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Biosynthesis of Silver Nanoparticles Using the *Falcaria Vulgaris* (*Alisma Plantago-Aquatica L.*) Extract and Optimum Synthesis

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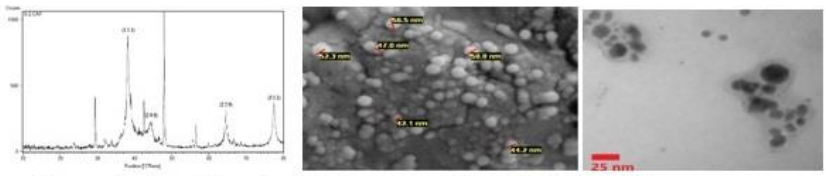
ABSTRACT

There are many reports about the use of medicinal plants in traditional medicine, as well as the application of metal nanoparticles in various biomedical fields. The purpose of the present study is bio synthesize of silver nanoparticles, using the aqueous extract of *Alisma Plantago-Aquatica L* plant and to achieve optimal conditions for the synthesis of these nanoparticles. For this reason, the effect of different parameters such as pH, extract volume, concentration of silver nitrate solution, temperature and reaction time were studied and their optimal amount was determined. Then, the nanoparticles synthesized in optimum conditions, UV-Vis, X-ray diffraction (XRD), Field-Emission Scanning Electron Microscopy (FESEM), Transmission Electron Microscope (TEM) and Fourier-Transform Infrared spectroscopy (FTIR) were evaluated. Strong and width peak of the visible UV spectrophotometer, at 438 nm wavelength, showed the formation of silver nanoparticles. The X-ray diffraction pattern confirmed the formation of crystalline silver nanoparticles at a size of about 25 nm. The results of FESEM showed nanoparticle shape in a spherical and monodisperse, with a particle size range of 20 to 58 nm. The TEM analysis also yielded a nanoparticle size of about 20 nm. The results of the Fourier transform infrared spectroscopy (FTIR), indicated the involvement of hydroxyl, amine and carboxyl groups in the plant extract in the synthesis of silver nanoparticles. The results of this study showed that the"*Alisma Plantago-Aquatica L.*" plant extract can be introduced as an appropriate, affordable and safe alternate in terms of green chemistry, instead of toxic and high-risk chemicals.

GRAPHICAL ABSTRACT

Falcaria Vulgaris plant_____Pure extract of *Falcaria Vulgaris* plant___Brown colloidal solution of silver nanoparticles



Characterization of biosynthesized silver nanoparticles using *Falcaria Vulgaris* extract

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Introduction

The environmental pollution is one of the most serious problems facing the modern world, which has many causes and origins. The nanotechnology is one of the most dynamic and advanced science available, with highly efficient and abundant capacities, for using in a variety of industries, including sanitary - cosmetics and the environment industries. The importance and applications of this technology in various fields not only make this technology as an option but as a necessity [1]. One of the most important applications of nanotechnology is the use of metal nanoparticles in the absorption of environmental pollutants. Since in recent decades, the nanoparticles are a bridge between the bulk of material and atomic or molecular state, the attention of science and industry has focused on the production of nanoparticles. In the meantime, the metal nanoparticles have been widely considered for wide application in fields such as, catalytic, optoelectronics, pharmacy, environmental pollution control, food and clothing, drug delivery systems and chemistry materials [2-5].

Among nanoparticles, silver nanoparticles have been widely used in various pharmaceutical and cosmetic industries because of their unique physical, chemical and biological properties. One of the reasons why these nanoparticles are widely used are their antimicrobial, antifungal and antioxidant potential. The potential antimicrobial potential of silver nanoparticles suggests their application as an important strategy to overcome the serious problem of antibiotic resistance that threatens human health. Increasing bacterial resistance to antibiotics causes a serious health problem. Therefore, there is a strong incentive to improve new antibiotics. Therefore, the use of nanomaterials can be an effective step forward, in advancing the research and its use in bio-drugs. For this reason, the use of silver nanoparticles is increasing every day, to fight infection. The single-capacity silver compounds have been used extensively for decades as a treatment against bacterial infections, and the studies have shown that the silver nanoparticles also have these properties [6]. The silver nanoparticles are effective in a wide range of bacteria and do not have adverse effects on human cells, because human cells are as tissue. Unlike antibiotics, which are deformed and inactive after the cell's reaction, silver nanoparticles are released after exposure to microbes and affect other microorganisms. Contrary to the fact that antibiotics that, after reacting with the cell, become deformed and inert, silver nanoparticles are released after exposure to microbes and affect other microorganisms. These silver nanoparticles are plentiful for pathogens, but for living tissues and ultimately for humans, they are almost harmless [7, 8].

For a long time, nanoparticles have been produced only by various physical and chemical methods, such as laser production, chemical reduction, photochemical reduction and the use of radiolysis that they are still at the development stage, and often have problems, including the stability of nanoparticles produced, the control of crystal growth, as well as the accumulation of particles with slight changes in temperature and pH, etc. [9].

The chemical and physical techniques that are used to synthesize the nanoparticles are often very expensive, and usually the presence of residues of toxic reactive and sometimes carcinogenic substances resulting from these techniques, leads to inefficiencies in the bio-application of the resulting nanoparticles. Therefore, the development of clean, non-toxic and cost-effective methods for the synthesis of nanoparticles is very valuable.

In recent years, the use of biological methods such as the use of plants (as renewable sources) because of its simplicity, low cost, high efficiency, non-toxicity and environmental compatibility, abundance and availability, completeness and the low reaction time has attracted special attention compared with other methods. The advantage of using the extracts and essential oils of plants in the synthesis of nanoparticles and the presence

of a wide variety of secondary metabolites on them, such as polyphenols, alkaloids, Terpenoids, quinones, tannins, etc., are involved in the action of biological ion recovery [10-12].

Among the various herbs, especially medicinal plants, the attention has been paid to the synthesis of metal nanoparticles. Polysaccharides in these plants have many factors, including hydroxyl groups and organic compounds, which can regenerate metal-containing solutions.

One of these herbs is *"Alisma Plantago-Aquatica L."* which has chemical compounds such as palmitic acid, stearic acid, oleic acid, linoleic acid, fufuraldehyde, sparagin, phytosterol, phytosterolin, resin, sugar, starch, Protein, and so on.

In this study, the efficacy of extracts prepared from *Falcaria Vulgaris* plant was investigated for the synthesis of silver nanoparticles. To this end, the effect of effective parameters on synthesis, such as pH, extract volume, concentration of silver nitrate solution, temperature and reaction time, and finally synthesizing silver nanoparticles, were performed in optimum conditions and also, evaluating and characterizing the synthesized nanoparticles by TEM, SEM, XRD, UV-Vis and FTIR techniques were performed.

Material and methods

All of the chemicals used in this study were prepared with high purity. For the synthesis of silver nanoparticles, an extract of *Falcaria Vulgaris* plant and silver nitrate (from Merck, with a molecular weight of 169.88) were used. To adjust the pH of the solutions, chloric acid and soda were used.

Preparation of aqueous extract

The Plant specimens were collected in spring season around the city of Arak (Markazi province of Iran) and were washed three times with deionized water to remove their dust. Then, fresh leaves were crushed into small pieces, and 20 grams of crushed leaves were added to Erlenmeyer containing 200 ml of deionized water at 80 °C. After 30 minutes, the reaction mixture was filtered, using Whatman No. 42 paper filter. To completely remove the suspended particles, this solvent was centrifuged at 10000 rpm for 30 minutes, then the extract was stored at 4 °C for next use.

Figure 1: *Falcaria Vulgaris* plant (alisma plantago-aquatica L.)

Synthesis of silver nanoparticles by Extract of Falcaria Vulgaris plant

For the synthesis of silver nanoparticles, 95 ml of silver nitrate (1 mM) was added to 5 ml of the *Falcaria Vulgaris* plant extract. Then, the solution was placed in a darkness for 30 minutes on a shaker at a speed of 150 rpm. The color change and the formation of a brown colloidal solution confirmed the synthesis of nanoparticles, which was used to ensure the synthesis of sample absorbance by a Ultra-Violet spectrophotometer – Visible in the absorption range of 330-800 nm.

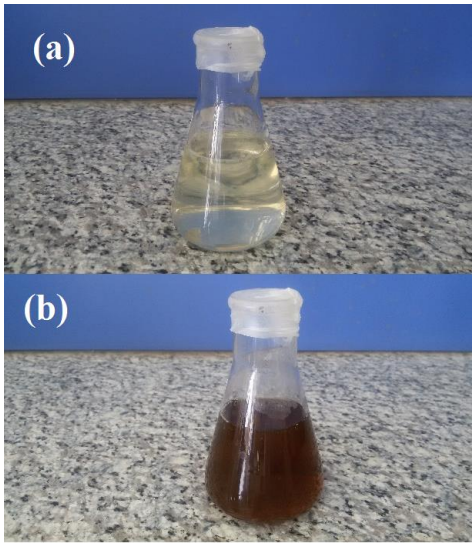

Figure 2: a) Pure extract of *Falcaria Vulgaris* plant b) The colloid solution formed after the reaction of the extract with a salt solution of silver nitrate

Investigating the effective parameters on the biosynthesis of silver nanoparticles

To optimize the pH value, five solutions containing 5 ml of extract and 95 ml of silver nitrate solution at a concentration of 1 mM, were added and their pH was adjusted to 2, 4, 6, 8 and 10. The Erlenmeyer containing the solutions were arranged for 30 minutes on a shaker at 150 rpm at room temperature. Absorption spectra of solutions were taken by UV-visible spectrophotometer in absorption range of 330 to 800 nm and optimum pH was selected. To adjust the pH of the solutions, two NaOH or HCl solutions at 0.1 M concentration were used. Adjusting pH with 0.1 M acid and base was based on preliminary studies and experiments that other researchers had reported on the synthesis of silver nanoparticles using plant extracts.
[13-14].

In order to investigate the effect of plant extract, the amounts of 2, 4, 6 and 8 ml were added to 95 ml of silver nitrate solution at a concentration of 1 mM. The pH of the reaction was adjusted to the optimum pH and the same as the previous stage after the appropriate time from each of the solutions was separately extracted from the UV-Vis spectrophotometric spectrum. Finally, the optimum volume of the extract was determined**.**

To evaluate the effect of silver ion concentration, the optimized extract volume was added to 95 ml at different concentrations of nitric acid solution 1, 3, 5 and 10 mM. After adjusting the optimum pH, the elapsing the appropriate time (as in previous steps), was considered for the spectrophotometric spectra of UV-Vis spectra and the optimal concentration was selected.

In order to determine the optimum temperature of the reaction, the five-solution series, containing an optimal amount of extract volume and 95 ml of silver nitrate solution with optimal concentration were prepared, pH of which all were set at optimal pH. Then, the solutions were placed at 20, 45, 60, 80 and 100 °C for 30 minutes, and each of the solutions was separately extracted from the spectrophotometric UV-Vis spectrum and finally, the optimum response value was determined.

Considering the optimized parameters, including pH, amount of extract used, concentration of silver nitrate solution, reaction temperature and effect of time (at 20, 50, 90, 120 and 140 minutes) on the biosynthesis of silver nanoparticles were investigated. Then, the optimum time was determined according to the spectrophotometric UV-Vis spectra taken from samples.

Characterization of Biosynthesis silver nanoparticles

Spectrophotometric analysis (UV-Vis)

In order to study the efficacy of aqueous extract of *Falcaria Vulgaris*, in converting silver ions from a silver nitrate solution to silver nanoparticles, the specimen was used with a visible UV spectrophotometer, Drop Scan (manufactured by Jena Analytic of Germany) and wavelengths ranging from 300 to 800 nm.

X-ray diffraction analysis (XRD)

In order to confirm the formation of nanoparticles of silver, this was done by regenerating agents in the X-ray extract extracts. After performing the necessary operations, the powder or silver nanoparticles were used for X-ray diffraction analysis (using the PERTPRO X PANalitical model, Netherlands manufacturer), (With radiation $\lambda = 1.54$ at an angle θ 2 in degrees with a range of 10-80).

Scanning Electron Microscopy Analysis (SEM)

Studying and examination of morphology and microstructure of the specimens were performed, using scanning electron microscopy (SEM). Since the samples were to be dried for SEM imaging, the sediment was dried at 40 °C and converted to powder form.

The surface of samples that are examined by the SEM microscope should be electrically conductive so as not to make a charge, since in this case, the next electrons will have a static charge and the same name charge, they will collide, repel or divert; as a result, the resulting image becomes

unstable. Therefore, the specimens were fixed on the microscope's base, and they were covered with a layer of gold, to find electron conduction and eliminate the electrons on surface, thus improving the image transparency.

Fourier Transform Infrared Spectroscopy analysis (FTIR)

The analysis of the Fourier Transform infrared spectroscopy (Thermo nicolet; AVATAR 370 F) was performed to determine molecules and bioagent groups, which are responsible for the synthesis of silver nanoparticles. For this purpose, the purely dried powder extract was used before and also, after the reaction with silver nitrate.

Transmission Electron Microscopy analysis (TEM)

To determine the shape and size of the produced nanoparticles, imaging was performed with a Transmission Electron Microscopy (TEM). After dissolving the nanoparticles produced in deionised water, a drop of silver nanoparticle solution was placed on the carbon grades, coated with copper, and allowed to dry, then, the shape and size of the particles were investigated.

We dealt with confirming the results obtained from Spectrophotometric Ultraviolet-Visible spectrum and determining the distribution of the shape and size of silver nanoparticles synthesized, applying the effective factors by the transmitted electron microscope (Zeiss - EM10C).

Result and Dissection

After adding the extract of the *Falcaria Vulgaris* plant to the silver nitrate solution, color change was observed over time. The solution turned pale yellow to a very dark color. To control and ensure the production of silver nanoparticles, the absorption of the colloidal solution was measured using a visible UV ultraviolet spectrometer in the range of 330 to 800 nm. The absorption peak observed at 438 nm confirms the formation of the silver nanoparticles [15], because the optical properties of nanoparticles vary according to their shape and size.

Investigating the effective parameters on the biosynthesis of silver nanoparticles

One of the most important factors affecting the synthesis of metal nanoparticles is pH. Previous reports all indicate that this parameter does not affect the type of nanoparticle shape, but it affects the amount of nanoparticles synthesized by the plant extract [16, 17]. The effect of pH on the synthesis of silver nanoparticles by a *Falcaria Vulgaris* plant extract (Fig. 3) suggests that, with increasing pH from 2 to 10, the observed absorption peak indicates an increase in the plasmon surface resonance of silver nanoparticles, which represents an increase in the number of silver nanoparticles. And as far as the peak is symmetrical, it shows uniformity of the shape of the nanoparticles. However, as seen in Figure 3, the absorption region of silver nanoparticles (420 nm) at pH 2 and 4 does not show a significant change. In fact, silver nanoparticles are not formed, and Peak is not observed, but with increasing pH to 6-8 and then 10, the absorbance of the solution has increased significantly, which is related to the increase in the amount of synthesis of silver nanoparticles. The expansion of the absorption peaks at lower pH, will occur due to the connection of smaller particles together and the formation of coarse nanoparticles, which it causes the approximate expansion of the peaks. Peak expansion due to an increase in the size of nanoparticles was previously reported in studies by other researchers [18], which resulted in a pH of 10 as optimal pH.

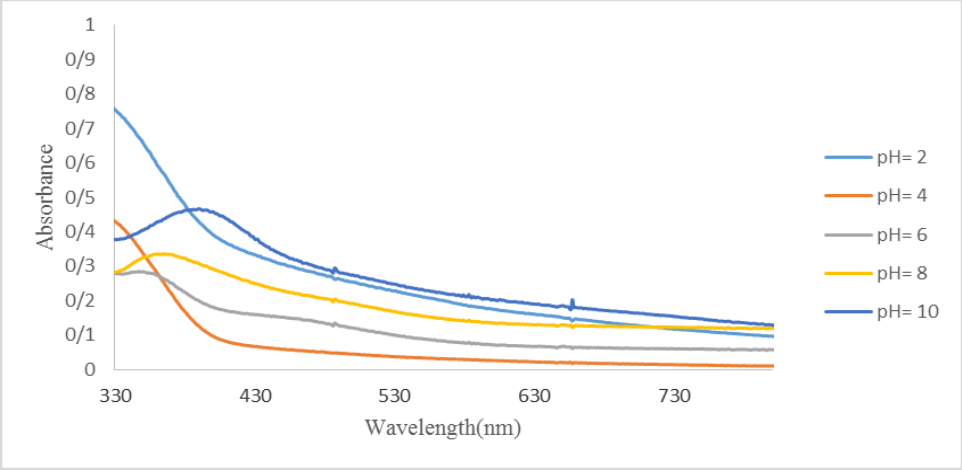

Figure 3: UV-Vis absorption spectra pH effect on biosynthesis of silver nanoparticles by *Falcaria Vulgaris* extracts. Reaction condition: volume of extract =5 ml, solution of silver nitrate salt = (95 mL, 1 mM), temperature=25 °C, contact time= 35 min, 150 rpm

As shown in Figure 4, by increasing the volume of the extract, the absorption, read by the ultraviolet spectrophotometer-visible spectrophotometer, increases. And this increase in the amount of absorption indicates an increase in the amount of nanoparticles formed, and, on the other hand, the symmetry and sharping of peaks, also indicate that the formation of smaller nanoparticles that are more stable. The *Falcaria Vulgaris* plant, as mentioned earlier, contains many antioxidant compounds, all of which play an important role in restoring metal ions and converting them into metal atoms, in nanoscale dimensions and also, stabilization of synthesized nanoparticles. For this reason, it is evident that no matter how much the volume of the extract increases, the amount of regeneration factors increases; as a result, the amount of nanoparticles of synthesized silver is increased. The studies by other researchers confirm this, which is why 8 ml of extract volume was chosen as optimum [19].

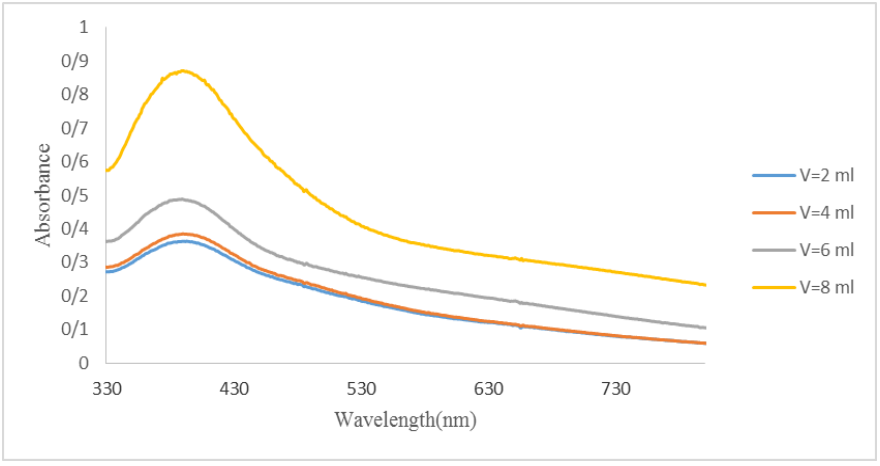

Figure 4: UV-Vis absorption spectra of extract volume effect on biosynthesis of silver nanoparticles. Reaction condition: solution of silver nitrate salt= (95 mL, 1 mM), pH=10, temperature=25 °C, contact time= 35 min, 150 rpm

The studies show that with increasing metal ion concentration, the observed absorbance significantly increases. The reason for this phenomenon is an increase in the amount of metal ion; consequently, the recovery of more ions happens followed by the formation of more nanoparticles [20].

According to Figure 5, with the gradual increase in the concentration of silver ion, the observed absorption observed for the silver nanoparticles shows a significant increase. As a result, the concentration of 10 mM of silver nitrate salt was selected as optimal concentration.

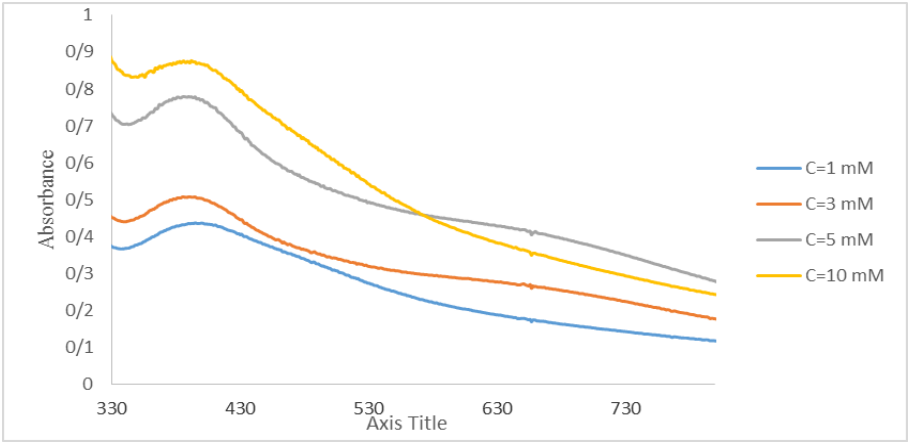

Figure 5: UV-Vis absorption spectra of silver nitrate salt concentration on biosynthesis of silver nanoparticles by *Falcaria Vulgaris* extract. Reaction condition: solution of silver nitrate salt =95 mL, pH=10, volume of extract=8 mL, temperature=25 °C, contact time= 35 min, 150 rpm

The results of the study of the temperature effect on the synthesis of silver nanoparticles by the extract of *Falcaria Vulgaris* plant are given in Figure 6. As seen from Figure 6, we are faced with a wide peak at 20 °C, which indicates a small formation of silver nanoparticles; however, with increasing temperatures at 45 °C and 60 °C, the formation rate of nanoparticles is higher than before and reaches its maximum at 100 °C. This is due to increased stimulation of silver ions and an increase in the recovery process of silver ions by the recovery agents in the *Falcaria Vulgaris* plant. For this reason, the temperature of 100 °C was selected as the optimum temperature.

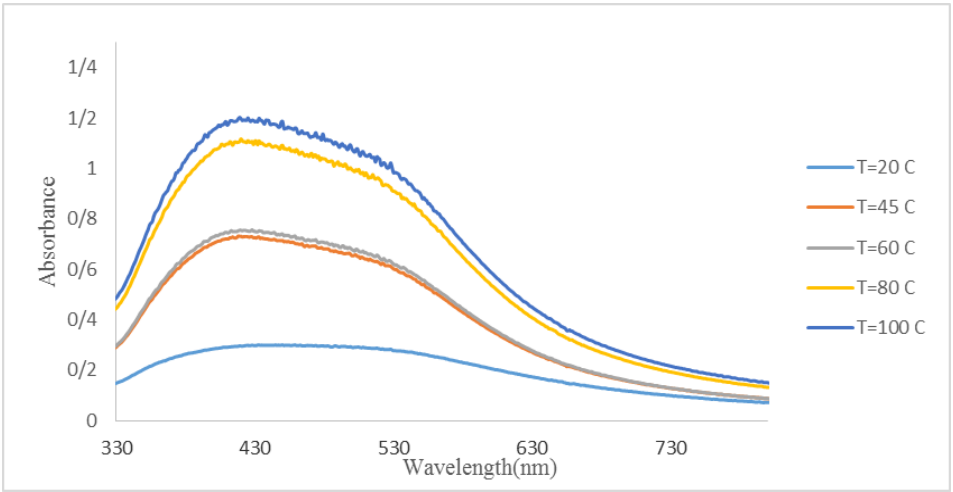

Figure 6: UV-Vis absorption spectra of temperature effect on the biosynthesis of silver nanoparticles using *Falcaria Vulgaris* extract. Reaction condition: solution of silver nitrate salt= (95 mL, 10 Mm), pH=10, volume of extract=8 mL, contact time= 35 min, 150 rpm

The time, like previous factors, has a significant effect on the synthesis and stability of nanoparticles. The reaction between silver ions and reducing agents in the plant extract was

studied over time. The results of this study (Fig. 7) show that the increasing in the interaction time between the reactants (from the moment the plant extract is mixed with a solution of silver nitrate) leads to a rise in the absorbance of the solution, due to the darkening of the soluble color. It indicates the formation of a greater amount of silver nanoparticles in the colloidal solution (140 min).

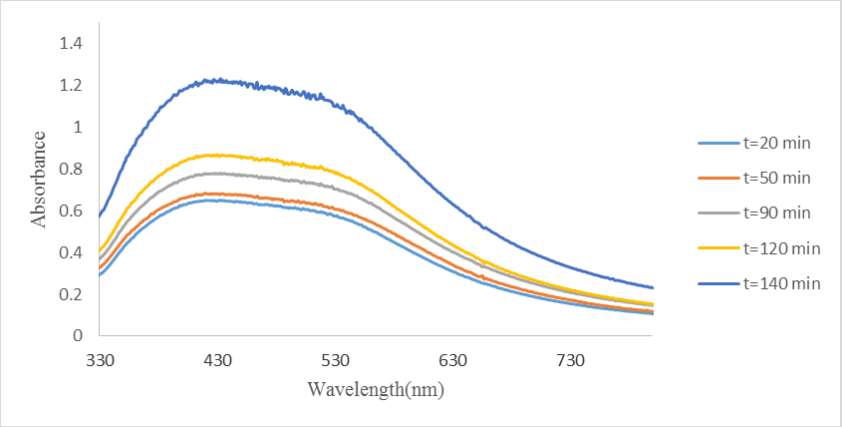

Figure 7: UV-Vis absorption spectra of time effect on the biosynthesis of silver nanoparticles using *Falcaria Vulgaris* extract. Reaction condition: solution of silver nitrate salt= (95 mL, 10 Mm), pH=10, volume of extract =8 mL, temperature=100 °C, 150 rpm

Characterization of biosynthetic silver nanoparticles

Ultraviolet-visible spectroscopy is an important method to determine the formation and sustainability of metal nanoparticles in aqueous solution. The color of the colloidal silver solution attributed to surface plasmon resonance (SPR) is due to the mass fluctuations of free electrons induced by interaction with the electromagnetic field. This is specific to each type of nanoparticle in any size and is due to plasmonic phenomenon ability in absorbing light in the region of the ultraviolet-visible absorption spectrum[21-.

The results of UV-Vis absorption spectra of the *Falcaria Vulgaris* extract after synthesis of silver nanoparticles are shown in Figure 8. When an optical beam hits the surface of the metal nanoparticles, the fluctuating field of the incident wave, causes the electron volatility conduction of metal, as a massive form. These massive oscillations of conduction electrons are called surface plasmons [26]. The surface plasmons of uniform nanoparticles have a high frequency in which the frequency shows the highest absorption and dispersion.

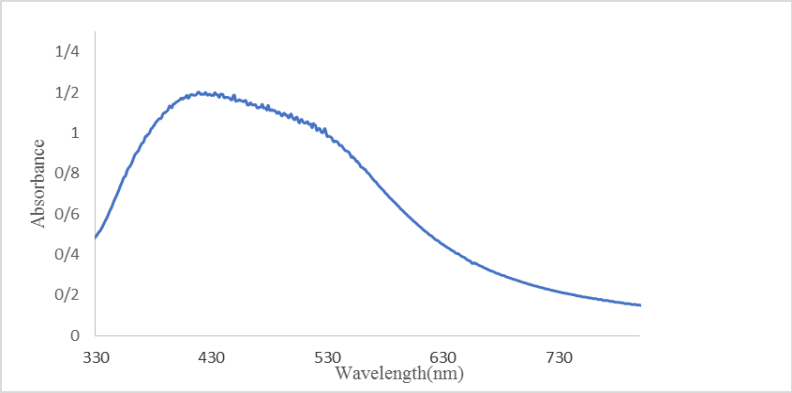

Figure 8: UV-Vis absorption spectrum of silver nanoparticles biosynthesized using *Falcaria Vulgaris* extract

X-ray diffraction analysis (XRD)

Figure 9 shows the XRD X-ray diffraction patterns, silver nanoparticles with *Falcaria Vulgaris* extract. As can be seen, the peaks (111, (200), (220) and (311) at 2θ are 38.9855, 44.2355, 66.7046 and 77.4776, respectively, related to the FCC structure of the silver nanoparticles, which is a perfect agreement with the standard X-ray diffraction pattern. Other researchers have reported these peaks in the nanoscale diagram of synthesized silver in their studies [20, 27].

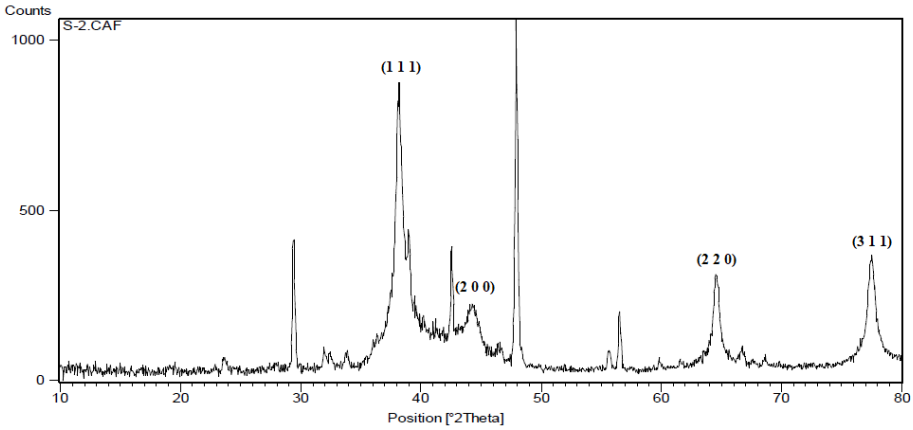

Figure 9: XRD pattern of silver nanoparticles biosynthesized using *Falcaria Vulgaris* extract

The crystalline size of silver nanoparticles is obtained from Scherrer's equation.

$D= K \lambda / \beta \cos \theta$

Where in the above relation K = 0.9, λ is the wavelength of the X-ray and is equivalent to 1.5406. The total width is at half the maximum peak diffraction and θ is the peak of the diffraction angle. From the calculation of Scherrer's equation, the crystalline size of silver nanoparticles was 20 nm, which is consistent with the size of the TEM.

Field Electron Scanning Electron Microscopy Analysis (FESEM)

Figure 10 shows the FESEM scanning electron microscope (FESEM) of silver nanoparticles synthesized with *Falcaria Vulgaris* extract, with a magnification of 200 nm. The FESEM image represents the nanometer size of a silver particle and represents an almost spherical shape in this magnification. Determining the size of the nanoparticles is not accurate due to FESEM because the FESEM resolution is lower than the TEM and is therefore used to express the mean size of the TEM analysis. According to FESEM, the cumulative size of nanoparticles is between 20 and 58 nm.

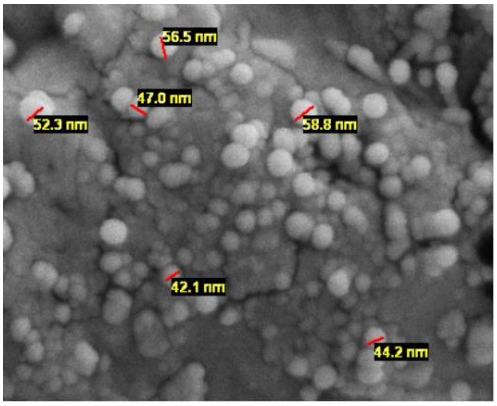

Figure 10: FESEM image of silver nanoparticles biosynthesized using *Falcaria Vulgaris* extract

Transmission electron microscopy analysis (TEM)

Figure 11 shows the TEM transmitted electron microscope, silver nanoparticles synthesized with the *Falcaria Vulgaris* plant extract. As the image shows, silver nanoparticles are darker in the image and have a spherical shape and are well distributed, and around the nanoparticles there is a clear background that is related to the solvent, because the solvent density is less than the density of silver nanoparticles in the passing light.

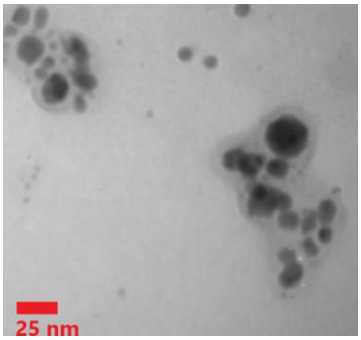

Figure 11: TEM image of silver nanoparticles biosynthesized using *Falcaria Vulgaris* extract

Fourier transform infrared spectroscopy analysis (FTIR)

The FT-IR spectrum is used to identify the quality of reducing agents in plants and stabilizers around nanoparticles.

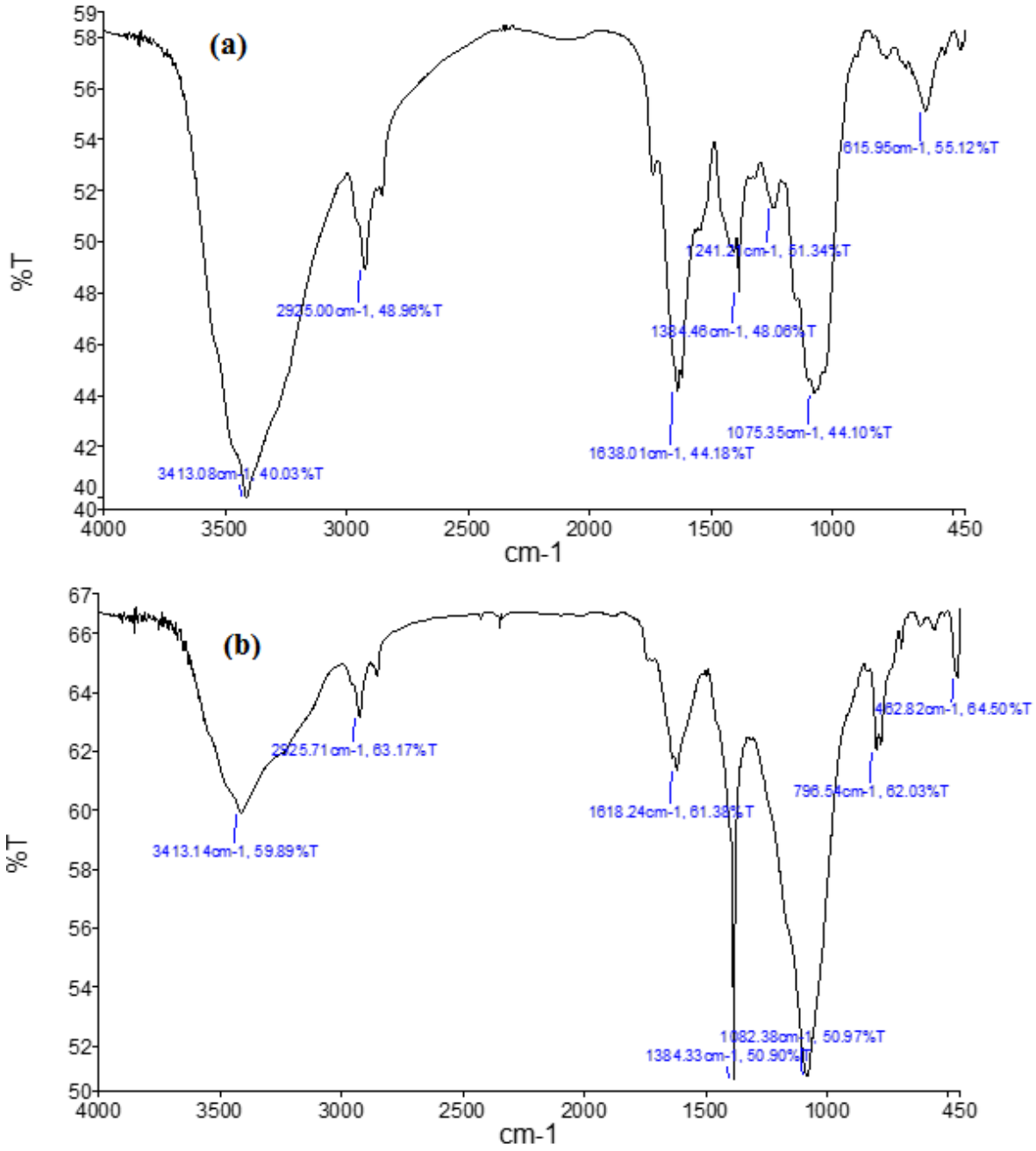

Figure 12: FTIR Spectra of a) Before biosynthesis of silver nanoparticles and b) After biosynthesis of silver nanoparticles

Figure 12 shows clear bands in the region of 3413.08, 2925, 1638.01, 1384.33, and 1075.35 cm^{-1}, respectively, which are related to tensile vibrations of OH, -NH, -CH aliphatic groups, C = C is attached to the aromatic rings, -CN and –CO, which is attributed to phenolic, protein, and flavonoids in the plant extract. These compounds, in addition to regenerating silver ions, cover the silver nanoparticles, and they become a stabilizing agent and prevent the accumulation and bonding of nanoparticles of synthesized silver. The results obtained from the FTIR are consistent with those found in the literature [26]. The researchers have also confirmed the existence of agent groups in their studies. As shown in Figure 8, after the pure extract of the *Falcaria Vulgaris* plant extract with silver nitrate, some displacements in place and peak height were formed in the synthesized nanoparticle spectrum. This displacement at 3387 cm^{-1} peak place, is related to the breakdown of the hydrogen bond and the direct role of hydrogen in reducing silver ions.

Conclusion

In this study, using UV-Vis spectrophotometric apparatus, the stages of biosynthesis of silver nanoparticles, using *Falcaria Vulgaris* plant extract were studied, and the optimum conditions for synthesizing were obtained. The size of silver spherical nanoparticles was obtained by using 8 ml of *Falcaria Vulgaris* plant extract and 4 ml of silver nitrate 10 mM, at pH = 10 at a 100 ˚C, after a time of 140 min with a size of 20 to 58 nm. The formation of silver nanoparticles was determined using spectrophotometer UV-Vis and x-ray diffraction. The synthesis of silver nanoparticles with a maximum absorption length of 450 nm was confirmed. Considering the above studies, we can conclude that *Falcaria Vulgaris* plant, with a lot of medicinal properties, can be considered as a suitable alternative for nanoparticle production. Among the nanoparticle production methods, this bio-production method is a clean, inexpensive, low-risk, and environmentally friendly method.

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Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all the aspects of this work.

Conflict of Interest

We have no conflicts of interest to disclose.

References

[1]. Joseph T., Marrison M., *A Nanoforum Report*; *Nanotechnol. Agri. Food,* 2006, **14**: Available at: www.nanoforum.org.

[2]. Zhang L., Gu F.X., Chan J.M., Wang A.Z., Langer R.S., Farokhzad O.C., *Clin. Pharmacol. Ther***,** 2008, **83**:761 [Crossref], [Google scholar], [Publisher]

[3]. Hong B. Kai J. Ren Y. Han J. Zou Z. Ahn C.H. Kang K.A., *Highly Sensitive Rapid, Reliable, and Automatic Cardiovascular Disease Diagnosis with Nanoparticle Fluorescence Enhancer and Mems.* Springer, Boston, MA, 2008, Chapter 30 [Crossref], [Google scholar], [Publisher]

[4]. Marambio-Jones C., Hoek E.M., *J. Nanopart. Res*, 2010, **12**:1531 [Crossref], [Google scholar], [Publisher]

[5]. Rai,M.K., Deshmukh, S.D., Ingle A.P., Gade A.K., *J. Appl. Microbiol,* 2012, **112**:841 [Crossref], [Google scholar], [Publisher]

[6]. Elrafie H.M., Hamed M.A., *Adv. Nat. Sci. Nanosci. Nanotechnol,* 2014, **5**:1 [Crossref], [Google scholar], [Publisher]

[7]. Rawani A., Ghosh A., Chandra G., *Acta. Trop***,** 2013, **128**: 613 [Crossref], [Google scholar], [Publisher]

[8]. Agnihotri S., Mukherji S., *Nanoscale*, 2013, **5**:7328 [Crossref], [Google scholar], [Publisher]
[9] Kavitha K.S., Syed Baker R., Rakshith D., Kavitha H.U, Yashwantha Rao H.C., Harini BP., Satish S., *Int. Res. J. Biol. Sci,* 2013, **2**:66 [PDF], [Google scholar], [Publisher]
[10]. Khodaie M., Ghasemi N., Ramezani M., *Eurasian Chem. Commun*, 2019, **7**:502 [Crossref], [Google scholar], [Publisher]
[11]. Rai M., Yadav A., *IET Nanobiotechnol*, 2013, **7**:117 [Crossref], [Google scholar], [Publisher]
[12]. Chitra C., Annadurai G., *BioMed Research International,* 2014, 725165 [Crossref], [Google scholar], [Publisher]
[13]. Handayani W., Ningrum A. S., Imawan C., J. Phys.: Conf. Ser, 2020, **1428**:012021 [Google scholar], [Publisher]
[14]. Suvith V.S., Philip D., *Spectrochim Acta A; Mol. Biomol. Spectrosc*, 2014, **118**:526 [Crossref], [Google scholar], [Publisher]
[15]. Waghmar S.S., Deshmukh A.M., Sadowski Z., *Afr. J. Microbiol. Res***,** 2014, **8**: 138 [Crossref], [Google scholar], [Publisher]
[16]. Armendariz V., Herrera I., Peralta -Videa J.R., Jose -Yacaman M., *J. Nanopart. Res***,** 2004, **6**:377 [Crossref], [Google scholar], [Publisher]
[17]. Sheny D., Mathew J., Philip D., *Spectrochim. Acta. A. Mol. Biomol. Spectrosc,* 2011, **79**:254 [Crossref], [Google scholar], [Publisher]
[18]. Dubey S.P., Lahtinen M., Sillanpää M., *Process Biochem*, 2010, **45**:1065 [Crossref], [Google scholar], [Publisher]
[19]. Verma A., Mehata M.S., *J. Radiat. Res. Appl. Sci,* 2016, **9**:109 [Crossref], [Google scholar], [Publisher]
[20]. Adebayo-Tayo B., Salaam A., Ajibade A., *Heliyon*, 2019, **5**:e02502 [Crossref], [Google scholar], [Publisher]
[21]. Ebrahiminezhad A., Barzegar Y., Ghasemi Y, Berenjian A., *Chem. Ind. Chem. Eng. Q*, 2017**, 23**:31 [Crossref], [Google scholar], [Publisher]
[22]. Donag S., Chanda S., *Artif. Cells Nanomed. Biotechnol*, 2021**,** **49**:292 [Crossref], [Google scholar], [Publisher]
[23]. Mahmoudi R., Aghaei S., Salehpour Z., Mousavizadeh A., Khoramrooz S.S., Taheripour Sisakht M., Christiansen G., Baneshi M., Karimi B., Bardania H., *Appl Organomet Chem*, 2020, **34**:e5394 [Crossref], [Google scholar], [Publisher]
[24]. Naidu K.S.B., Murugan N., Adam J.K., *Bionanoscience*, 2019, **9**:266 [Crossref], [Google scholar], [Publisher]
[25]. Alkhathlan A.H., AL-Abdulkarim H.A., Khan M., Khan M., AlDobiy A., Alkholief M., A lshamsan A., Alkhathlan H.Z., Siddiqui M., *Sustainability*, 2020, **12**: 10523 [Crossref], [Google scholar], [Publisher]
[26]. Ibrahim H.M., *J. Rad. Res. Appl. Sci*, 2015, **8**:265 [Crossref], [Google scholar], [Publisher]

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