. Afterward, 1. 25 mL of trichloroacetic acid and 0.25 mL of $FeCl_3$ were to the mixture and vortexed. Absorbance was determined at 700 nm on a spectrophotometer (Ozen et al. 2011).

Antibacterial activity

The antibacterial effect of sn-AgNPs and extract was investigated by microdilution broth methods using Gram-negative: *Salmonella Enteritidis* (ATCC 13311), *Escherichia coli* (ATCC 25922), and two Gram-positive bacteria: *Listeria monocytogenes* (ATCC 15313), *Staphylococcus aureus* (ATCC 29213). Firstly, the concentrations of bacteria were adjusted at 0.5 Mc Farland standard (1.5×10^8 CFU/mL). While the initial concentration was confirmed 100%, the extract and synthesized silver nanoparticles were diluted from 10^{-2} to 10^{-8}. Then, 100 µL of the tested bacterial solution in Muller–Hinton broth was inoculated into each well, excluding negative control (medium only), and incubated at 37 °C for 24 h. Subsequently, 10 µL of each sample was spread on the surface of blood agar (Ozen et al. 2020). Then, incubation was executed for 24 h at 37 °C.

Quantitative analysis of phenolics

The quantitative analysis of phenolics is significant for the phytochemistry of the plants. In this study, quantitative analysis of phenolics in *S. nigra* was performed by HPLC (Agilent 1260 infinity) with C-18 column (4.6 mm × 250 mm, 5 µm). 20 mg of extract was dissolved in a methanol/water mixture (1/1) and then filtrated. The extract solution was prepared (10,000 ppm) and injected into the column. The oven column temperature was settled to 30 °C, and the injection volume was 10 µL. The eluent was regulated as X: 0.1% phosphoric acid in water and Y: acetonitrile as 0 min, 80% X; 0–5 min, 75% X; 6–15 min, 70% X; 16–25 min, 65% X; 26–30 min, 60% X; 31–35 min, 55% X; 36–40 min, 50% X; 41–46 min, 45% X; 47–50 min, 40% X (Erenler et al. 2023).

Statistical analysis

The statistical analysis for biological activity was performed by GraphPad Prism (v.8.0). After verifying the normality of distribution and homogeneity of the data, one-way ANOVA followed by Turkey's test were employed. The results were stated as mean values with SDs ($P < 0.05$).

Result and discussion

The use of nanotechnology in the field of plants is the important research topics of recent years. Nanoparticles have the ability to influence the growth and development of plants. Both enhancing and detrimental effects are observed in seed germination, shoot growth, biomass production and physiological/biochemical activities (Verma et al. 2018). Silver nanoparticles were synthesized using the leaf extract of *Coleus forskohlii* leaves, and it was determined that the synthesized nanoparticles showed a high effect against pathogenic bacteria (Chakraborty et al. 2022). The synthesis of AgNPs was achieved using banana leaf extract and a positive correlation was reported between the concentrations of nanoparticles and the growth response of stevia shoot cultures (Laha et al. 2023).

UV–Vis analysis

The absorption at 480 nm in UV–vis analysis presented the desired product. In addition, the color change established the sn-AgNPs formation. The mechanism was indicated

using the catechin since the extract includes the catechin. The characteristic signal in the UV–vis spectrum between 350 and 550 nm presents the growth of silver nanoparticles (Fig. 1). Since the *S. nigra* includes the catechin, the reaction mechanism was demonstrated by the catechin (Fig. 2).

FTIR measurement

The compounds in leaves were determined by FTIR analysis. In FTIR spectrum of extract exhibited absorption at 3192 cm^{-1} belonging to the O–H stretching. The signals at 2101 cm^{-1} and 1983 cm^{-1} can be assigned to CH bending and alkyne stretching, respectively. The carbon–carbon double bond stretching signal was observed at 1590 cm^{-1}. The peak at 1373 cm^{-1} can be assigned to O–H bending. The C–O signal appeared at 1042 cm^{-1}, and the peak at 524 cm^{-1} may be assigned to C–I stretching (Fig. 3) (Al-Zaban et al. 2021).

Scanning electron microscope and transmission electron microscopy

The morphology and particle size were defined by SEM and TEM analyses (Fig. 4). The sn-AgNPs displayed regular distribution, high density, and low aggregation. The particle size sn-AgNPs was calculated as 28.6 nm and 27.4 nm by SEM and TEM images, respectively. The particle size distribution was also provided (Fig. 4). In the EDX spectrum, the intense signals at 2.6–3.9 keV approved the formation of sn-AgNPs. Elemental analysis revealed that the nanoparticles were 83.6% pure. The intense silver peaks and weak nitrogen, chlorine, and oxygen were observed in the EDX spectrum. These weak signals were mostly associated with the bioactive compounds found in extract absorbed by nanoparticles (Maity et al. 2020).

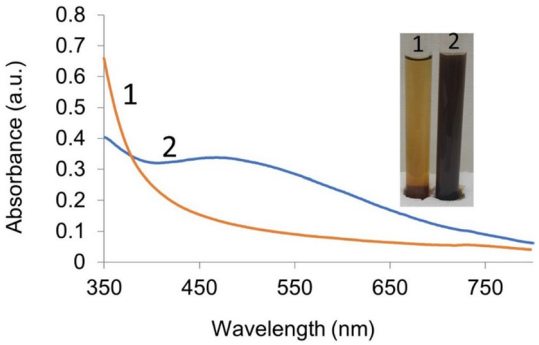


Fig. 1 UV–vis spectrum of extract (1) and sn-AgNPs (2)

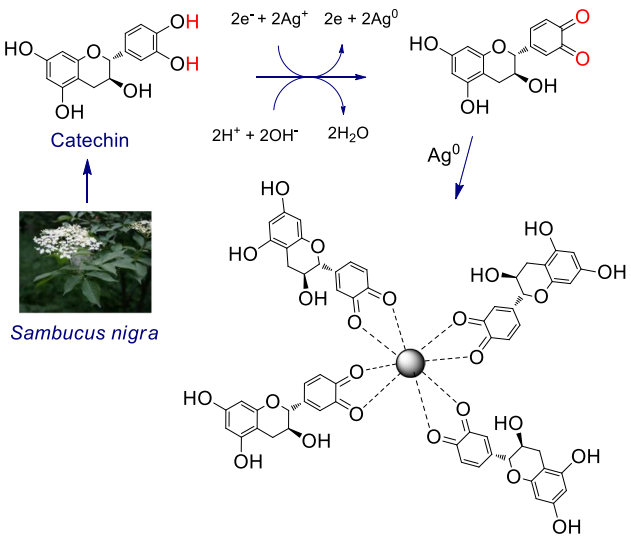


Fig. 2 Reaction mechanism of silver nanoparticles synthesis

XRD analysis

The crystal structure of nanoparticles was established by XRD analysis. The intense peak at (2θ) 38.20°, 44.40°, 64.61°, 77.61°, and 81.76° corresponded to the plane of 100, 020, 202, 131, and 222, respectively, suggesting the nanoparticles to be fcc structure (Fig. 5) (Alomar et al. 2020). The EDX spectrum confirmed the proposed structure (Fig. 6) and elemental analysis displayed the formation of the nanoparticle with a high yield (83.60%).

Zeta potential

The zeta potential analysis displayed the stability of sn-AgNPs. The potential was measured as −51.3 mV indicating high stability (Fig. 7). In addition, the average size of sn-AgNPs in suspension was calculated as 31.01 nm (Fig. 8). Electrostatic repulsions between negative charges stabilize the nanoparticle in colloidal solution. Besides, a high negative charge resulted in stability. The negatively charged

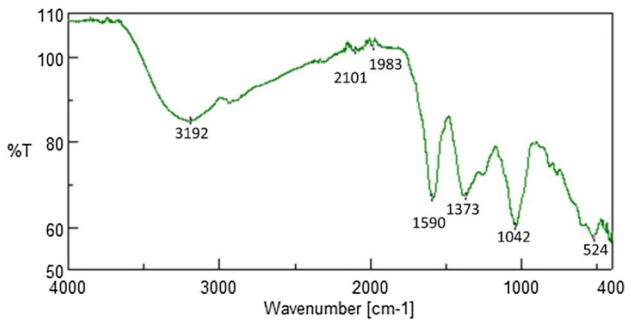


Fig. 3 FTIR spectrum of *Sambucus nigra* leaf extract

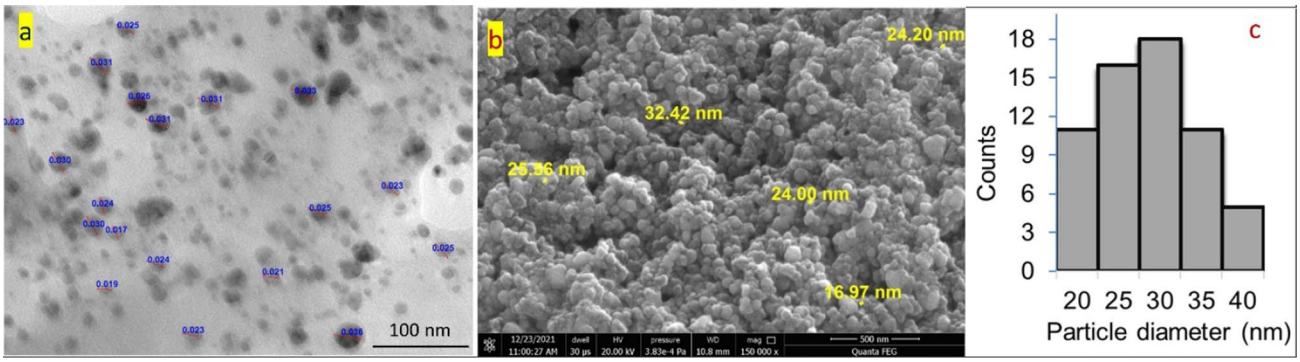


Fig. 4 SEM image of sn-AgNPs and particle size distribution

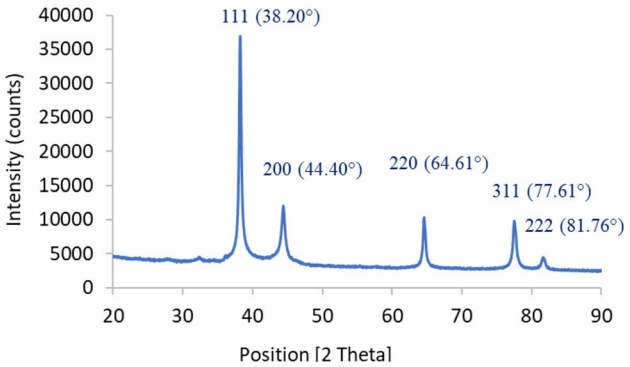


Fig. 5 XRD pattern of silver nanoparticles

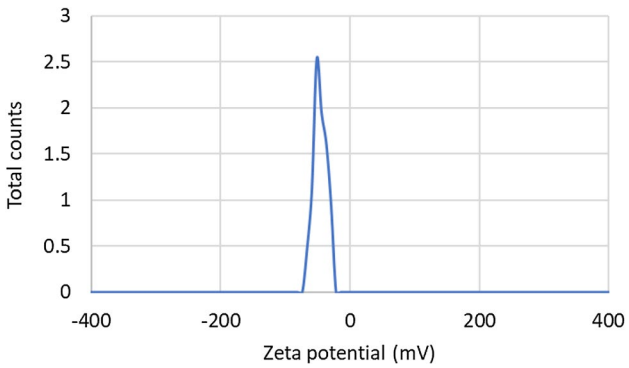


Fig. 7 Zeta potential **a** and dynamic light scattering (DLS) **b** of sn-AgNPs

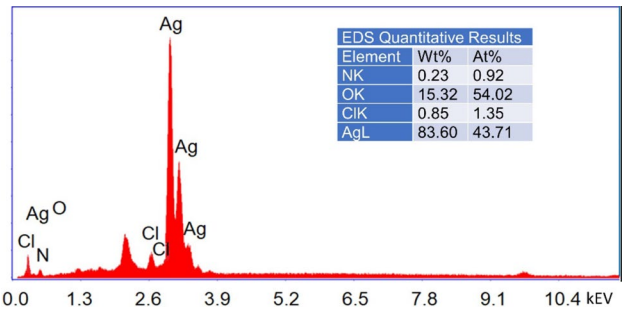


Fig. 6 EDX spectrum of AgNPs

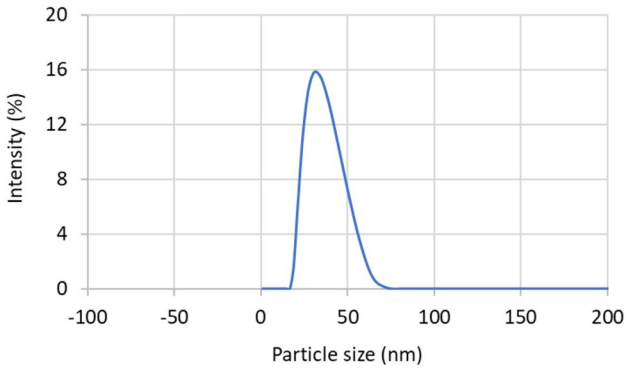


Fig. 8 Dynamic light scattering (DLS) **b** of sn-AgNPs

nanoparticles prevented aggregation and controlled shape and size (Paosen et al. 2017).

Quantitative analysis

Quantification of phenolics was performed by HPLC (Table 1). Chlorogenic acid and *t*-ferulic acid were the chief compounds with a quantity of 10.76 mg/g extract and 10.07 mg/g extract, respectively. In addition, sinapic acid (6.59 mg/g extract), catechin (2.07 mg/g extract), catechin hydrate (2.53), and naringin (1.56) were determined in *S. nigra* water extract abundantly. Dietary polyphenols are beneficial to human health due to a variety of biological effects. Epidemiological studies have determined that there is a relationship between the consumption of foods rich in polyphenols and the prevention of diseases such as cancer and heart disease. Phenolic acid and flavonoids are the class of polyphenols. Hydroxycinnamic acid is the major class

Table 1 Quantitative analysis of phenolic compounds in S. nigra leaves (mg/g extract)

Compounds	Quantity
Catechin	2.07
Vanillic acid	Nd
Gentisic acid	nd
Sinapic acid	6.59
Hyperoside	nd
İsoquercitrin	0.77
Protocatechuic acid ethyl ester	0.28
Baicalin	0.12
Oleuropein	nd
Hesperidin	0.15
6-hydroxy flavone	0.23
Curcumin	nd
Clorogenic acid	10.76
Catechin hydrate	2.53
Caffeic acid	nd
4-Hydroxy benzoic acid	0.06
Vanillin	0.05
p-Coumaric acid	0.19
Rutin	0.13
t-Ferulic acid	10.07
Hydroxy sinamic acid	0.06
Naringin	1.56
o-Coumaric acid	0.11
Rosmarinic acid	0.02
Salicylic acid	0.09
Resveratrol	0.13
Quercetin	0.50
t-Cinnamic acid	0.06
Naringenin	0.10
Chrysin	0.50
Flavone	0.01

of phenolic acid, and chlorogenic acid is the main representative of hydroxycinnamic acid. Chlorogenic acid is widespread in plants, fruits, and vegetables. Chlorogenic acid was stated to display antimutagenic, carcinogenic, and antioxidant activities (Sato et al. 2011). Ferulic acid was described to display various biological activities including antioxidant, antimicrobial, anti-inflammatory, and anticancer activities (Ou and Kwok 2004). Silver nanoparticles capped by compounds could be an effective agent for pharmacy.

Antioxidant effect

Antioxidant effects of extract and sn-AgNPs were performed employing the ABTS, DPPH, and FRAP assay (Fig. 9). In the DPPH assay, sn-AgNPs exhibited excellent activity (lC_{50}, µg/mL, 12.1 ± 0.19) in comparison with the extract. sn-AgNPs also revealed considerable ABTS activity (lC_{50}, µg/mL, 3.1 ± 0.1), even better than the standards. Concerning the FRAP assay, the same trend was observed. The activity of nanoparticles was found better than that of the extract. Previous scientific studies reported that silver nanoparticles exhibited considerable antioxidant activity. *Origanum majorana* was employed for of AgNPs synthesis that showed great antioxidant activity (Erenler and Dag 2022). In addition, the synthesis of nanoparticles by *Astragalus logopodioides* was achieved and exhibited excellent antioxidant activity (Erenler and Gecer 2022a). *Sideritis montana* was applied for the synthesis of silver nanoparticles that demonstrated a substantial antioxidant effect (Erenler and Gecer 2022b). Bioactive compounds such as phenolic compounds are capable of capping, stabilizing, and reducing silver ions. Hence, silver nanoparticles could reveal antioxidant activity.

Antibacterial effects

Antibacterial activity of extract and sn-AgNPs was performed. MIC values of *S. nigra* extract and sn-AgNPs are given in Table 2. sn-AgNPs displayed strong antibacterial activity against *S. Enteritidis* and *E.coli* at MIC values of 64 µg/mL and 32 µg/mL, respectively. The sn-AgNPs showed considerable antibacterial activity at 64 µg/mL and 16 µg/mL against *S. aureus* and *L. monocytogenes,* respectively. The extract has effective antibacterial activity against *E.coli* and MIC value was 64 µg/mL. Tetracycline standard revealed the excellent activity at low concentrations (4 µg/mL) against *E. coli.* In some reported studies for black elderberry, black elderberry exhibited antioxidant, antibacterial, antimicrobial, antiviral, and anti-inflammatory effects (Młynarczyk et al. 2018).

Bioactive molecules such as phenolic acids, flavonoids, steroids, and terpenes in the content of plants serve the synthesis of silver nanoparticles. Silver nanoparticles to be formed will also be of great importance due to the efficient and effective pharmacological properties of the relevant bioactive molecules. It is possible to form nanoparticles from copper, zinc, titanium, magnesium, gold, and silver metals. Among them, silver is the metal with the most effective antimicrobial and antioxidant effect (Mohanpuria et al. 2008). When we investigated the nanoparticle studies of *S. nigra*, silver nanoparticles were synthesized from the fruit extract, and antioxidant studies were carried out (Moldovan et al. 2016). There are not many studies on silver nanoparticle synthesis and the antimicrobial effect of the plant in the pieces of literature. The effect of *S. nigra* silver nanoparticle synthesis against *Staphylococcus aureus* and *Escherichia coli* bacteria was investigated by agar well diffusion test, and it was reported that it had a wonderful effect against these bacteria. Unlike our study, silver nanoparticle synthesis was made from *S. nigra*

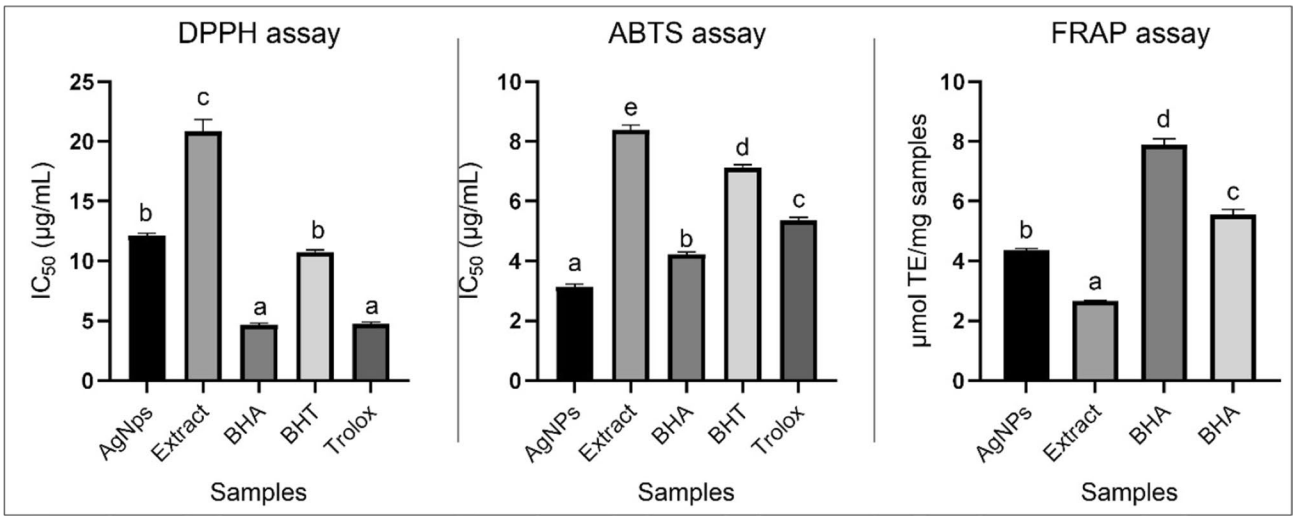


Fig. 9 Antioxidant activity

Table 2 Antibacterial activity of extract and sn-AgNPs (µg/mL)

Samples	*S. Enteritidis*	*E. coli*	*S. aureus*	*L. monocytogenes*
Sn-AgNPs	64	32	64	16
Extract	128	64	128	32
Tetracycline	64	4	64	16

leaf. The effects of extracts and nanoparticles against *S. Enteritidis* and *E.coli* from Gram negative bacteria and *L. monocytogenes* and *S. aureus* from Gram positive bacteria were investigated by MIC value. It was determined that the antibacterial effect of nanoparticle against *S. Enteritidis* was better than the extract.

Conclusions

Silver nanoparticles were synthesized using *S. nigra* leaf extract by eco-friendly, cheap, and scalable approach. Sn-AgNPs demonstrated promising antioxidant activity in comparison with the standards, BHA, BHT, and Trolox. Hence, sn-AgNPs may be a promising ingredient for food and drug development. In particular, it could be raw material in the drug development stage for the disease caused by excess free radicals. Due to the displaying antibacterial activity of sn-AgNPs, they can be employed as antimicrobial agents. The plant extract contained chlorogenic acid and ferulic acid as major compounds. Hence, the antioxidant and antimicrobial activity could be due to these compounds or the synergic effect of bioactive compounds in plants.

Acknowledgements The authors thank to Dr. Ozgur Eminagaoglu for providing the plant.

Author contributions The extraction and synthesis of silver nanoparticles were carried out by RE. Activity tests were executed by ZG, spectral interpretations were carried out by UK, and manuscript preparation and project design were carried out by TK.

Funding Yozgat Bozok University, Scientific and Research Unit was supported of this study (BAP 6602a-VET/21–454).

Availability of data and materials The datasets are provided upon reasonable request.

Declarations

Conflict of interest The authors declare that there are no competing interests.

References

Alomar TS, AlMasoud N, Awad MA, El-Tohamy MF, Soliman DA (2020) An eco-friendly plant-mediated synthesis of silver nanoparticles: characterization, pharmaceutical and biomedical applications. Mater Chem Phys 249:123007. https://doi.org/10.1016/j.matchemphys.2020.123007

Al-Zaban MI, Mahmoud MA, AlHarbi MA (2021) Catalytic degradation of methylene blue using silver nanoparticles synthesized by honey. Saudi J Biol Sci 28:2007–2013. https://doi.org/10.1016/j.sjbs.2021.01.003

Ameen F, Srinivasan P, Selvankumar T, Kamala-Kannan S, Al Nadhari S, Almansob A, Dawoud T, Govarthanan M (2019) Phytosynthesis of silver nanoparticles using *Mangifera indica* flower extract as bioreductant and their broad-spectrum antibacterial activity. Bioorg Chem 88:102970. https://doi.org/10.1016/j.bioorg.2019.102970

Chakraborty A, Haque SM, Ghosh D, Dey D, Mukherjee S, Maity DK, Ghosh B (2022) Silver nanoparticle synthesis and their potency against multidrug-resistant bacteria: a green approach

from tissue-cultured *Coleus forskohlii*. 3 Biotech 12:228. https://doi.org/10.1007/s13205-022-03295-z

Dawidowicz AL, Wianowska D, Baraniak B (2006) The antioxidant properties of alcoholic extracts from *Sambucus nigra* L. (antioxidant properties of extracts). LWT-Food Sci Technol 39:308–315. https://doi.org/10.1016/j.lwt.2005.01.005

Demirtas I, Ayhan B, Sahin A, Aksit H, Elmastas M, Telci I (2011) Antioxidant activity and chemical composition of Sideritis libanotica Labill. ssp linearis (Bentham) Borm. (Lamiaceae). Nat Prod Res 25:1512–1523. https://doi.org/10.1080/14786410903293191

Elmastaş M, Telci İ, Akşit H, Erenler R (2015) Comparison of total phenolic contents and antioxidant capacities in mint genotipleri-inin toplam fenolik içerikleri ve antioksidan kapasitelerinin karşılaştırılması. Turk J Biochem 40:456–462. https://doi.org/10.1515/tjb-2015-0034

Elmastas M, Erenler R, Isnac B, Aksit H, Sen O, Genc N, Demirtas I (2016) Isolation and identification of a new neo-clerodane diterpenoid from *Teucrium chamaedrys* L. Nat Prod Res 30:299–304. https://doi.org/10.1080/14786419.2015.1057583

Elmastas M, Celik SM, Genc N, Aksit H, Erenler R, Gulcin İ (2018) Antioxidant activity of an anatolian herbal tea—*Origanum minutiflorum*: isolation and characterization of its secondary metabolites. Int J Food Prop 21:374–384. https://doi.org/10.1080/10942912.2017.1416399

Erenler R, Dag B (2022) Biosynthesis of silver nanoparticles using *Origanum majorana* L. and evaluation of their antioxidant activity. Inorg Nano-Met Chem 52:485–492. https://doi.org/10.1080/24701556.2021.1952263

Erenler R, Gecer EN (2022a) Green synthesis of silver nanoparticles from *Astragalus logopodioides* L. leaves. Turk J Agric Food Sci Tech 10:1112–1115. https://doi.org/10.24925/turjaf.v10i6.1112-1115.5190

Erenler R, Gecer EN (2022b) Synthesis of silver nanoparticles using *Sideritis montana* L. leaf extract: characterization, catalytic degradation of methylene blue and antioxidant activity. J Nano Res 75:17–28. https://doi.org/10.4028/p-333bjm

Erenler R, Yaman C, Demirtas I, Alma MH (2023) Phytochemical investigation of *Hypericum heterophyllum* Flowers: LC-ESI-MS/MS analysis, total phenolic and flavonoid contents. Antioxidant Act Nat Prod J 13:e120123212672. https://doi.org/10.2174/2210315513666230112165545

Eser F, Altun M, Demirtas I, Behcet L, Aktas E (2022) Three new iridoids from the aerial parts of *Nepeta teucriifolia* Willd. and antiproliferative activities of extracts. Nat Prod Res. https://doi.org/10.1080/14786419.2022.2036148

Ferreira SS, Silva AM, Nunes FM (2022) *Sambucus nigra* L. fruits and flowers: chemical composition and related bioactivities. Food Rev Intl 38:1237–1265. https://doi.org/10.1080/87559129.2020.1788578

Gecer EN, Erenler R, Temiz C, Genc N, Yildiz I (2021) Green synthesis of silver nanoparticles from *Echinacea purpurea* (L.) Moench with antioxidant profile. Part Sci Technol 40:50–57. https://doi.org/10.1080/02726351.2021.1904309

Geetha K, Umadevi M, Sathe GV, Erenler R (2013) Spectroscopic investigations on the orientation of 1,4-dibromonaphthalene on silver nanoparticles. Spectrochim Acta A Mol Biomol Spectrosc 116:236–241. https://doi.org/10.1016/j.saa.2013.07.039

Genc N, Yildiz I, Chaoui R, Erenler R, Temiz C, Elmastas M (2021) Biosynthesis, characterization and antioxidant activity of oleuropein-mediated silver nanoparticles. Inorg Nano-Met Chem 51:411–419. https://doi.org/10.1080/24701556.2020.1792495

Guzel A, Aksit H, Elmastas M, Erenler R (2017) Bioassay-guided isolation and identification of antioxidant flavonoids from *Cyclotrichium origanifolium* (Labill.) Manden and Scheng. Pharmacogn Mag 13:316. https://doi.org/10.4103/0973-1296.204556

Karan T, Erenler R, Bozer Moran B (2022) Synthesis and characterization of silver nanoparticles using curcumin: cytotoxic, apoptotic, and necrotic effects on various cell lines. Z Naturforsch C J Biosci 77:343–350. https://doi.org/10.1515/znc-2021-0298

Laha S, Subrahmanyeswari T, Verma SK, Kamble SN, Singh S, Bhattacharyya S, Gantait S (2023) Biogenic synthesis, characterization and application of silver nanoparticles as biostimulator for growth and rebaudioside—a production in genetically stable stevia (*Stevia rebaudiana* Bert.) under in vitro conditions. Ind Crop Prod 197:116520. https://doi.org/10.1016/j.indcrop.2023.116520

Maity GN, Maity P, Choudhuri I, Sahoo GC, Maity N, Ghosh K, Bhattacharyya N, Dalai S, Mondal S (2020) Green synthesis, characterization, antimicrobial and cytotoxic effect of silver nanoparticles using arabinoxylan isolated from Kalmegh. Int J Biol Macromol 162:1025–1034. https://doi.org/10.1016/j.ijbiomac.2020.06.215

Młynarczyk K, Walkowiak-Tomczak D, Łysiak GP (2018) Bioactive properties of *Sambucus nigra* L. as a functional ingredient for food and pharmaceutical industry. J Funct Foods 40:377–390. https://doi.org/10.1016/j.jff.2017.11.025

Mohanpuria P, Rana NK, Yadav SK (2008) Biosynthesis of nanoparticles: technological concepts and future applications. J Nanopart Res 10:507–517. https://doi.org/10.1007/s11051-007-9275-x

Moldovan B, David L, Achim M, Clichici S, Filip GA (2016) A green approach to phytomediated synthesis of silver nanoparticles using *Sambucus nigra* L. fruits extract and their antioxidant activity. J Mol Liq 221:271–278. https://doi.org/10.1016/j.molliq.2016.06.003

Ou S, Kwok KC (2004) Ferulic acid: pharmaceutical functions, preparation and applications in foods. J Sci Food Agric 84:1261–1269. https://doi.org/10.1002/jsfa.1873

Ozen T, Demirtas I, Aksit H (2011) Determination of antioxidant activities of various extracts and essential oil compositions of *Thymus praecox* subsp *skorpilii* var. *skorpilii*. Food Chem 124:58–64. https://doi.org/10.1016/j.foodchem.2010.05.103

Ozen T, Bora N, Yenigun S, Korkmaz H (2020) An investigation of chemical content, enzyme inhibitory propert, antioxidant and antibacterial activity of *Aristolochia bodamae* Dingler (develiotu) (Aristolochiaceae) root extracts from Samsun, Turkey. Flavour Frag J 35:270–283. https://doi.org/10.1002/ffj.3559

Paosen S, Saising J, Septama AW, Voravuthikunchai SP (2017) Green synthesis of silver nanoparticles using plants from Myrtaceae family and characterization of their antibacterial activity. Mater Lett 209:201–206. https://doi.org/10.1016/j.matlet.2017.07.102

Sahin Yaglioglu A, Erenler R, Gecer EN, Genc N (2022) Biosynthesis of silver nanoparticles using *Astragalus flavesces* Leaf: identification, antioxidant activity, and catalytic degradation of methylene blue. J Inorg Organomet Polym Mater 32:3700–3707. https://doi.org/10.1007/s10904-022-02362-5

Sato Y, Itagaki S, Kurokawa T, Ogura J, Kobayashi M, Hirano T, Sugawara M, Iseki K (2011) In vitro and in vivo antioxidant properties of chlorogenic acid and caffeic acid. Int J Pharm 403:136–138. https://doi.org/10.1016/j.ijpharm.2010.09.035

Uzlasir T, Kadiroglu P, Selli S, Kelebek H (2021) LC-DAD-ESI-MS/MS characterization of elderberry flower (*Sambucus nigra*) phenolic compounds in ethanol, methanol, and aqueous extracts. J Food Process Pres 45:e14478. https://doi.org/10.1111/jfpp.14478

Verma SK, Das AK, Patel MK, Shah A, Kumar V, Gantait S (2018) Engineered nanomaterials for plant growth and development: a perspective analysis. Sci Total Environ 630:1413–1435. https://doi.org/10.1016/j.scitotenv.2018.02.313

Yaglioglu AS, Gurbuz DG, Dolarslan M, Demirtas I (2022) First determination of anticancer, cytotoxic, and in silico ADME evaluation of secondary metabolites of endemic *Astragalus leucothrix* Freyn & Bornm. Turk J Chem 46:169. https://doi.org/10.3906/kim-2104-23

Yaman C, Önlü Ş, Ahmed H, Erenler R (2022) Comparison of phytochemicals and antioxidant capacity of *Hypericum perforatum;* wild plant parts and in vitro samples. J Anim Plant Sci 32:596–603. https://doi.org/10.36899/JAPS.2022.2.0459

Zerrouki S, Mezhoud S, Sahin Yaglioglu A, Bensouici C, Nuri Atalar M, Demirtas I, Ameddah S, Mekkiou R (2022) Antioxidant, anticancer activities, and HPLC-DAD analyses of the medicinal halophyte *Limoniastrum guyonianum* Dur. extracts. J Res Pharm 26:598–608. https://doi.org/10.29228/jrp.157

Zhang D, Ma X-l, Gu Y, Huang H, Zhang G-W (2020) Green synthesis of metallic nanoparticles and their potential applications to treat cancer. Front Chem 8:799. https://doi.org/10.3389/fchem.2020.00799

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.