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Green synthesis of silver nanoparticles using the aqueous extract of *Larrea tridentate* and *Eucalyptus*

Síntesis verde de nanopartículas de plata a partir del extracto acuoso de *Larrea tridentata* y *Eucalyptus*

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Abstract

In this paper, we report the synthesis of silver nanoparticles (AgNPs) using $AgNO_3$ as a precursor salt and the aqueous extracts of *Eucalyptus* and *Larrea tridentate* as reducing agents for the metal salt and stabilizing agents of the nanoparticles obtained. 15 ml of a 0.1 M solution of $AgNO_3$ and 10 ml of the extract were mixed, and the reaction mixture was vigorously stirred for 24 hrs at 50 °C. The extracts obtained were analyzed by the HPLC-Ms technique, to know the compounds and families that contain the aqueous extracts and identify the functional groups responsible for the reduction of Ag^+ ions. This information was of great relevance to propose a reaction mechanism for the synthesis of nanoparticles. On the other hand, by means of DRX the obtaining of the AgNPs was confirmed because the results showed a crystalline nature in the cubic structure centered on the face corresponding to the silver, in addition to the Uv-vis spectroscopy the surface plasmon resonance was observed in the characteristic 430-450 nm range of these nanoparticles, the presence of functional groups on the surface of the nanoparticles was confirmed by infrared spectroscopy, and by SEM a quasi-spherical morphology and average sizes of 20-100 nm were observed using the extract of *Eucalyptus* and 20-60 nm with *Larrea tridentate* extract.

Keywords: Green synthesis, silver nanoparticles, aqueous extract.

Resumen

En este trabajo, se presenta la síntesis de nanopartículas de plata (NPsAg) utilizando $AgNO_3$ como sal precursora y los extractos acuosos de *Eucalyptus* y *Larrea tridentata* como agentes reductores para la sal metálica y agentes estabilizadores de las nanopartículas obtenidas 15 ml de una solución de $AgNO_3$ y 10 ml de extracto se mezclaron. La mezcla de reacción se agitó vigorosamente durante 24 hors a 50 °C. Los extractos obtenidos se analizaron mediante la técnica HPLC-Ms, para conocer los compuestos y familias que contienen los extractos acuosos e identificar los grupos funcionales responsables de la reducción de iones Ag^+. Esta información fue de gran relevancia para proponer un mecanismo de reacción para la síntesis de nanopartículas. Por otro lado, mediante DRX se confirmó la obtención de los NPsAg debido a que los resultados mostraron una naturaleza cristalina en la estructura cúbica centrada en la cara correspondiente a la plata, además en la espectroscopía Uv-vis se observó la resonancia del plasmón superficial en el rango característico de 430-450 nm de estas nanopartículas, la presencia de grupos funcionales en la superficie de las nanopartículas se confirmó mediante espectroscopía infrarroja, y mediante SEM se observó una morfología cuasiférica y tamaños promedio de 20-100 nm usando el extracto de *Eucalyptus* y 20-60 nm con el extracto de *Larrea tridentata*.

Palabras clave: Síntesis verde, nanopartículas de plata, extractos acuosos.

1 Introduction

One of the main limitations that occur during the synthesis of nanoparticles is the use of chemical reagents for the reduction of the precursor salts of the metal nanoparticles to be synthesized, which in addition to being toxic generating pollution for the environment are usually expensive (Seyedeh *et al*., 2020).

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In recent years the synthesis of materials on a nanometric scale has been of great interest, due to the properties they exhibit, being materials of great use for various applications, among which the optical and electrical properties can be highlighted, which derive from the oscillation of the valence electrons known as plasmon surface resonance, which is defined as a collection of the electrons of noble metal NPs obtained when their frequency matches the incident electromagnetic radiation.and which gives them a UV-Vis absorption band, which is characteristic of the metal and its morphology (Marwa, 2018; De Silva *et al*., 2020), resulting in a wide range of applications from cells solar, litography, biosensors, tumor markers, surface-enhanced resonance Raman scattering, antimicrobials among others.

The propierties and the applications, are mainly dependent on the sizes, shapes and stabilities of silver nanoparticles (Chunfa *et al*., 2016). Silver particles in nanometric size are the most commercialized due to the increase in their use in various areas such as electronics, catalysis, pharmaceuticals and medicine (Saber *et al*., 2018). Currently, in the medical and pharmaceutical area has been increasing when used in surgical instruments, drug administration, wound dressings, bone prostheses, antibacterial formulations (Saber *et al*., 2018), because silver nanoparticles have significant characteristics as they are not toxic to eukaryotic cells, but of great toxicity to prokaryotes such as micro-organisms (Keshary *et al*., 2018).

A wide variety of methods has been developed to synthesize metal nanoparticles with different morphologies, an example of this is the chemical reduction obtaining nanorods (Rekha *et al*., 2018), nanodiscs (Mahmoud, 2015) and nanotriangles (Ardianrama *et al*., 2019), the laser ablasion obtaining nanospheres (Kumar *et al*., 2018; Boutinguiza *et al*., 2015) as well as electrochemical methods (Ravichandran *et al*., 2019). Chemical methods are the most commonly used, due to their ease in developing large-scale procedures, which allow the size, size and shape distribution of nanoparticles to be adequately controlled, and also because they are precise methods and monodisperse nanoparticles are obtained (Mankad *et al*., 2018). However, these methods have a great drawback in involving toxic reagents generating waste that is harmful to health and the environment (Lopes *et al*., 2018).

Presently the biological methods, which have been great interest when using biological organisms such as bacteria, plants and fungi for the synthesis of nanoparticles, managing to avoid the use of toxic reagents in addition to being effective, safe and profitable methods (Kobashigawa *et al*., 2018).

Due to the development of new chemical or physical methods, and the concern for environmental pollution since the chemical procedures involved in the synthesis of nanoparticles generate a large number of hazardous by-products, awareness has been made of the need to use "green chemistry" in the synthesis of nanoparticles, prioritizing clean, non-toxic, environment friendly and mild reaction conditions. In this regard, biological sources such as bacteria, fungi or plants have been used as easy and viable alternatives compared to the chemical or physical methods available for such obtaining (Konishi *et al*., 2007; Borase *et al*., 2014). Qualitative biochemical studies have been performed that suggest the participation of various plant metabolites such as terpenoids, flavonoids, polyphenols, amines, saponins, aldehydes, ketones, proteins, arabinose and galactose in the synthesis of metal nanoparticles. In general, these functional groups function as reducing agents, since they react with metal ions of the precursor salt and thereby reduce metal ions to nanoparticles with different shapes and sizes (Bhattacharya *et al*., 2005). The synthesis of silver nanoparticles from plant extracts have been used more frequently (Nilavukkarasi *et al*., 2020; Seyedeh *et al*., 2020; Gomathi *et al*., 2020) when compared to the synthesis assisted by bacteria and fungi (Hekmati *et al*., 2020), this because the synthesis used fungi and bacteria is very slow compared to the synthesis assisted with plant extracts (Ahmed *et al*., 2016), another advantage of plant extracts is that they can act as reducing and stabilizing agents without the need to add an additional reducing or stabilizing agent to the plant extract and the precursor salt, which is why this synthesis method has a great advantage , being an easy, scalable and inexpensive method for obtaining nanoparticles (Sur *et al*., 2018). Different plants had been used for the synthesis of silver nanoparticles such as chili bergamot (*Mint piperita*) (MubarakAli *et al*., 2011), pig quelite (*Chenopodium murale*) (Abdel-Aziz *et al*., 2014), coconut oil (Mena *et al*., 2013), Chamomile chamomile (*Matricaria recutita*) (Uddin *et al*., 2017), green tea (Münever *et al*., 2017), saffron (*Crocus sativus* L.) (Bagherzade *et al*., 2017). These plants possess chemical compounds such as terpenoids, eugenol, polyphenols, among others, that act as reducing agents, and also functionalize the resultant nanoparticles (Chaha *et al*., 2018). This article presents a green methodology for the synthesis of silver nanoparticles using aqueous extracts of

Eucalyptus and *Larrea tridentata*, in order to avoid toxic reagents to obtain them.

2 Materials and methods

2.1 Materials

Silver nitrate (≥ 99%, $AgNO_3$) were purchased from the Jalmek and the leaves of the plants were collected in the southern region of Coahuila Mexico (*Eucalyptus* and *Larrea tridentate*). All reagents were bought and used directly without further treatment.

2.2 Synthesis of AgNPs

The leaves of the plants were washed and dried to later be crushed. They were placed in 60 ml of double distilled water at a temperature of 60 °C for 1 hr The solution was filtered to remove solids and obtain aqueous extract from plants (Ya *et al*., 2015). 25 ml of a 0.1 M solution of $AgNO_3$ and 10 ml of the aqueous extracts were mixed. The reaction was kept under stirring at 50 °C for 24 hrs. The AgNPs were three times washed with double-distilled water in a centrifuge at 8500 rpm for 15 min This procedure was performed for eachextract.

2.3 Characterization of plant extracts

Plant extracts of *Eucalyptus* and *Larrea tridentata* were characterized by HPLC-Ms technique and FT-IR spectroscopy (Martins *et al*., 2013; Bañuelos *et al*., 2018).

2.3.1 Analysis of the composition of the extracts by HPLC-Ms

A Varian Prostar 330 liquid chromatograph with diode array detector coupled to a Varian 500 ms mass spectrometer with ion trap was used. The chromatographic separation was developed with a C18 ACE Excel 3 Super column, with dimensions of 150 x 2.1 mm, of a particle size of 3 μm. The mobile phase used was acetronityl (a) / formic acid 0.2% in water (b) and the injected sample was 5 μl.

2.3.2 Analysis of the extracts by infrared spectroscopy (FT-IR)

FT-IR spectroscopy was permormed on a Perkin-Elmer Nicolet Nexus 47 equipped with an attenuated total reflectance accessory with an incidence angle of 45° and an ATR diamond crystal at a resolution of 4 cm^{-1}, to analyze functional groups present in plant extracts, as well as in silver nanoparticles (AgNPs).

2.4 Characterization of AgNPs

The AgNPs obtained were characterized by X-ray diffraction (XRD), (FT-IR), UV-vis spectroscopy and Scanning electron microscopy (SEM).

2.4.1 UV-vis spectroscopy

UV-vis spectra were obtained using a Shimadzu UV-2401 PC double beam spectrometer using 50 W D2 and halogen lamps, at a resolution of 0.1 nm.

2.4.2 X-ray diffraction (XRD)

X-ray diffraction measurements were carried out to identify the crystalline phase of the AgNPs on a Panalytical Emyrean model, with Cu anode, operating with a current at 30 kV and 20 mA, with a 2θ step of 0.02°. The measurement parameters were programmed from 20-80 ° at angle 2θ.

2.4.3 Scanning electron microscopy (SEM)

The morphology was examined by scanning electron microscopy (SEM) using a scanning electron microscope Hitachi SU8010, with an acceleration of 3000 V, at a working distance of 1.9 mm and 7.7 mm, with a secondary electron detector.

3 Results and discussion

3.1 Materials characterization

3.1.1 Determination of the main coumponds of the extracts used for the synthesis of nanoparticles

Table 1 shows the compounds, families and retention times of the *Eucalyptus* extract, where it is observed that hydroxycinnamic acids, flavonols, lignans, anthocyanins and methoxybenzaldehydes are the main compounds present in the *Eucalyptus* extract.

Table 1. Compounds identified by HPLC-Ms of the extract of *Eucalyptus*.

Retention time	Mass (g/mol)	Chemical compound	Family
3.48	377	3,4-DHPEA-EA	Tyrosols
4.19	337	3-p-Coumaroylquinic acid	Hydroxycinnamic acids
4.84	191	p-Coumaric acid ethyl ester	Hydroxycinnamic acids
7.99	331	Galloyl glucose	Hydroxybenzoic acids
8.98	801	Spinacetin 3-O-glucosyl-(1->6)-[apiosyl(1->2)]-glucoside	Methoxyflavonols
9.48	154	Eucaliptol	Myrtaceae
14.49	771	Kaempferol 3,7,4'-O-triglucoside	Flavonols
16.64	285	Kaempferol	Flavonols
18.68	783	Kaempferol 3-O-(2"-rhamnosyl-6"-acetyl-galactoside) 7-O-rhamnoside	Flavonols
20.57	353	1-Caffeoylquinic acid	Hydroxycinnamic acids
21.92	337	4-p-Coumaroylquinic acid	Hydroxycinnamic acids
23.19	325	p-Coumaroyl glucose	Hydroxycinnamic acids
24.99	305	(+)-Gallocatechin	Catechins
25.45	337	5-p-Coumaroylquinic acid	Hydroxycinnamic acids
25.7	337	p-Coumaroylquinic acid	Hydroxycinnamic acids
26.59	377	Oleuropein-aglycone	Tyrosols
27.05	371	7-Oxomatairesinol	Lignans
27.51	371	Sesamolinol	Lignans
27.98	337	Demethoxycurcumin	Curcuminoids
30.3	301	Quercetin	Flavonols
31.05	477	Quercetin 3-O-glucuronide	Flavonols
32.81	595	Quercetin 3-O-glucosyl-xyloside	Flavonols
37.88	503	Peonidin 3-O-(6"-acetyl-galactoside)	Anthocyanins
39.99	181	Syringaldehyde	Methoxybenzaldehydes

Table 2. Compounds identified by HPLC-Ms of the extract of *Larrea tridentate*.

Retention time	Mass (g/mol)	Chemical compound	Family
3.35	191	Scopoletin	Hydroxycoumarins
4.84	190.9	Scopoletin	Hydroxycoumarins
11.72	270.9	Arbutin	Other polyphenols
13.19	254.9	Pterostilbene	Stilbenes
15.4	285	Luteolin	Flavones
16.72	285	Scutellarein	Flavones
17.92	304.9	(+)-Gallocatechin	Catechins
21.1	288.9	(+)-Catechin	Catechins
24.19	283.9	Geraldone	Methoxyflavones
26.87	370.9	Sinensetin	Methoxyflavones
27.75	755	Kaempferol 3-O-glucosyl-rhamnosyl-galactoside	Flavonols
30.34	609	Kaempferol 3,7-O-diglucoside	Flavonols
35.14	365	Secoisolariciresinol	Lignans
37.68	697	Cyanidin 3-O-(6"-malonyl-3"-glucosyl-glucoside)	Anthocyanins
41.48	330.9	Carnosic acid	Phenolic terpenes
45.73	328.9	3,7-Dimethylquercetin	Methoxyflavonols
46.86	347	5-Heptadecylresorcinol	Alkylphenols
47.29	299	Hispidulin	Methoxyflavones
49.59	301.1	Quercetin	Flavonols

On the other hand, in the *Larrea tridentate* extract (Table 2) the families found were methoxyflavones, flavones, hydroxycoumarins, catechins, stilbenes, lignans, phenokines, anthocyans, terpenes and alkylphenols. Several researchers have reported that these types of plants have very interesting compounds such as lignin which is responsible for antimicrobial activity, which is why their study has been of great interest (Juaréz, 2002). Other secondary metabolites such as flavonoids (Kaempferol and Querecetin) have been indicated as important, due to the fact that present biological activity of great interest in the healthy area (Martins *et al*., 2013). Other natural compounds that present this type of extracts are terpenes and phenols, to which antiseptic, antifungal, antioxidant and antitumor properties are attributed (Bañuelos *et al*., 2018). They also have flavonols and flavones in their main components (García *et al*., 2010).

In general, various compounds present in the extracts such as flavonols, hydroxycinnamic acids, hydroxycoumarins, polyphenols and catechins have functional groups such as alcohols, carboxylic acids and phenols in their structures (Borase *et al*., 2014), where primary and secondary alcohols can oxidize and form more reactive groups like aldehydes and ketones, helping to reduce metal (Wade, 2004).

3.1.2 FTIR analysis of extracts

Infrared spectroscopy was used for the purpose of identifying the functional groups present in the aqueous extracts of *Eucalyptus*, and *Larrea tridentate* which were used as reducing agents for $AgNO_3$ and stabilizing nanoparticles.

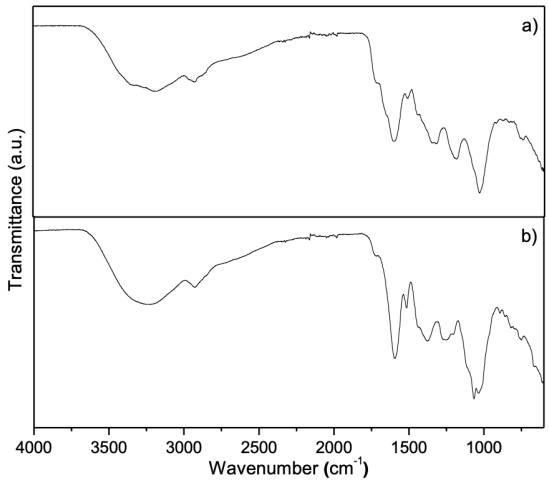


Fig. 1. FT-IR spectra of the extracts of a) *Eucalyptus* y b) *Larrea tridentata*.

Figure 1 shows a) the FT-IR spectra of the aqueous extracts of *Eucalyptus* and b) the FT-IR spectra of the *Larrea tridentate*, where similar bands are observed between both extracts, because in both functional groups such as phenols, ketones, carboxylic acids, esters, these being responsible for the reduction of silver ions. In both FT-IR spectra, the broad band between 3250 and 3500 cm^{-1} corresponds to hydroxyl groups (-OH). In 2930 cm^{-1} the stretches of -CH_2- are observed. The band 1690 cm^{-1} corresponds to the stretching of the C=O function attributed to ketones, carboxylic acids, esters, present in the compounds of the aqueous extracts, in 1365-1370 cm^{-1} a band is observed which represents the flexures of the methyl groups $(CH\text{-}CH_3)_2$ present, the band of 1200 cm^{-1} corresponds to the phenol, in 1050 cm^{-1} a characteristic band of the stretching of CO of the ethers is shown. The functional groups present in the extracts (García *et al*., 2010) are responsible for reducing Ag^+ to Ag^0 (Zia *et al*., 2016).

3.1.3 UV-visible spectroscopy analysis of extracts

Figure 2 shows the UV-vis spectra of extracts can be observed in both cases that have an absorption in the range of 300-380 nm in the ultraviolet range, which is attributed to some compounds that have conjugated π bonds and heteroatoms with pairs of non -shared electrons such as oxygen (Salmeron *et al*., 2017), without the presence of absorption in the visible region.

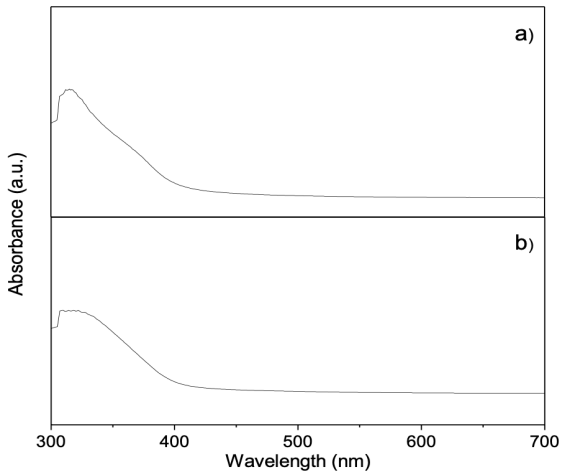


Fig. 2. UV-visible spectra of a) *Eucalyptus* y b) *Larrea tridentata*.

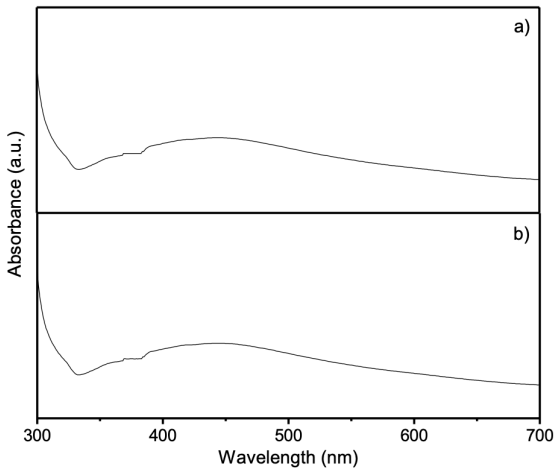


Fig. 3. UV-visible spectra of AgNPs obtained from extracts a) *Eucalyptus* and b) *Larrea tridentate*, at 50 °C for 24 hrs.

3.1.4 UV- visible spectroscopy analysis of nanoparticles

Figure 3 shows the UV-vis spectra of the AgNPs obtained from the aqueous extracts of *Eucalyptus* y *Larrea tridentate*, where the absorption in the range of 430-460 nm due to the oscillation of conduction band electrons of Ag known as the surface plasmon resonance confirms the presence of silver nanoparticles (Chunfa *et al*., 2016) and indicating a small size of the AgNPs, due to this absorbance is sensitive to the nature, shape and size of the particle obtained (Cruz *et al*., 2012).

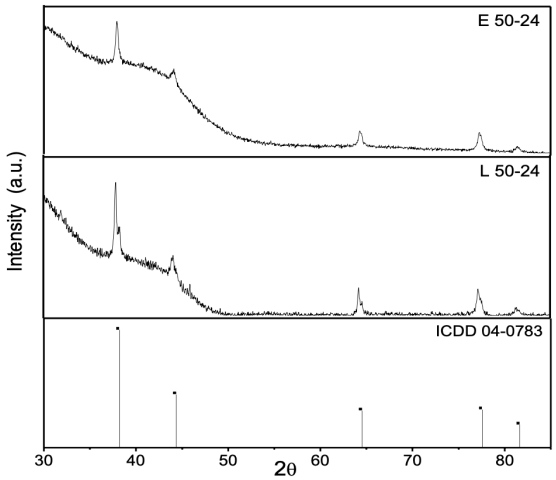


Fig. 4. XRD pattern of AgNPs obtained from the extracts of a) *Eucalyptus* and b) *Larrea tridentate* at 50 °C for 24 hrs.

3.1.5 X-ray diffraction análisis

XRD patterns of the AgNPs are shown in Figure 4, in which XRD peaks located at an angle 2θ = 38°, 44°, 65° and 78°, can be indexed as (111), (200), (220) and (311) respectively, belonging to face center cubic structure (FCC) of metallic silver (ICDD 04-0783), confirming the presence of pure crystalline silver, however, an amorphous part and large background noise can be observed, which is attributed to the organic part of the absorbed aqueous extract on the AgNPs, which explains the good oxidation stability that nanoparticles maintain (Chunfa *et al*., 2016).

3.1.6 SEM analysis

The SEM analysis of the AgNPs obtained from the *Eucalyptus* extract are presented in Figure 5a, which shows prominently a spherical shape with a size between 20-90 nm and using the Image J software the measurement of particles obtaining an average size of 63.62 nm (Figure 6a).

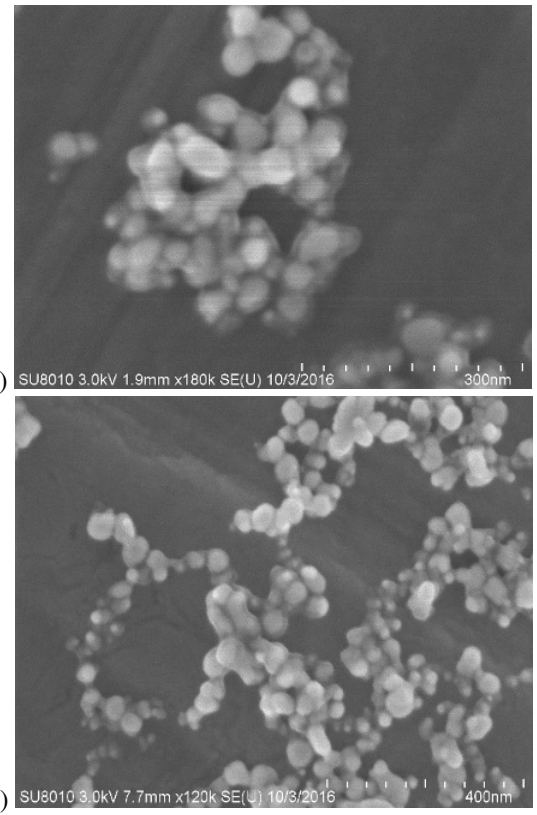


Fig. 5. SEM images of the AgNPs obtained by the extract of a) *Eucalyptus* and b) *Larrea tridentate* at 50 °C for 24 hrs.

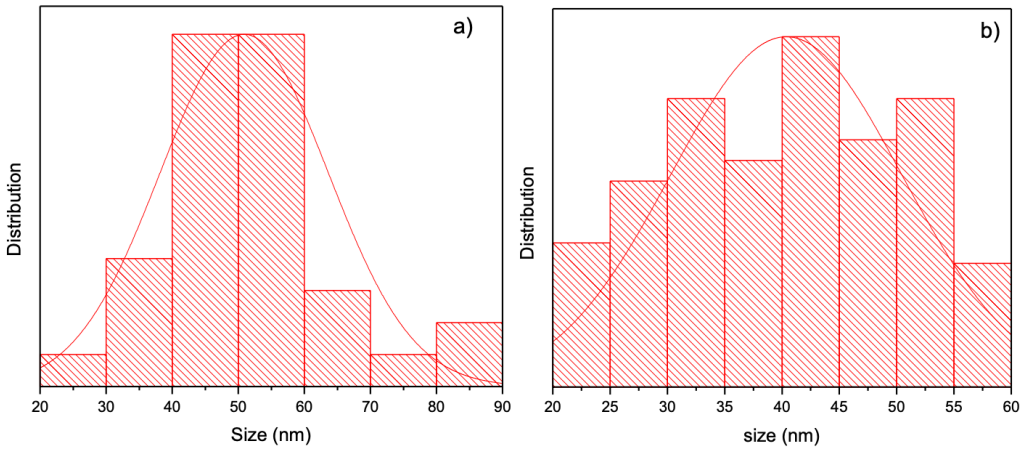


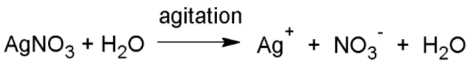
Fig. 6. Average size distribution graphs of a) AgNPs obtained from *Eucalyptus* and b) *Larrea tridentate* extracts.

Figure 5b shows the AgNPs obtained from the *Larrea tridentate* extract with an average particle size between 20-60 nm and using the Image J software an average size of 35.32 nm was obtained (Fig. 6b), these being smaller than those obtained with *Eucalyptus* extract. The plant extracts used for the reduction of silver are important for the determination of size, as well as the desired morphology (Hebbalalu *et al*., 2013), so if it is required to synthesize AgNPs of a particular size and shape, it can be achieved varying the type of plant extract (reducing agent).

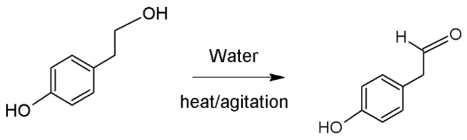
3.1.7 Proposed reaction mechanism for the synthesis of AgNPs with the aqueous extract of Eucalyptus and Larrea tridentate

The mechanism of synthesis of AgNPs with extracts of *Eucalyptus* and *Larrea tridentata* can be carried out in three stages. In the first stage, dissociation of the precursor salt in water is carried out.

Followed by the second stage, where the oxygenated functional groups present in the aqueous extracts of *Eucalyptus* and *Larrea tridentate* (Table 1 and 2) presents a common compound, belonging to the family of flavonols, therefore, the second and Third stage with these extracts is the same.



Scheme 1. Oxidation reaction with the Tyrosol family forming an aldehyde, present in the extract of *Eucalyptus*.



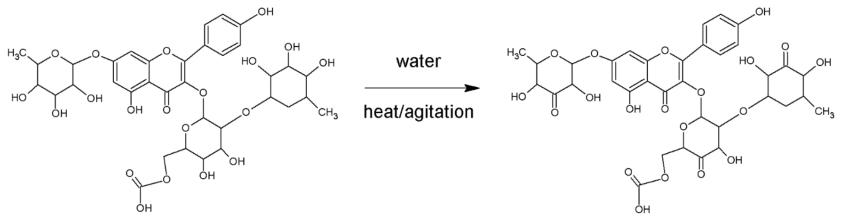
Scheme 2. Oxidation reaction with the Tyrosol family forming an aldehyde, present in the extract of *Eucalyptus*.

Scheme 2 shows the Tyrosol family, and the reaction corresponds to the oxidation of a primary alcohol (only present in the extract of *Eucalyptus*), which in the presence of water, mechanical agitation and heat forms an aldehyde (Wade, 2004).

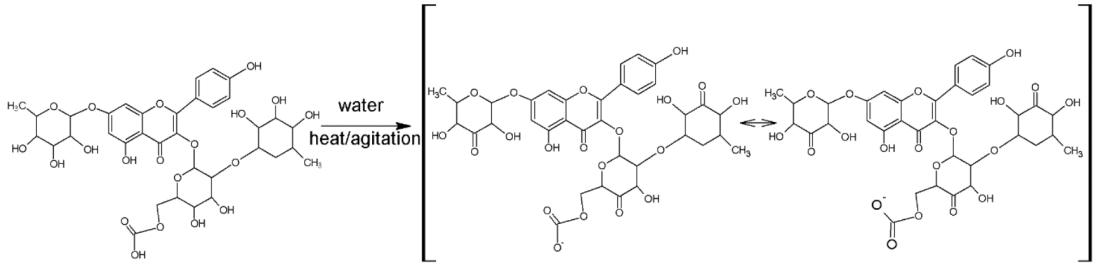
Scheme 3 corresponds to the oxidation of secondary alcohols (in this case flavonols, present in both extracts) which form ketones, donating a proton (H^+).

Scheme 4 shows the dissociation of the carboxylic acid (present in the flavonols), forming carboxylate ions, due the carboxylic acids being very reactive are able to donate (H^+).

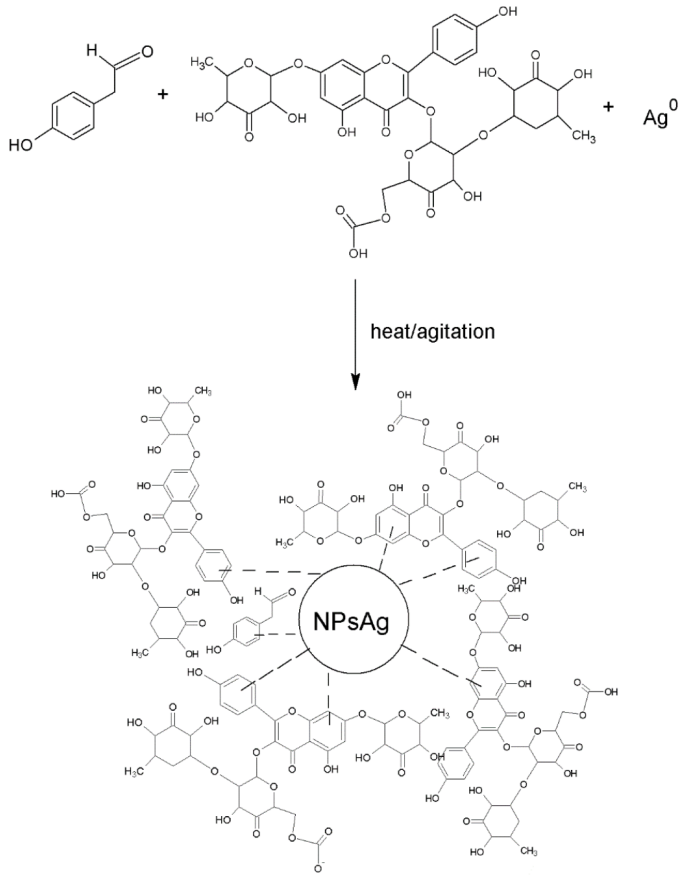
The oxidized compounds (Scheme 2, 3 and 4) favor the reduction of Ag^+ to Ag^0, as reported by Zhao *et al*. In 2010, who studied the reduction of Ag^+ using chemical agents such as ethylene glycol. The reaction of Ag^+ with ethylene glycol (primary alcohol) are capable of forming aldehydes, which, being very reactive, can donate protons (H^+) promoting the reduction of Ag^+ to Ag^0 (Wade, 2004; Tao *et al*., 2010).



Scheme 3. Oxidation reaction with the Flavanols family (present in the extracts of Eucalyptus, and Larrea tridentate) forming ketones.



Scheme 4. Oxidation reaction with the family of Flavonols forming the carboxylate ion.



Scheme 5. Reduction reaction with the families of the extract of *Eucalyptus, Larrea tridentate*, Ag^{+} and AgNPs functionalization.

Finally, in the third stage, the mixture of compounds with functional groups formed as aldehydes, ketones and carboxylic acids promote the reduction of Ag^+ obtaining Ag^0, where Ag^0 is functionalized or capped with polar groups belonging to the extract compounds (Scheme 5). Due Ag is a metal, it has the ability to form π-type interactions with the conjugate systems of the extracts, forming complexes sandwich-type (Klepetarova *et al*., 2018), this is the reason why AgNPs are obtained with functional groups on the surface or encapsulated.

3.1.8 FTIR analysis of AgNPs

The FT-IR spectra of the AgNPs are shown in Figure 7 showing an absorption band at 3200-3250 cm^{-1} which is attributed to the stretching vibrations of the hydroxyl group (-OH). The band at 1650 cm^{-1} corresponds to C=O bond of the carbonyl group from ketones, carboxylic acids, esters, present in the compounds of both aqueous extracts, the band in 1370 cm^{-1} represents flexures of the methyl groups $(CH\text{-}CH_3)_2$, the band 1200 cm^{-1} corresponds to the phenol, in 1050 cm^{-1} a characteristic band of the stretching of C-O of the ethers is shown. Due to the results obtained in the different characterizations and the bands of the functional groups that are observed in the FT-IR spectra of the nanoparticles obtained, it is evident that the extracts have a double role in the synthesis of AgNPs, since they work as a reducing agent and a stabilizing agent. On the other hand, according to reported by Zia and collaborators the interaction between the biomolecules and the surface of the nanoparticle is through carbonyl groups or interactions of the π-electron type (Zia *et al*., 2016).

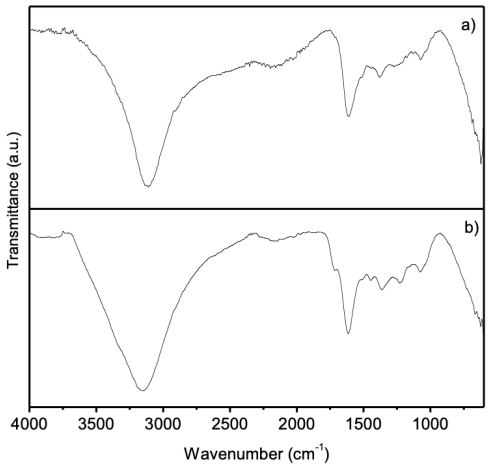


Fig. 7. FT-IR spectra of the AgNPs of a) *Eucalyptus* y b) *Larrea tridentate.*

Conclusions

The aqueous extracts of *Eucalyptus* and *Larrea tridentate* proved to be excellent reducing agents for $AgNO_3$ by containing compounds capable of substituting toxic reagents, in addition to acting significantly as stabilizing agents, allowing to obtain functionalized nanoparticles, without the need to add reducing and stabilizing agents during synthesis. Ag^0 nanoparticles were obtained, showing an absorbance between 430-460 nm indicating surface plasmon resonance confirming its obtaining. Through the use of the extracts involved, a variation in size was obtained, playing an important role in the size of the nanoparticles, which in both cases sizes were obtained within the nanometric scale with spherical morphology, this being of great importance in having a better surface area for future applications. The method used in this research provides a simple, efficient, low-cost and environmentally friendly route, which makes it an attractive method for obtaining AgNPs.

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Nomenclature

AgNPs	Silver nanoparticles
$AgNO_3$	Silver nitrate
Ag^+	Silver ion
Ag^0	Elemental silver
DRX	X-ray diffraction
FTIR	Fourier Fourier transform infrared spectroscopy
HPLC-ms	High-performance liquid chromatography coupled to mass spectrometry
M	Molar concentration
SEM	Scanning electron microscope
UV-Vis	Visible utraviolet spectroscopy

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