Journal of Inorganic and Organometallic Polymers and Materials (2022) 32:3700–3707
https://doi.org/10.1007/s10904-022-02362-5

Biosynthesis of Silver Nanoparticles Using *Astragalus flavesces* Leaf: Identification, Antioxidant Activity, and Catalytic Degradation of Methylene Blue

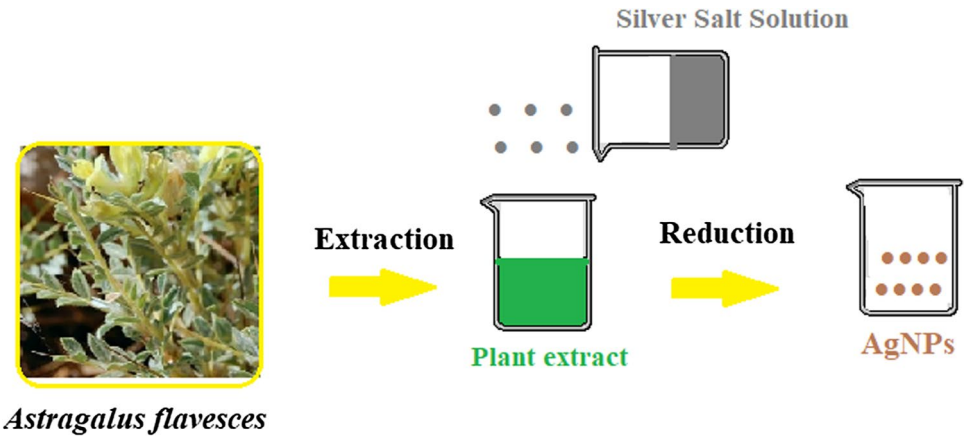
Ayse Sahin Yaglioglu[1] · Ramazan Erenler[2] · Esma Nur Gecer[2] · Nusret Genc[2]

Received: 9 March 2022 / Accepted: 27 April 2022 / Published online: 24 May 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract

Nanoparticles (NPs) are used in many fields. For example, electronics, optics, textiles, pharmaceuticals, catalysts, water treatment, and environmental remediation. In this work, the biosynthesis of silver nanoparticles (Af-AgNPs) from *Astragalus flavesces* leaf was synthesized. Af-AgNPs were featured by UV–visible, Fourier-transform infrared spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy, and powdered X-ray diffraction (XRD) analyses. The maximum absorption peak was detected at 417 nm. The average size of Af-AgNPs was 63.15 nm and their spherical shape was determined by SEM spectral analysis. XRD spectral analysis at 2θ degrees of 38.1°, 44.3°, 64.4°, and 77.4° can be indexed to the (111), (200), (220), and (311) face-centered cubic crystalline structure. Af-AgNPs have the potential of − 29.1 mV which indicated the stability of nanoparticles as well as repulsion among the particles. Antioxidant activities of Af-AgNPs and the extract were investigated by the $DPPH^{\cdot}$, $ABTS^{\cdot+}$, and FRAP assays. Af-AgNPs showed antioxidant activity to a degree that can be used in the food and pharmaceutical industries. The catalytic activity of Af-AgNPs was studied and at 28 h, 69% degradation was observed in the methylene blue solution.

Graphical Abstract



Keywords *Astragalus flavesces* · Spectroscopy · Nanoparticles · Antioxidant activity · Catalytic activity

✉ Ayse Sahin Yaglioglu
aysesahin1@gmail.com

[1] Department of Chemistry and Chemical Process Technology, Technical Sciences Vocational School, Amasya University, Amasya, Turkey

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

1 Introduction

Nanoparticles (NPs) have many commercial applications such as optical devices, environmental cleanup, biomedical engineering, catalysis, energy applications, etc. [1].

Nanoparticles are synthesized by three methods: physical, chemical, and biological methods. The high energy consumption in physical methods, the use of organic solvents, and toxic reagents in chemical methods that cause harmful waste to the environment limit the use of these meters. On the contrary, the biological or green synthesis method has advantages such as being environmentally friendly, inexpensive, easy to use, low harmful potential, and compatible with living organisms. In these methods, bacteria, fungi, algae and plants are used [2, 3]. Among them, plant extracts contain many compounds such as flavonoids, terpenoids, ketones, carboxylic acids, amides, proteins, and enzymes [4]. The secondary metabolites can act as reducing, stabilizing, and capping agents in the reduction of metal ions to metallic nanoparticles (MNPs) [5] In addition; the synthesis of plant-based NPs overcomes the aggregation problems of NPs and provides greater stability and faster reduction rate compared to other methods [6]. However, the green synthesis does not require high pressure, high energy, high temperature, and toxic chemicals [7]. Therefore, plant extracts have been used in the synthesis of many NPs [8–14].

In addition, NPs synthesized with plant extracts, a synergistic activity occurs when the activity of both materials (plant extract and MNPs) is combined [15].

Astragalus L. (Fabaceae) species is one of the largest genera in the world with approximately 3000 taxa [16]. In Turkey, the genus is represented by 476 taxa with 51% endemism [17]. Saponins, flavonoids, and polysaccharides are the main active components of *Astragalus* species [18]. At the same time, the species have anthraquinones, alkaloids, amino acids, β-sitosterol and metallic elements [19] and many phenolic compounds [20, 21].

Among the plant-based synthesized metal NPs, AgNPs have many biological activities such as antimicrobial, wound-healing, antibacterial, antiviral, antifungal, anti-inflammatory, and anticancer activities, especially antioxidant activity [15, 22]. AgNPs synthesized from some *Astragalus* species have antioxidant, antibacterial, and anti-inflammatory activity [23–25].

Hydroxyl (OH·), peroxyl (ROO·), superoxide ($O_2 \cdot^-$), peroxynitrite ($\cdot ONOO^-$) radicals are reactive oxygen species produced during oxidation in humans. Although humans have many protection systems against oxidative stress, they can sometimes be insufficient. Accordingly, radicals cause diseases by damaging the cell membrane. For this purpose, foods containing antioxidant substances that prevent the oxidation of the substrate should be consumed. Phenolic compounds found in plants are produced by plants. The plants are natural antioxidants because of inhibiting oxidation [26].

In this work, Af-AgNPs were synthesized from *Astragalus flavesces* leaf and their structures were determined by spectroscopic methods. In addition, antioxidant activities of silver nanoparticles and plant extract were performed. The catalytic activity of the synthesized nanoparticles was investigated. This is the first report on the synthesis and identification, antioxidant activity and, catalytic degradation of silver nanoparticles from the leaf of *Astragalus flavesces*. AgNPs are increasingly used in the medical, food, health, consumer and industrial fields. Every plant contains secondary metabolites. AgNPs, which are capped and stabilized by phenolic compounds found in *A. flavesces*, could be promising materials for the food and pharmaceutical industries.

2 Materials and Methods

2.1 Chemicals and Instrumentation

All the chemicals and solvents with analytical grades were purchased from Sigma-Aldrich. Fourier Transforms Infrared (FTIR) measurement with Jasco FT/IR 4700 spectrometer, Scanning Electron Microscope (SEM) analysis by Quanta Feg450.

2.2 Plant Materials

Astragalus flavesces was collected from Izmir, Odemis, and identified by Dr. Serdar G. Senol, Ege University, Faculty of Sciences, Department of Biology. A voucher specimen was deposited at the herbarium of Ege University (EGE-19536).

2.3 Synthesis of Silver Nanoparticles

Astragalus flavesces leaf was separated and dried. Then the leaf was powdered. The leaf powder (100 g) was taken in erlenmeyer and above-added water (0.5 L). The mix was heated at 80 °C for two hours. The resulting mixture was filtered and the plant extract was obtained. The prepared $AgNO_3$ (2.5 g/ 200 mL distilled water) solution was added dropwise onto the plant extract and taken into the reaction flask. The flask was boiled at 70 °C for two hours under reflux. A change from yellow to brown was observed in the reaction medium with the reduction of Ag + to Ag0 (Fig. 1). After completion of the reaction, Af-AgNPs were obtained by repeated centrifugation at 5000 rpm for 20 min then washed thoroughly with distilled water. The Af-AgNPs were dried by lyophilisation [27].

2.4 UV–Vis Measurement

Ultraviolet-visible (UV–Vis) measurements of Af-AgNPs solution were measured by Hitachi U-2900 spectrophotometer. The measurement has been taken between 300 and 800 nm.

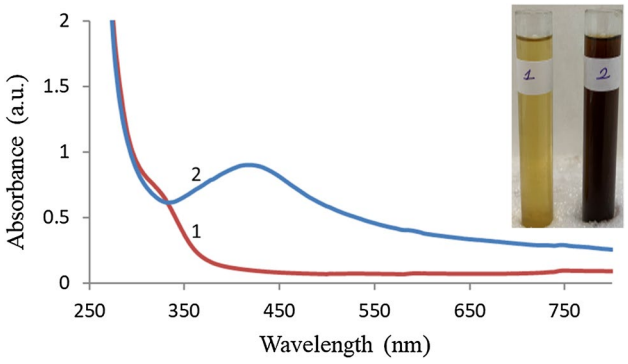


Fig. 1 UV–Vis spectrum of extract (1) and Af-AgNPs (2) at 417 nm. The aqueous solution of extract (1), Af-AgNPs (2)

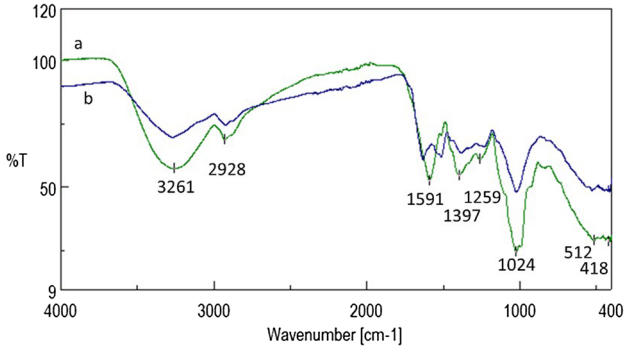


Fig. 2 FTIR spectrum of extract (*a*) and Af-AgNPs (*b*)

2.5 X-ray Diffraction (XRD) Analysis

XRD analysis was carried out by Malvern Panalytical Diffractometer With Highscore Plus. Af-AgNPs' dimensions were detected by dynamic light scattering (DLS) on a DelsaNano C instrument.

2.6 Scanning Electron Microscope (SEM) Analysis

The properties of Af-AgNPs were observed by SEM analysis. The elemental analysis of Af-AgNPs was detected by EDAX detector and EDX. The analysis methods were used by Gecer et al. [27].

2.7 Transmission Electron Microscopy (TEM)

Morphology and particle size analysis on biosynthesized Af-AgNPs were achieved by TEM measurements (Hitachi HighTech HT7700).

2.8 Zeta Potential

Zeta potential measurement was carried out by the Zetasizer Nano ZSP (Malvern) instrument.

2.9 Antioxidant Activity

2.9.1 DPPH· Free Radical Scavenging Activity

2,2-diphenyl-1-picril hydrazyl radical (DPPH·) scavenging effect for *Astragalus flavesces* aqueous extract and Af-AgNPs were carried out according to the method of Sahin Yaglioglu et al. [28]. The results were calculated as IC50.

2.9.2 ABTS·+ Scavenging Activity

ABTS·+ radical cation scavenging activities of the extracts and Af-AgNPs were performed according to the method of Güzel et al. [29]. The activity results of the extract and Af-AgNPs were calculated as IC50.

2.9.3 Ferric Reduction Power (FRAP)

FRAP antioxidant power of the extract and Af-AgNPs was investigated according to Oyaizu methods [30] with small modifications [28].

2.10 Statistical Analysis

The statistical analysis was performed by GraphtPad Prism software (version 8.00) with one-way ANOVA. Results were expressed as mean values ± standard deviation ($P < 0.05$).

2.11 Catalytic Degradation of Methylene Blue

Catalytic degradation of methylene blue methods was done according to Suvith and Philip, 2014 method [31].

3 Results and Discussion

3.1 Synthesis of Silver Nanoparticles

Astragalus flavesces aqueous extract and $AgNO_3$ at 70 °C for 2 h were used for Af-AgNPs. A color change from light yellow to deep brown was observed in the reaction medium due to the reduction of Ag^+ to Ag^0 and this change supported the formation of Af-AgNPs (Fig. 1) [1].

3.2 UV–Vis Spectroscopic Analysis

Color change from light yellow to brown was observed with Ag0 reduction of Ag+. Accordingly, it supported the

Table 1 FTIR analysis of Af-AgNPs synthesized from *Astragalus flavesces* leaves

No.	υ (cm^{-1})	Attribution
1	3261	O–H stretching
2	2928	C–H stretching of alkane
3	1591	N–H bending of amine
4	1397	O–H bending of carboxylic acid
5	1259	C–O stretching of an aromatic ester
6	1024	C=C bending, alkene
7	512	Silver oxide
8	418	Silver oxide

formation of Af-AgNPs due to this reduction in UV–Vis analysis. Af-AgNPs synthesized from *Astragalus flavesces* were determined to have a strong band at 350–550 nm in the UV–Vis spectrum. Also, the peak detected at the 417 nm peak promoted the synthesis of Af-AgNPs (Fig. 1). The absorption bands between 410 and 420 nm indicate the presence of the biosynthesized silver nanoparticles [4].

3.3 Fourier-Transform Infrared Spectroscopy (FTIR)

FTIR analysis was performed to determine the secondary metabolites of *Astragalus flavesces* aqueous extract (Fig. 2), which are involved in the surface coating and stabilization of Af-AgNPs, and the functional groups responsible for the reduction of silver ions. In Table 1 are given FTIR analysis results of Af-AgNPs synthesized from *Astragalus flavesces* leaves. The band assigned at 3261 cm^{-1} and 2928 cm^{-1} corresponds to –OH stretching vibration with polyphenols present in the plant and –CH stretching vibration [1, 4]. Characteristic signals were found, identified as the symmetric bending at 1591 cm^{-1} N–H bending of amine [2]. The band observed at 512 cm^{-1} corresponds to Ag–O tensile vibrations [1].

3.4 X-ray Diffraction (XRD)

XRD displayed the crystalline nature of Af-AgNPs synthesized from *Astragalus flavesces* aqueous extract (Fig. 3). In XRD spectrum observation of 38.1°, 44.3°, 64.4° and 77.4° with 2θ degrees led to (111), (200), (220), and (311) Bragg's reflections of the face-centered cubic (fcc) crystalline structure of silver respectively (JCPDS No. 87-0720) [32]. This structure of our AgNPs is parallel to the XRD pattern of the synthesized silver nanoparticles from plant extract [4, 26]. The Debye-Scherrer formula was used to calculate the size of Af-AgNPs. Rietveld analysis was carried out and presented in Fig. 3A. The EDX spectrum of Af-AgNPs in Fig. 3B and the EDX quantitative results (%) of Af-AgNPs in Table 2 was given. The intense peak of AgNPs in the EDX spectrum at 3.2 keV confirmed the synthesis of AgNPs. The metallic silver nanoparticles show the typical strong signal peak at 3.0–3.3 keV due to the surface plasmon resonance [26].

3.5 Scanning Electron Microscope (SEM)

The morphology of Af-AgNPs was determined by SEM analysis (Fig. 4). The average particle size was detected as 63.15 nm. The presence of Af-AgNPs was confirmed by the energy disperses analysis (EDX) (Fig. 4).

3.6 Transmission Electron Microscopy (TEM)

Typical TEM images of Af-AgNPs are shown in Fig. 5. The average particle size was calculated as 9.3 nm.

Table 2 EDS Quantitative results (%)

Element	Weight	Atomic
CK	15.63	51.81
OK	8.05	20.03
AgL	76.32	28.17

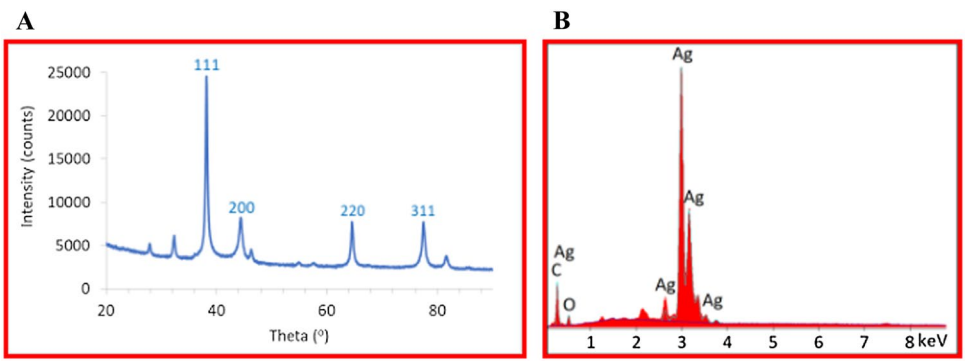


Fig. 3 XRD pattern (**A**) and EDX spectrum (**B**) of Af-AgNPs

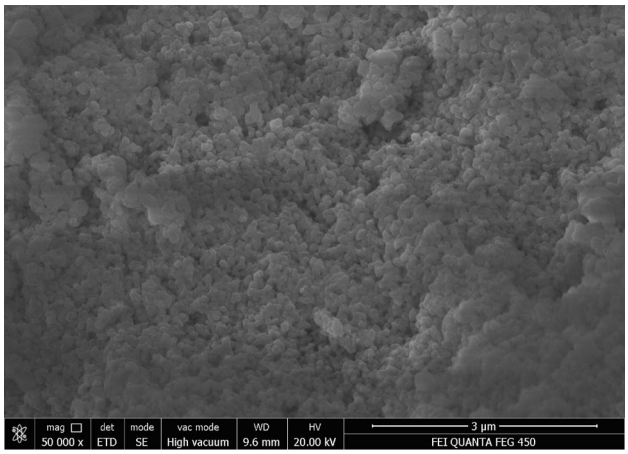


Fig. 4 SEM image of Af-AgNPs. Particle size is 63.15 nm

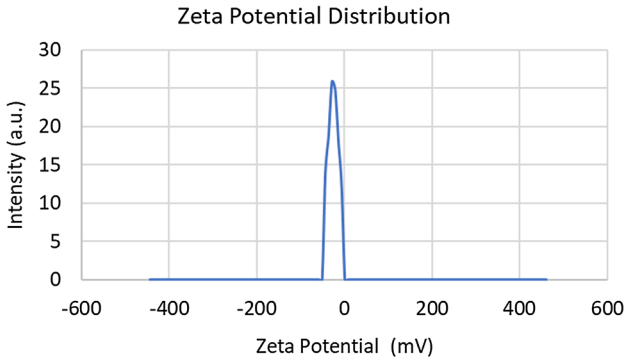


Fig. 6 Zeta potential of Af-AgNPs

3.7 Zeta Potential

The electrical potential between the inner Helmholtz layer near a particle's surface and the bulk liquid in which the particle is suspended is defined as zeta potential. It is a parameter that represents a particle's charge and signifies the potential stability of a colloidal system. If all of the particles in suspension have a large negative or positive zeta potential, they will repel each other and will not flocculate. But if the particles have a low zeta potential value, there will be no force to prevent the particles to be aggregating and agglomeration will occur. The zeta potential provides an opportunity to understand the interactions between particles in suspension. Thus, it is also possible to examine the cell structure in terms of surface-loaded properties. Af-AgNPs have the potential of − 29.1 mV which indicated the stability of nanoparticles as well as repulsion among the particles (Fig. 6).

3.8 Mechanism of Formation of Af-AgNPs

Silver ions are reduced by bioactive compounds as shown in Fig. 7. Silver nanoparticles were obtained by ion reduction, aggregation, and growth of nanoparticles [33]. The reaction mechanism has been modified from Gecer 2021 [27] for the quercetin compound found in *Astragalus* species [20, 21].

3.9 Antioxidant Activity

Antioxidant activity of *Astragalus flavesces* aqueous extract and silver nanoparticles were determined using the DPPH, ABTS, and FRAP assays (Fig. 8).

In DPPH· scavenging tests were used BHA, BHT and, Trolox as standard compounds. According to the test, Af-AgNPs showed high activity (IC50, 11.31 µg/mL) than the extract. Also, Af-AgNPs displayed approximate activity with BHT (IC50, 10.78 µg/mL). Similarly, ABTS scavenging activity was compared with the same standard compounds. In ABTS scavenging activity tests, the Af-AgNPs (IC50, 10.29 µg/mL) showed higher activity than the extract (IC50 14.41 µg/mL). However, It was noted that there was

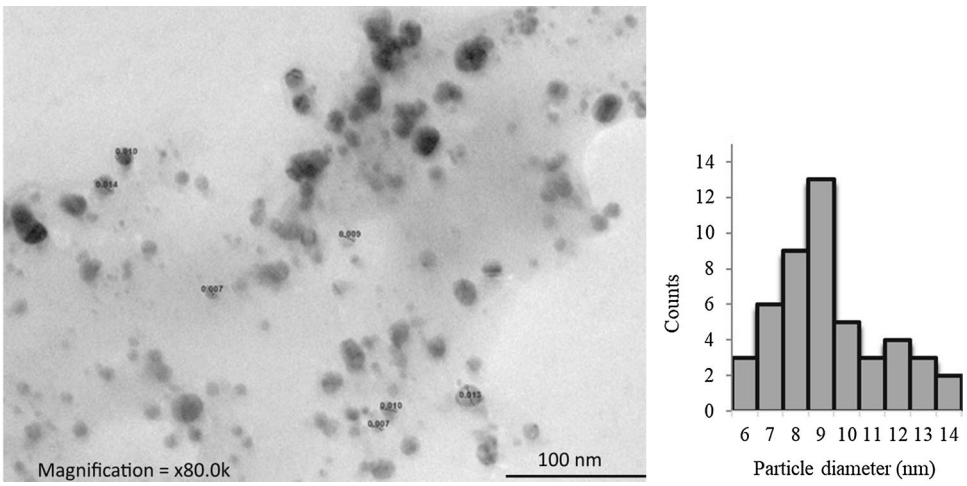


Fig. 5 TEM image of Af-AgNPs

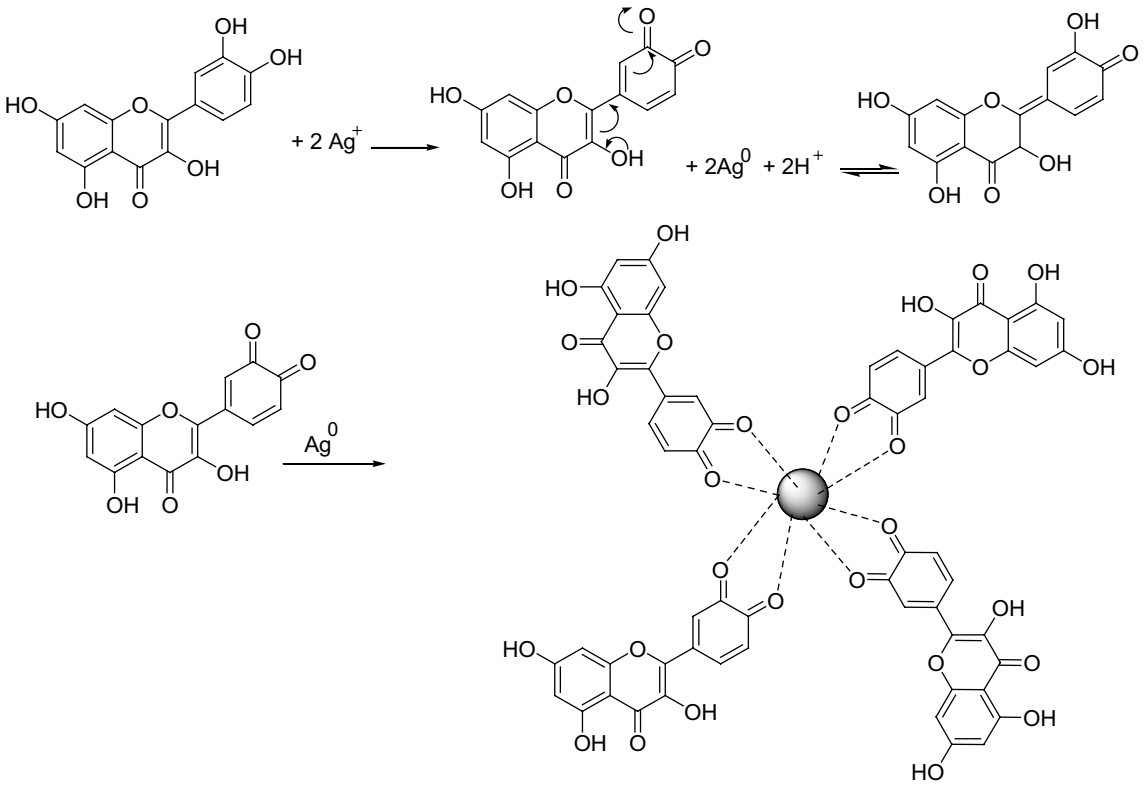


Fig. 7 Feasible reaction mechanism of synthesis of Af-AgNPs

a significant difference in activity between the plant extract and the Af-AgNPs .

In the reducing power activity test, the activities were compared with BHA and BHT. The activity of Af-AgNPs (4.73 µmol TE/mg extract) was better than the plant extract (3.53 µmol TE/mg extract). Also, the activity of extract and Af-AgNPs was weaker than the activity of standards.

In tests of antioxidant activity of Af-AgNPs, a mechanism of action such as hydrogen transfer or electron transfer is observed. Many in vitro methods (DPPH assay, ABTS, FRAP, H_2O_2, etc.) are used for this. The basic mechanism in these methods is attributed to the oxidation (Ag^+ and Ag^{2+}) of silver in Af-AgNPs depending on the reaction conditions. Synthesized Af-AgNPs quench free radicals by gaining or losing electrons [34].

As a result of these activity studies, the plant extract and Af-AgNPs from *Astragalus flavesces* showed antioxidant activity to a degree that can preferable in the food and pharmaceutical industries. Af-AgNPs were synthesized for the first time in this study using *Astragalus flavesces*.

Some *Astragalus* species were used for the green synthesis of silver nanoparticles, such as *Astragalus verus*, *A. tribuloides*, *Astragalus membranaceus* and, *Astragalus gummifer.* Morever, these species show antibacterial [23, 24, 35, 36] and antioxidant activity [24].

3.10 Catalytic Activity of Silver Nanoparticles

The function of metal nanoparticles as an electron transfer catalyst is dependent on chemistry and size [37]. The size-dependent catalytic activity of silver nanoparticles can be determined by reducing methylene blue (MB) to Leuco Methylene Blue (LMB) with NaBH4. In aqueous media, MB gives an absorption band at 614 nm with a shoulder at 664 nm [38]. Under sunlight, Af-AgNPs were used to catalyze the breakdown of MB. After incubation of Af-AgNPs and exposure to solar light, the dye's deep blue colour transformed to a light blue color. At 28 h, the 69% deterioration was complete. With the passage of time, the adsorption of Af-AgNPs on the methylene blue solution increased, resulting in dye degradation (Fig. 9). The reduction of MB to LMB using reducing agents is a reversible reaction and is used in various fields such as data storage media, holographic industries, and data recording [39] (Fig. 9).

4 Conclusions

This work used *Astragalus flavesces* leaf extract, a natural, low-cost biological reducing agent, to make silver nanoparticles. Af-AgNPs were characterized by UV–Vis, TEM,

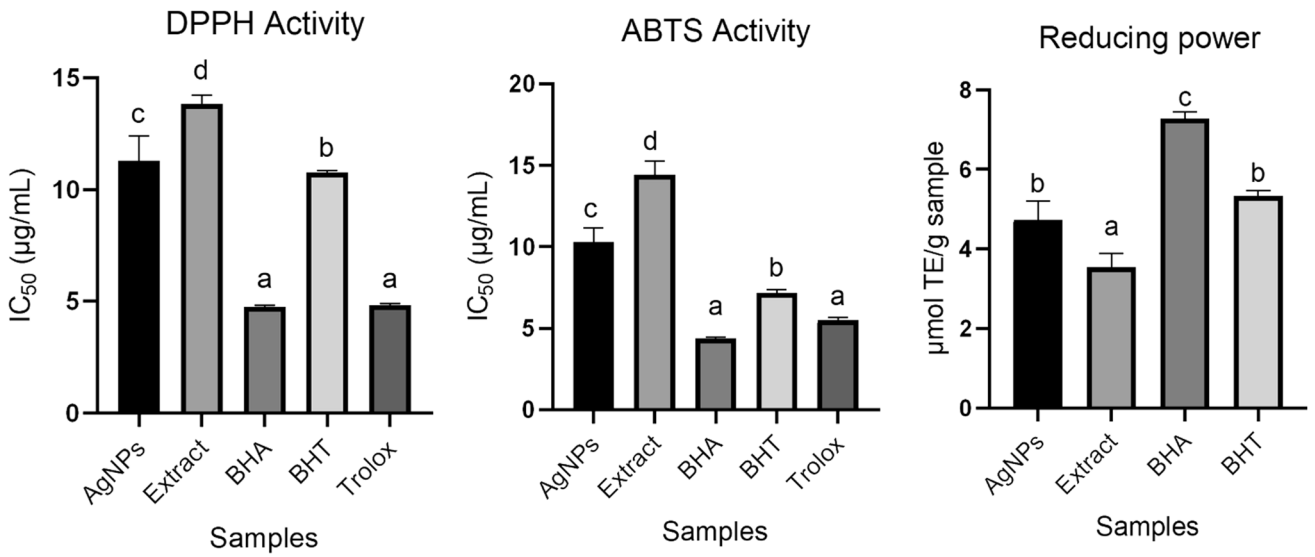


Fig. 8 Antioxidant activity of Af-AgNPs and extract. The results were reported as mean values ± SDs of three independent assays ($P < 0.05$)

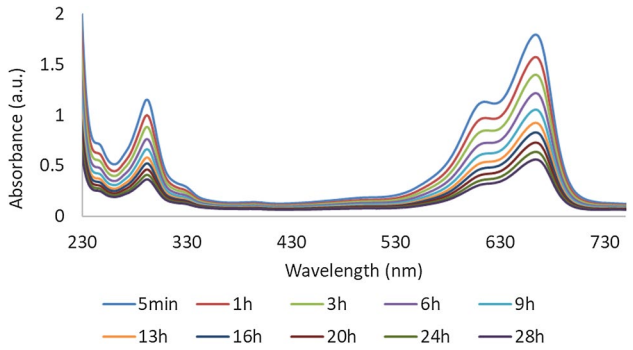


Fig. 9 Photocatalytic degradation of methylene blue by Af-AgNPs

FT-IR, SEM with EDX, Zeta potential, and XRD techniques. The average size of nanoparticles was 63.15 nm and their spherical shape was determined by SEM spectral analysis. Af-AgNPs was face-centered cubic crystalline structures. The functional group and elemental analysis were determined through FT-IR and EDX. The biosynthesis of Af-AgNPs from the plant extract is simple, available, non-toxic, low cost, and environmentally friendly compared with synthetic chemical procedures. In addition, the biosynthesized silver nanoparticles showed intense antioxidant activity as well as good catalytic activity. Therefore, it is thought that Af-AgNPs can be used as storage materials in the food and pharmaceutical industries due to both the antimicrobial and antibacterial effects of AgNPs and their remarkable antioxidant activities in our study.

Author contributions All authors contributed to the whole article.

Funding None.

Data Availability Data are given in the manuscript and they are confidential.

Declarations

Conflict of interest The authors have no conflict of interest to declare.

Ethical Approval Ethical rules are followed.

References

1. H.B. Herbin, M. Aravind, M. Amalanathan, M.S.M. Mary, M.M. Lenin, C. Parvathiraja, M.R. Siddiqui, S.M. Wabaidur, M.A. Islam, J. Inorg. Organomet. Polym. Mater. **32**, 1103 (2022). https://doi.org/10.1007/s10904-021-02210-y
2. D.A. Lomeli-Rosales, A. Zamudio-Ojeda, O.K. Reyes-Maldonado, M.E. Lopez-Reyes, G.C. Basulto-Padilla, E.J. Lopez-Naranjo, V.M. Zuniga-Mayo, G. Velazquez-Juarez, Molecules (Basel, Switzerland) **27**(5), 1692 (2022). https://doi.org/10.3390/molecules27051692
3. H. Tolouietabar, A.A. Hatamnia, R. Sahraeir, E. Soheyli, J. Nanostruct. **10**(1), 44 (2020). https://doi.org/10.22052/JNS.2020.01.006
4. L.N. Khanal, K.R. Sharma, H. Paudyal, K. Parajuli, B. Dahal, G.C. Ganga, Y.R. Pokharel, S.K. Kalauni, J. Nanomater. (2022). https://doi.org/10.1155/2022/1832587
5. B.M. Abdallah, E.M. Ali, ACS Omega **6**(12), 8151 (2021). https://doi.org/10.1021/acsomega.0c06009
6. A. Karmous, K. Pandey, B. Haj, A. Chaoui, Biol. Trace Elem. Res. **196**, 330 (2020). https://doi.org/10.1007/s12011-019-01895-0
7. G. Pradheesh, S. Suresh, J. Suresh, V. Alexramani, Int. J. Pharm. Investig. **10**(2), 146 (2020). https://doi.org/10.5530/ijpi.2020.2.27
8. L.H. Abdel-Rahman, B.S. Al-Farhan, D. Abou El-ezz, M.A. Abd–El, M.M. Sayed, A.M. Zikry, Abu-Dief, J. Inorg.

Organomet. Polym. **32**, 1422 (2022). https://doi.org/10.1007/s10904-021-02186-9
9. K.S. Aiswariya, V. Jose, J. Inorg, Organomet. Polym. **31**, 3111 (2021). https://doi.org/10.1007/s10904-021-01951-0
10. K. Dulta, G.K. Ağçeli, P. Chauhan, P.K. Chauhan, J. Inorg. Organomet. Polym. **31**, 1846 (2021). https://doi.org/10.1007/s10904-020-01837-7
11. M.S. Rajiri, M. Aminsalehi, M. Shahbandeh, A. Maleki, P. Jonoubi, A.C. Rad, Toxicol. Environ. Health Sci. (2020). https://doi.org/10.1007/s13530-020-00067-1
12. S. Rajput, D. Kumar, V. Agrawal, Plant Cell. Rep. **39**, 921 (2020). https://doi.org/10.1007/s00299-020-02539-7
13. Y. Wang, X.D. Zhang, Y.Z. Bai, W. Li, X. Li, X.L. Xing, C.L. Wang, L.L. Gao, M. Yogi, M.K. Swamy, K. Dupadahalli, G.R. Rudramurthy, B. Purushotham, K.C. Rohit, J.H. Fu, J. Nanosci. Nanotechnol **20**(7), 4143 (2020). https://doi.org/10.1166/jnn.2020.17524
14. R. Sattari, G.R. Khayati, R. Hoshyar, J. Clust. Sci. **32**, 593 (2020). https://doi.org/10.1007/s10876-020-01818-3
15. E.Y. Ahn, Y. Park, Mater. Sci. Eng. C **116**, 111253 (2020). https://doi.org/10.1016/j.msec.2020.111253
16. P. Popova, Y. Zarev, R. Mihaylova, G. Momekov, I. Ionkova, Pharmacia **68**(1), 217 (2021). https://doi.org/10.3897/pharmacia.68.e63421
17. B. Tunçkol, Z. Aytaç, N. Aksoy, A. Fişne, Acta Bot. Croat **79**(2), 131 (2020). https://doi.org/10.37427/botcro-2020-023
18. P. Liu, H. Zhao, Y. Luo, Aging Dis. **8**(6), 868 (2017). https://doi.org/10.14336/AD.2017.0816
19. X. Li, L. Qu, Y. Dong et al., Molecules **19**(11), 18850 (2014). https://doi.org/10.3390/molecules191118850
20. M. Mahmoudi, R. Abdellaoui, F. Boughalleb, B. Yahia, M. Mabrouk, N. Nasri, Food Chem. **339**, 127824 (2021). https://doi.org/10.1016/j.foodchem.2020.127824
21. C. Sarikurkcu, G. Zengin, Biology **9**, 231 (2020). https://doi.org/10.3390/biology9080231
22. H.D. Beyene, A.A. Werkneh, H.K. Bezabh, T.G. Ambaye, SM&T **13**, 18 (2017). https://doi.org/10.1016/j.susmat.2017.08.001
23. Z. Askari, M.R. Vahabi, A. Allafchian, S.A. Mousavi, S.A.H. Jalali, Micro Nano Lett. **15**(2), 66 (2020). https://doi.org/10.1049/mnl.2019.0306
24. M. Sharifi-Rad, P. Pohl, F. Epifano, J.M. Alvarez-Suarez, Nanomaterials **10**, 2383 (2020). https://doi.org/10.3390/nano10122383
25. S. Khorrami, F.J. Najafabadi, A. Zarepour, A. Zarrabi, BioNanoSci. **9**, 603 (2019). https://doi.org/10.1007/s12668-019-00646-8
26. E.N. Gecer, J. Inorg, Organomet. Polym. **31**, 4402 (2021). https://doi.org/10.1007/s10904-021-02057-3
27. E.N. Gecer, R. Erenler, C. Temiz, N. Genc, I. Yildiz, Part. Sci. Technol. **40**(1), 50 (2021). https://doi.org/10.1080/02726351.2021.1904309
28. A. Sahin Yaglioglu, F. Eser, M.S. Yaglioglu, I. Demirtas, Flavour. Fragr. J. **35**, 511 (2020). https://doi.org/10.1002/ffj.3586
29. A. Guzel, H. Aksit, M. Elmastas, R. Erenler, Pharmacogn. Mag. **13**(50), 316 (2017). https://doi.org/10.4103/0973-1296.204556
30. M. Oyaizu, Japanese J. Nutr. Dietetics **44**, 307 (1986). https://doi.org/10.5264/eiyogakuzashi.44.307
31. V.S. Suvith, D. Philip, S. Acta, A. Mol, Biomol. Spectrosc. **118**, 526 (2014). https://doi.org/10.1016/j.saa.2013.09.016
32. S.B. Aziz, G. Hussein, M. Brza, S.J. Mohammed, R.T. Abdulwahid, S. Raza Saeed, A. Hassanzadeh, Nanomaterials **9**(11), 1557 (2019). https://doi.org/10.3390/nano9111557
33. S. Jain, M.S. Mehata, Sci. Rep. **7**, 15867 (2017). https://doi.org/10.1038/s41598-017-15724-8
34. T. Shanmugasundaram, M. Radhakrishnan, V. Gopikrishnan, Colloids Surf. B Biointerfaces **111**, 680 (2013). https://doi.org/10.1016/j.colsurfb.2013.06.045
35. A.J. Kora, J. Arunachalam, J. Nanomater. (2012). https://doi.org/10.1155/2012/869765
36. Y. Ma, C. Liu, D. Qu, Y. Chen, M. Huang, Y. Liu, Biomed. Pharmacother. **89**, 351 (2017). https://doi.org/10.1016/j.biopha.2017.02.009
37. C.N.R. Rao, G.U. Kulkarni, P.J. Thomas, P.P. Edwards, Chem. Eur. J. **8**, 28 (2002)
38. N. Cheval, N. Gindy, C. Flowkes, A. Fahmi, Nanoscale Res. Lett. **7**, 182 (2012). https://doi.org/10.1186/1556-276X-7-182
39. Y. Galagan, W.-F. Su, J. Photochem, Photobiol. A **195**, 378 (2008). https://doi.org/10.1016/j.jphotochem.2007.11.005

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