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ORIGINAL RESEARCH PAPER

Parameters Affecting the Biosynthesis of Gold Nanoparticles Using the Aquatic Extract of *Scrophularia striata* and their Antibacterial Properties

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ABSTRACT

Green synthesis is a simple, low-cost, non-toxic, environmentally friendly and efficient approach to use. Leaf extract of plants rich in polyphenols, such as flavonoids, is a powerful agent in reducing the synthesis of gold nanoparticles. The purpose of this study is to investigate the parameters affecting the biosynthesis of gold nanoparticles using the aqueous extract of *Scrophularia striata* plant and their antimicrobial activity. Biosynthesis of gold nanoparticles was accomplished by the interaction of golden salt (HAuC$l_4.3H_2o$) with aqueous extract of *Scrophularia striata*. In order to obtain uniform and spherical nanoparticles, the following parameters affecting the biosynthesis of nanoparticles were investigated and optimized by ultraviolet-spectrophotometric technique; golden salt concentration, extract volume, pH and reaction time. Transmission electron microscopy and X-ray diffraction technique were also used to further characterize nanoparticles. Finally, the anti-bacterial properties of gold nanoparticles were investigated by disc diffusion method. The resulting absorption spectra exhibited strong peaks at 570 nm, which is a specific wavelength for gold nanoparticles. Transmission electron microscopy studies showed that the gold nanoparticles had a spherical shape with a mean diameter of 5-10nm, and the highest diameter of the growth inhibition zone was observed on the diameter of the hafnium bacteria (14mm). In this study, it was observed that, with the aid of *Scrophularia striata* aqueous extracts, a golden nanoparticle showed an antibacterial activity against gram-negative bacteria.

Keywords: *Antimicrobial activity; Biosynthesis; Gold nanoparticles; Scrophularia striata*

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INTRODUCTION

Nowadays, nanotechnology research and applications have made remarkable progress. One of the most important branches of nanotechnology is nanoparticles. Various metallic nanoparticles such as silver, gold, platinum, titanium, palladium, iron, aluminum and copper are of great interest to many researchers. Among them, gold nanoparticles are especially important. Gold on a nanoscale shows features that make it an important metal in nanotechnology processes [1, 2]. Most of the used chemical and physical methods for the production of nanoparticles are expensive and avoid the use of toxic solvents in the synthesis protocol, which may pose environmental risk [3, 4]. Green synthesis is simple, low cost, non-toxic, environmentally friendly and efficient for exploitation [5]. Leaf extract of plants that are rich in polyphenols,

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such as flavonoids, is a potent factor in reducing the synthesis of gold nanoparticles. Therefore, in many papers, the use of plant extracts is indicated for the synthesis of nanoparticles [5, 6]. According to Mameneha et al., *Scrophularia striata* contains flavonoids, anthocyanins and high levels of an acid such as oxalic acid, succinic acid, and organic acids. Researches indicate the presence of germicidal plants such as alkaloids, resin glycosides, "iridoids and crypthophilic acids. However, studies on this plant shows that, the plant contains polyphenols, flavonoids, as well as high antioxidant properties [7]. Polyphenylene compounds are reductive compounds that in addition to reducing properties have the ability to stabilize metal nanoparticles [8]. Among all the above-mentioned goals, metal nanoparticles have promising antibacterial properties due to their high levels of volume. Increasing microbial resistance to antibiotics and the development of resistant strains have attracted researchers' interest in the antimicrobial effects of metallic nanoparticles [9, 10]. Since nanoparticles are the basis of nanotechnology, their use in medicine has opened up a new perspective on the fight against pathogenic bacteria [11, 12]. Because of this, an antimicrobial activity of the nanoparticles is first measured and if possible, used for drug use. Types of nanoparticles, such as nanosilver, nano-titanium and zinc nanoparticles, have antibacterial activity [13, 14]. Several studies have reported the synthesis of gold nanoparticles using plant extracts. Gardea and colleagues, first reported the formation of gold nanoparticles in alfalfa which were cubic, twin, and twin in sizes of 4 and 6 to 10 nm, [15]. Shankar and colleagues reported the recovery of gold ions by the leaves of geranium and lemon extracts [16]. In 2010, Dwivedi et al. reduced the leaves of Chenopodium album to gold nanoscale dimensions of 10-30 nm in spherical shape [17]. Grace et al., in their study synthesized gold nanoparticles, studied their physicochemical properties and then studied the antimicrobial effects of nanoparticles by disc diffusion method on Pseudomonas aeruginosa, *Mucocus lut*eus, Staphylococcus aureus and Escherichia coli bacteria. The average size of gold nanoparticles in this study was 12-15 nm with a concentration of 0.5 mM; this also indicated that gold nanoparticles had no antimicrobial activity at this concentration [18].

In the present study, in addition to characterizing and evaluating the parameters affecting the biosynthesis of gold nanoparticles from the aqueous extract of *Scrophularia striata*, the effect of synthesized gold nanoparticles on several pathogenic bacteria was also evaluated.

MATERIALS AND METHODS

Preparation of the Plant Extract

The flowers of *Scrophularia striata* (Family: Scrophulariaceae) were collected from the Western Zagros Mountains in Iran, Ilam province, in March and April 2018. The flowers were washed thoroughly with deionized water. 10 g of flowers was added to 10 0mL of deionized water and boiled for 15 min in a water bath. The mixture was then filtered with Whatman filter paper no. 1.

To remove any remaining impurities, the extract was centrifuged with a Sigma centrifuge model of 3-30 k for 30 minutes at 10,000 rpm. The extract was stored for further use at 4 °C for 72 hours [19]. These extracts were used as reducing agents as well as the stabilizing agent [15]. In order to synthesize gold nanoparticles, the Sigma Al-Darych and Deionize water were used in all stages of the study of golden salt ($HAuCl_4.3H_2O$). For this purpose, 4 ml of a 1 mM solution of gold was added to 2 ml of the extract at room temperature and the pH of the solution was read by a pH meter (827-pH lab; 230 V, EU with Primatrode, Germany). The practice of reducing golden salt was quickly observed by changing the solution color from pink to purple, and it remained stable, indicating the formation of gold nanoparticles. To ensure the synthesis of gold nanoparticles, the UNICOUV-2100 Ultraviolet Spectrophotometer (UV Spectrophotometer) [8] spectrally evaluated 1 ml of the solution.

Optimizing the Parameters for the Synthesis of Gold Nanoparticles

The goal of optimizing various parameters is to obtain nanoparticles of smaller sizes and uniformity. In other words, we are looking for conditions to optimize the various parameters using the visible spectrophotometer -ultraviolet spectroscopy. By spectating this device, it is easy to detect the synthesis or non-synthesis of nanoparticles. For this purpose, four parameters of extract volume, soluble pH, golden salt concentration and reaction time for optimization were investigated. Optimization for the synthesis of gold nanoparticles was performed using different volumes of extract (1, 2, 3, 4) ml and the fixed volume of 4 ml of golden salt of 1 mM at constant pH as a reducing agent. After determining the optimal volume of the extract to investigate the effects of pH on the size and rate of synthesis of gold nanoparticles, the pH of the reaction solutions using sodium hydroxide and hydrochloric acid (made by the German Merck Corporation) 0.1 M (4, 5, 6, 7, 8). Adjustment and proper pH were evaluated. To determine the concentration of gold salt in the reaction process, the experiments were repeated with different concentrations of golden solution (0.1, 0.5, 1 and 5) mM, and then the effect of time on the nanoparticle synthesis process was investigated and the spectra absorption of each stage in the range of 400 to 800 nm was recorded by a spectrophotometer.

Morphological Study of Gold Nanoparticles

To characterize and investigate the morphology of synthesized gold nanoparticles, one or more samples were optimized according to the conditions and extracted nanoparticles from the solution by an electron beam transducer model Zeiss -EM10C-80KV made in Germany and an X-ray diffraction pattern of Philips model (X 'Pert) constructed in Germany.

Antimicrobial properties of gold nanoparticles

Antibacterial activity of gold nanoparticles has been studied by disk diffusion method on two gram-positive bacteria of (*Staphylococcus aureus* ATCC 25923) and (*Enterococcus faecalis* ATCC 29212); four gram-negative bacteria *Escherichia coli* (*E. coli* ATCC 25922), (*Hafnia ahvei* PTCC 1289), (*Salmonella enterica* subsp. *enterica* ATCC 13076) and (*Shewanella sp.* PTCC 1711) prepared from People's Friendship University of Russia (PFUR) collection center. First, each bacterium was cultured in a culture medium (temperature 37°C, shaker at 200 rpm for 24 hours). After 24 hours, each bacterium was prepared with a concentration equal to the concentration of the MacFarlend's half, and from each bacterial suspension was inoculated 0.1ml (10^8 *cfu/ml*) agar and cultured massively with swabs. Afterward, paper discs (6 mm) stained with gold nanoparticle solution were placed on the culture of the bacterium and finally placed the plates in an incubator at 37°C and the diameter of the no-growth zone created around each disc then was measured from 24 to 48 hours. In order to compare the antibacterial effect of gold nanoparticles against tested bacteria, the susceptibility of these bacteria to the Co-amoxiclav antibiotic disks was investigated [21, 22].

RESULT

The Study of Ultraviolet Absorption Spectroscopy- Visible Synthesis of Gold Nanoparticles. The synthesis of gold nanoparticles by decreasing the gold ion from Au^0 to Au^{3+} with the naked eye can be clearly distinguished by changing the color of the sample from pink to purple. Maximum peak absorption by ultraviolet spectrophotometer-visible at 580nm (Fig. 1) represents the adsorption band for surface Plasmon resonance for gold nanoparticles. Therefore, it can be moved by changing the factors affecting the peak Plasmon. One of the most interesting features of metallic nanoparticles is their optical properties, which varies with the shape and size of the nanoparticles. In metal nanoparticles, surface Plasmon resonance is responsible for their unique properties, which is influenced by factors such as the size and shape of nanoparticles, their distance from each other, and the refractive index of the surrounding environment [16, 22]. In practice, the change in peak plasmonic intensity is accomplished

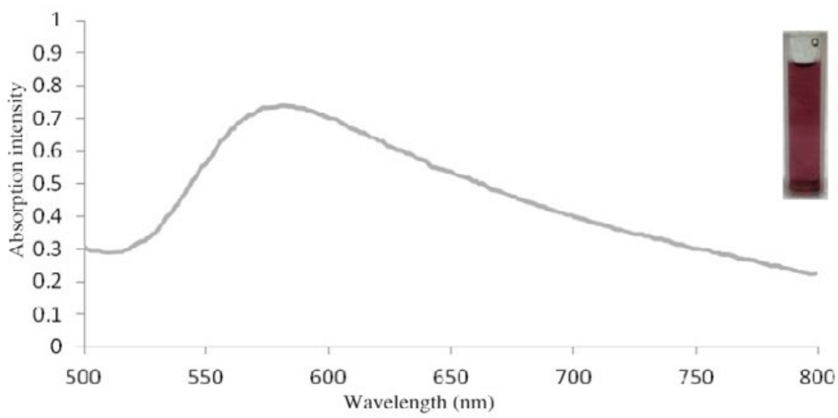

Fig. 1. Absorption spectra of nanoparticles of synthesized gold using *Scrophularia striata* aqueous extract after optimal conditions.

by varying the ratio of reactants and changing reaction conditions.

The volume effect of the extracts on the reaction

The extract of the plant is used as a reducing agent for the recovery of ions Au^0 to Au^{3+} So the concentration of the extract plays an important role in the process of regeneration. The higher concentration of the extract equal to the faster the recovery of Au^{3+} ion, which will result in the rapid formation of gold nanoparticles [17]. The absorption spectra of gold nanoparticles in different volumes of the *Scrophularia striata* (Fig. 2) show that in the region of 580nm, the volume of 2 ml of the extract has the highest absorption and severity of the peak, ultimately the volume of 2ml of extract was selected as optimal volume.

Investigating the effect of pH on the reaction

The ultraviolet absorption spectra of the nanoparticles of synthesized gold at different pH of 4, 5, 6, 7, 8 are shown in (Fig. 3). By increasing the pH, the adsorption band of the surface Plasmon resonance increases with a slight gradient and decreases at pH 8 by the end. It can be said that at lower pH, due to the relatively large size of nanoparticles, a broad spectrum of absorption is observed [21, 23]. By examining the ultraviolet-visible spectrum, it was observed that the synthesized gold nanoparticles were stable in a wide range of pH. The displacement at a wavelength of 580 nm to 570 nm at pH 7 is a change in the size or shape of the nanoparticles, which was eventually selected as the optimum pH.

Investigation of the effect of golden salt concentration in the reaction process

The concentration of gold metal ions will also affect the formation of nanoparticles that way by examination of the Visible ultraviolet absorption spectrum (Fig. 4), by increasing the concentration of metal ions from 1 mM to 5 mM, the absorption band

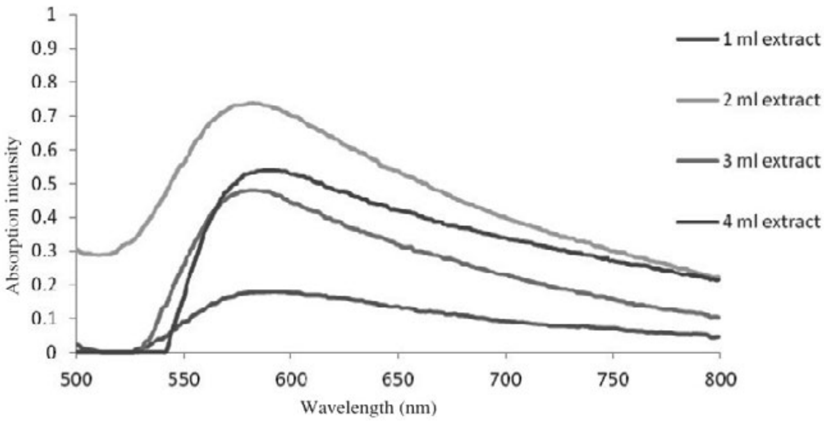

Fig. 2. The absorption spectrum of gold nanoparticles in different amounts of aqueous extract of *Scrophularia striata* (ml extract is the amount of volume removed from the aqueous extract of the plant for the synthesis of gold nanoparticles)

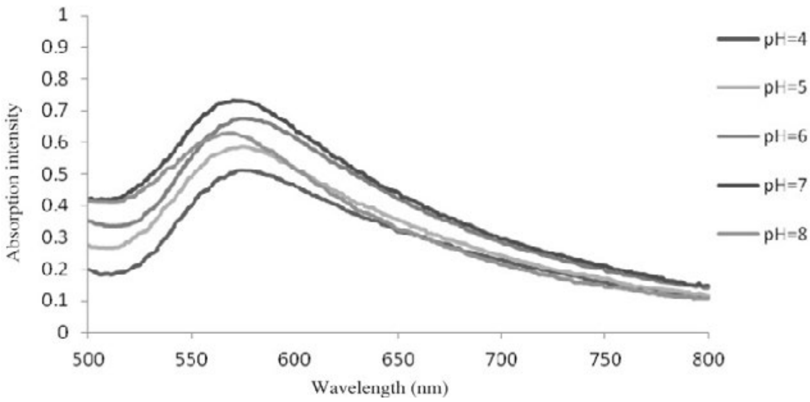

Fig. 3. Effect of different pH on absorption spectra of nanoparticles of gold synthesized using aqueous extract of *Scrophularia striata.*

of the exacerbation of a very large surface Plasmon indicated the formation of coarse and non-uniform nanoparticles. In addition, poor absorption spectra are observed in concentrations of 0.1 mM and 0.5 mM that indicate low synthesis or non-synthesis of nanoparticles. Among the different concentrations of metal ions, the concentration of 1mM of golden salt has the highest maximum absorption. We have chosen 4ml of golden salt (1mM) as optimal concentration.

The effect of time on the reaction process

Investigating the effect of time on the reaction process (Fig. 5) showed that the absorption due to the surface Plasmon resonance, from the initial reaction time to 40 minutes after the reaction at a constant wavelength (570 nm) increased and then remained constant. As a result, the ideal time to synthesize gold nanoparticles is 40 minutes. In this case, the peaks are sharper and the color of the violet solution is more intense. Eventually, 40 minutes were selected as the optimal time to synthesize gold nanoparticles.

The morphology of gold nanoparticles synthesized by Transmission Electron Microscopy (TEM) and X-ray diffraction (XRD). After obtaining optimal conditions using ultraviolet-optical spectroscopy, a TEM image was developed to compare the morphology and uniformity of the distribution of the gold nanoparticles produced by the TEM image. The results of the photos of the electron microscope (Fig. 6) showed that the average size of the nanoparticles is between 5 and 10 nm and the shape of the particles is almost spherical. Another method used to characterize the gold nanoparticles is the X-ray diffraction pattern (XRD). This method can also be used to determine the crystalline structure of nanoparticles. The X-ray diffraction pattern of gold nanoparticles (Fig. 7) shows in regions 38/25, 44/60, 64/68, nanoparticles show sharp and sharp peaks, which is a reason for the synthesis of gold nanoparticles. Structural analysis shows that nanoparticles have a crystalline structure with miller indexes (1 1 1), (200), (220)

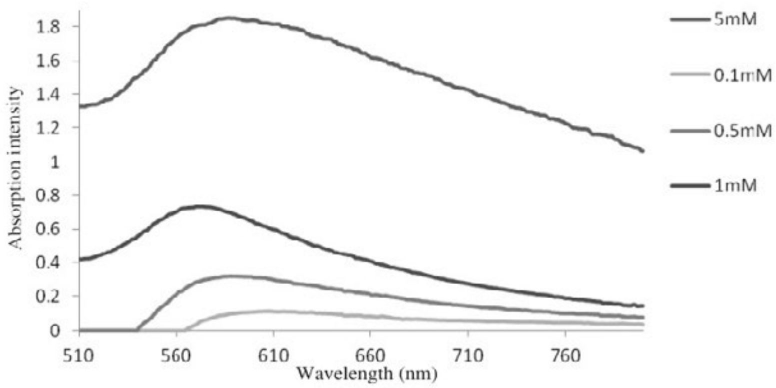

Fig. 4. Absorption spectra of gold nanoparticles formed by various concentrations of gold salt (mM represents the concentration of a solution of gold salt).

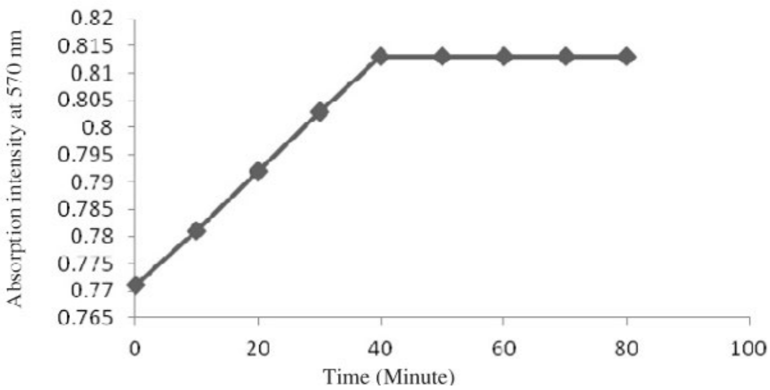

Fig. 5. Shows the absorption rate of the Nano-sized particles of gold synthesized at different times.

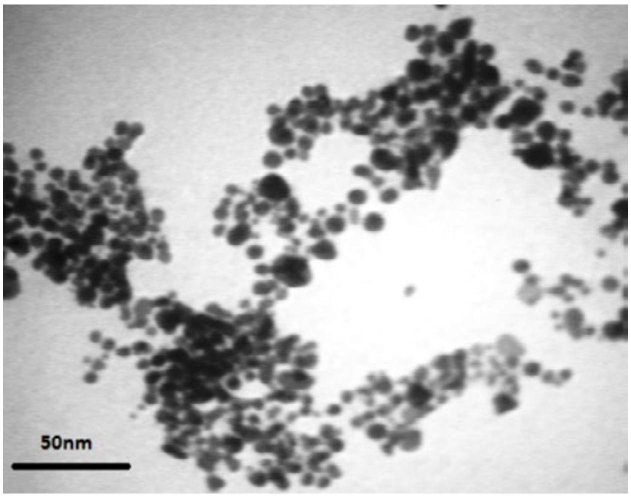

Fig. 6. An image of an electron microscope transmitted by synthesized gold nanoparticles using a reaction of 4 ml of a 1 mM gold (III) solution with 2 ml of aqueous extract of *Scrophularia striata* at pH 7 and room temperature at 40 minutes

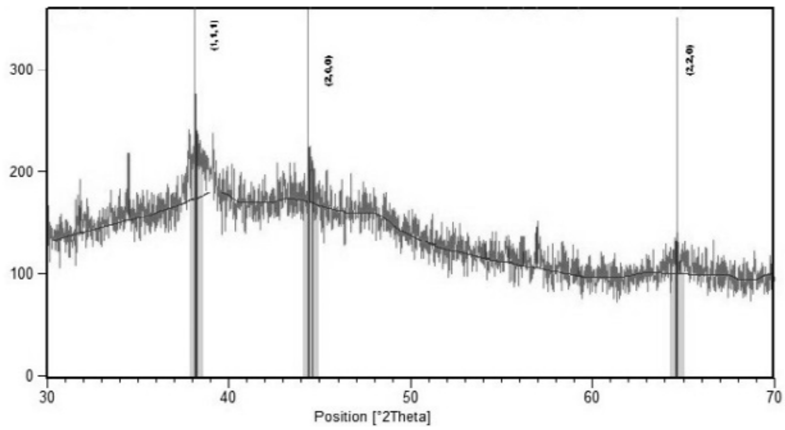

Fig. 7. X-ray diffraction pattern of nanoparticles synthesized using the *Scrophularia striata* blue eyed.

in a cubic network. From the comparison of peak intensity, we find that peak (1 1 1) is more intense than other peaks, because of which the crystalline nanoparticles are further formed in this direction. The average size of nanoparticles can be calculated using the Debye-Saline relationship (Eq. 1).

$$D = 0.9\lambda/\beta \cos\theta \quad (1)$$

B is the width of the peaks in half the maximum height, λ the wavelength of the X-ray is 1.54 nm, θ is the angle between the reflected beam and the radiation, and D is the size of the crystalline grains. The average size of crystalline grains of synthesized gold nanoparticles was estimated to be 4.9 to 9.87 nm. These results are consistent with the data obtained from the transmitted electron microscope images and the results obtained from the ultraviolet spectrophotometer spectrum.

Antibacterial effect of gold nanoparticles

The results of antimicrobial activity of synthesized gold nanoparticles on four Gram-negative bacteria and two Gram-positive bacteria are shown in (Table 1). In order to ensure the antibacterial effect of synthesized nanoparticles in this study, the comparison with standard antibiotic effect as a positive control was used.

According to the results, the antibacterial activity of nanoparticles of synthesized gold on gram-negative bacteria were more than the gram-positive bacteria used in this study. Therefore, the maximum diameter of the growth was related to the hafnium plum bacterium (14 mm).

Table 1. Results of antimicrobial effects of gold nanoparticles synthesized from aqueous extract of *Scrophularia striata* compared to Coomucicular antibiotic.

Microorganisms (bacteria)	Diameter of inhibition zone (mm)	
	Gold nanoparticles	Co-amoxiclav antibiotic
Hafnia ahvei	14	35
Escherichia coli	13	28
Salmonella enterica	11	30
Shewanella sp.	10	29
Staphylococcus aureus	7	25
Enterococcus faecalis	7	25

DISCUSSION

Generally, the advantage of plant-based nanoparticles to other biological methods is safety, as well as the high capabilities of medicinal plants that are more reliable and healthier than bacteria, fungi, and yeast for the production of nanoparticles [22]. In addition, nanoparticles produced by medicinal plants can be used at lower risk in many cases, including the transfer of medicine in the body. Due to the cheap and easy availability of biological methods, especially herbal ones, economically, it can also be important from an economic point of view and be given serious attention [6].

Extracting plants that are rich in polyphenols such as flavonoids, which are powerful compounds for producing nanoparticles, such as AuNPs. However, in many studies, as well as in this study, the aqueous extract of the plant has been used to synthesize nanoparticles [37, 38]. The results of Yousefbeyk *et al.* showed that *Scrophularia striata* contains flavonoids, anthocyanins and high amounts of compounds such as alkaloids, resin glycosides, "iridoid", cryptophilic acid and organic acids [24, 25]. Polyphenolic compounds also have the ability to stabilize metal nanoparticles, in addition to their reduced properties.

As a result, adding polyphenol compounds to a solution, Au^{3+} ($HAuCl_4$) is reduced by polyphenolic compounds to metal gold, and the same polyphenolic compounds prevent the accumulation and melting of gold particles. Nanoparticles of gold are formed [18]. The change in color observed from pale pink to purple is due to the interaction of herbal extract and golden salt solution because of the study, with similar results from Grace *et al.* [10], Chandran *et al.* [16], and Shankar *et al.* [26]. The color change of the reaction solution is the first indication of the production of gold nanoparticles. UV-Vis spectroscopy is an important method for determining the formation and stability of metal nanoparticles in aqueous solution. The color of the colloidal solution of gold associated with the Surface Plasmon resonance (SPR) is due to the collective fluctuation of the electrons induced by interaction with the electromagnetic field, which is the absorption spectrum of the absorption spectrum for each particle of each size, specifically for the nanoparticles, and because of the plasmonic phenomenon. Ultraviolet is visible [27]. Similar results were reported in Narayanan *et al.* Researches around the 536 nm area, [28] and Philip *et al.* in the region of 573 nm. The initial absorption spectra obtained from ultraviolet spectrophotometry - aqueous extract of *Scrophularia striata* containing gold nanoparticles showed a strong and high absorption peak at 580 nm. The absorption of light by metallic nanoparticles follows the Beer method, which means that by changing the concentration of metal nanoparticles, the absorption of light changes linearly. The factors affecting peak plasma are the shape and size of nanoparticles. By increasing the size of the nanoparticles, effects such as reddening and expanding the resonance peak are observed. The deformation of the nanoparticles results in the geometric deformation of their surface and the resulting peak position depends on the number and edges of the nanoparticle's shape [29]. Also, Bluber *et al.* studied the absorption spectra of spherical nanoparticles made of Au, Ag, Al, K, Na. They concluded that the maximum absorption for any metal is a function of the size of the sphere [28, 29].

One of the parameters influencing the synthesis of gold nanoparticles is the amount of plant extract volume. Reports indicate that with increasing the amount of extract, the amount of reducing compounds such as phenolic, flavonoids and terpenoids increased in the solution [30]. Based on the results of this study, with increasing the amount of extract, the intensity of maximum absorption of the surface Plasmon resonance of gold nanoparticles increases and then decreases, as well as the displacement towards longer wavelengths. This event may be due to the absorption of metal ions by the biochemical molecules present in the extract, resulting in a reduction in the number of available ions for the restoration reaction. Therefore, the rate of formation of gold nanoparticles is lowered [17, 31]. Research shows that synthesizing nanoparticles at concentrations lower than the optimal number of stabilizing agents does not completely stabilize the nanoparticles and produce coarser particles. Additionally, adding more concentrations than optimal level lead to the accumulation of stabilizing particles around itself, as a result no stabilization occurs and particle size will be increased [19]. Previous reports indicate that pH does not have a significant effect on nanoparticle shape, only greatly affects them, making pH one of the most important factors in the synthesis of nanoparticles [31]. The results of pH effects on the synthesis of gold nanoparticles using the *Scrophularia striata* aqueous extract showed that these nanoparticles are stable in a wide range of pH. With increasing pH, the surface plasmonic absorption (SPR) initially increased with a slight gradient and then decreased to pH 8. The intensity of absorption, as well as the displacement towards shorter wavelengths (blue wavelengths), clearly occurs in the absorption spectrum from 580 to 570 nm at pH 7, which indicates a reduction in the size of the nanoparticles. Similar results were reported in studies by Zarzuela *et al.* [32], It turns out that at higher pH, with iodine hydrolysis (III) Au, we are faced with the formation of stable species of gold hydroxides ion and ultimately prevent ion entry into biological resuscitation [11] Spreads that have already been reported to increase as nanoparticles have been expanded [33].

Based on the results obtained at low concentrations of gold metal salt (0.1 and 0.5 mM), a decrease in surface plasmonic absorption is observed. This may be as a result of lack of proper formation of gold nanoparticles [10, 19, 33]. By increasing the concentration of metal ion, the size of the nanoparticles is increased and absorbed more, as more ions will be exposed [34]. In addition, due to this increase in absorption, the size of the synthesized nanoparticles is slightly increased, which is an increase in size due to the bonding of nanoparticles to each other [8]. At low concentrations of metal ion, the rate of gold nanoparticles formation is slow, so it is also poorly absorbed [10]. One of the factors that prove the stability of nanoparticles is the time factor and their absorption do not change over the time. In some, over time, the amount of adsorption decreases due to the adhesion and accumulation of synthesized nanoparticles. The basis of nanoscale synthesis is the particle, the recovery of their salt ions and the neutralization of the charge [5]. In this study, the process of synthesis of nanoparticles was performed over a 40-minute period at room temperature, indicating the high speed of this method and its high need for gold nanoparticles formation. The results are consistent with the research by Nayak *et al.* [35].

The results of the X-ray diffraction obtained in this study are quite similar to the previously published results [10, 19]. Transmission electron imaging shows the synthesis of spherical gold nanoparticles in sizes ranging from 5 to 10 nm, Narayanan *et al.* [27] Reported nanoparticle synthesis in the size range of about 6-60 nm [27, 35]. Lunardi *et al.* also synthesized gold nanoparticles in size from 30-60 nanometers using the *Euphorbia tirucalli* plant [36].

Antibacterial activity of nanoparticles depends mainly on the size of nanoparticles and their surface area [32]. Nanoparticles have a larger surface to surface ratio to contact with microorganisms so increase their biological and chemical activity, [11, 40, 41]. Studies have shown that the difference between gram-negative and gram-positive bacteria is related to their cell wall structure. Gram-negative bacteria have a thinner cell wall that has little strength and, on the other hand, there is the outer surface of the gram-negative bacteria of a layer of lipopolysaccharide that has a negative charge. Therefore, the presence of a positive charge on gold ions is necessary for antimicrobial activity due to the electrostatic interaction between the negative charge of the cell wall of the microorganism and the positive charge of the nanoparticle [36]. Available evidence from Wang *et al.* shows an antibacterial effect mechanism of the photocatalytic reactions of Gold nanoparticles. During the study, the researcher found that initial oxidative damage occurs on the cell wall, in which the photocatalytic level of the gold nanoparticles provides an initial contact with a healthy cell. After that, the cell wall protects the oxidative damage in the cytoplasmic membrane [42]. On the other hand, photocatalytic activity gradually increases the permeability of the cell, and the inner contents of the cell are released and cell death occurs. Gold nanoparticles may also gain access to the membrane of damaged cells, and direct attack on intracellular components can accelerate the death of cells [37].

Most studies have shown that nanoparticles of less than 10nm are toxic and have more potent antibacterial properties. The advantage of using golden nanoparticles against antibiotics is the lack of resistance of bacteria to these nanoparticles, a wide range of effects, and no maladaptive effect on human cells [14]. The important point is that in recent decade' gold nanoparticles have been used as a strong antibacterial. Therefore, that nanoparticle, especially gold nanoparticles, play an important role in the elimination of drug-resistant bacteria [24].

The results of this study showed that the synthesized gold nanoparticles were effective in the use of the aqueous extract of *Scrophularia striata* by disc diffusion method on 6 species of bacteria, except that they showed more activity on gram-negative bacteria than gram-positive bacteria. In addition, the highest non-growth halo diameter was observed on hafnium-bearing bacteria with a diameter (14 mm). Studies by Deng *et al.* [38] showed the antibacterial properties of gold nanoparticles, especially in a study of golden nanoparticles on linen fibers. The differences observed in this study on inhibiting bacterial growth can be attributed to the difference in the shape and diameter of gold nanoparticles. As Begum *et al.* [6] noted, the properties of each nanoparticle affected by its intrinsic properties, including the diameter of the nanoparticles. Gold nanoparticles synthesized by Colin *et al.* [5] of 3 to 9 nm have more antibacterial activity on gram-negative bacteria than gram-positive bacteria [5, 38]. In studies by Song *et al.* [26] on the antimicrobial activity of gold nanoparticles on gram-negative bacteria, *E. coli* and gram-positive *Bacillus subtilis* and *Staphylococcus aureus*, gold nanoparticles had the most effect on the gram-positive bacteria of *Staphylococcus aureus* [27, 39].

CONCLUSION

The results of this study indicate that the *Scrophularia striata* herb has the potential to synthesize gold nanoparticles, and so far, the use of this plant has not been reported to reduce the biological ions of gold. The performance of this plant at room temperature and standard pressure will be optimal. Due to the antibacterial properties of gold nanoparticles, they can be used to eliminate bacterial infections. Therefore, it can be said that, the *Scrophularia striata* plant, except its specific pharmaceutical role, can also be used to produce gold nanoparticles for medical and pharmaceutical use. Also further research is being conducted to identify the application of these nanoparticles.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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