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Synthesis of Metallic Nanoparticles Using Plant's Natural Extracts: Synthesis Mechanisms and Applications

Síntesis de Nanopartículas Metálicas Usando Extractos Naturales de Plantas: Mecanismos de Síntesis y Aplicaciones

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ABSTRACT

Metallic nanoparticles have a wide range of applications in health, electronics, optics, magnetism, bioremediation, chemistry, and materials science. Several methods used to produce nanoparticles are not friendly to the environment, so this review highlights the benefits of using plant extracts to prepare metallic nanoparticles to investigate an eco-friendly method. Plant extracts contain secondary metabolites, including flavonoids, alkaloids, terpenoids, phenolic compounds, polysaccharides, amino acids, and proteins. The compounds present in the extracts can reduce metal ions from salts and allow the formation of nanoparticles. The fundamentals of the *in-situ* nanoparticle synthesis were reviewed, a list of various plants used was made, the mechanisms proposed for nanoparticle synthesis, and finally, applications in several areas were addressed.

Keywords: Plant Extract; Metallic Nanoparticles; Formation Mechanism; Green Synthesis.

RESUMEN

Las nanopartículas metálicas tienen una amplia gama de aplicaciones en los sectores de la salud, la electrónica, la óptica, el magnetismo, la biorremediación, la química y la ciencia de los materiales. Varios métodos utilizados para producir nanopartículas no son amigables con el medio ambiente, por lo que esta revisión destaca los beneficios del uso de extractos de plantas para preparar nanopartículas metálicas para investigar un método ecológico. Los extractos de plantas contienen metabolitos secundarios, incluyendo flavonoides, alcaloides, terpenoides, compuestos fenólicos, polisacáridos, aminoácidos y proteínas. Los compuestos presentes en los extractos pueden reducir los iones metálicos de sales y permitir la formación de nanopartículas. Se revisaron los fundamentos de la síntesis de nanopartículas *in situ*, se realizó una lista de varias plantas utilizadas, los mecanismos propuestos para la síntesis de nanopartículas y, finalmente, se abordaron las aplicaciones en varias áreas.

Palabras clave: Extracto De Plantas; Nanopartículas Metálicas; Mecanismo De Formación; Síntesis Verde.

INTRODUCTION

In recent years, different researchers have improved their understanding of nanotechnology and focused their projects directly or indirectly on its associated topics. These studies include planning, synthesis, characterization, and evaluation of the properties obtained by modification of their size and shape. The term "nano", the keywords in these researches, comes from the Latin nanus, meaning "dwarf". This kind of technology is supported in physics, chemistry, materials science, biotechnology, and biosciences, among others, to achieve a multidisciplinary understanding of the phenomena that occur in the materials. A phenomenon called "nanorevolution" has been created, which aims to the manipulation and study of nanomaterials in a wide range of compositions, sizes, shapes, and morphologies (Kolahalam *et al.*, 2019; Hamers, 2017).

Nanoparticles are an important class of nanomaterials studied by nanotechnology, as they have applications in various fields, including those described by Hernández-Morales *et al.* (2019) who synthesized silver nanoparticles with antimicrobial capacity using *Salvia hispanica L.* seed extracts. Opris *et al.* (2017), synthesized gold nanoparticles using extracts of *Sambucus nigra L.* with the ability to lower the level of glucose in blood. It also reduces levels of inflammation and oxidative stress induced by hyperglycemia. Matinise *et al.* (2018) created iron-zinc oxide nanoparticles aided by *Moringa Oleifera* extract, with excellent electrochemical performance, suggesting great potential in this area. Lebaschi *et al.* (2017), employed extracts of *Camellia sinensis* to form palladium nanoparticles showing potent catalytic application for the synthesis of biaryls, by Suzuki cross coupling reaction and also reduction of 4-nitrophenol (4-NP) by $NaBH_4$. Samari *et al.* (2018), used extracts of *Mangifera indica L.* to synthesize silver nanoparticles capable of chemically sensing Hg^{2+} ions in water. Goutam *et al.* (2018) made use of *Jatropha curcas L.* for the green synthesis of titanium oxide, for the remediation of wastewater from tanneries, and Idrees *et al.* (2019) worked with *Sida acuta* extracts to develop silver nanoparticles that acted as suitable inhibitors for the corrosion of mild steel in 0.1 H_2SO_4 solutions. The European Union (EU) defines nano-

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materials as "A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range of 1 nm – 100 nm" (Gehr, 2018). However, in the biotechnological area the size of the particle used varies between 10 to 500 nm and rarely exceeds 700 nm (Mody *et al*., 2010).

The main reasons nanomaterials showed different properties than bulk materials are due to surface effects, since atoms on the surface have fewer neighbors than bulk atoms. This is associated with less coordination and dissatisfied bonds in nanomaterials. Therefore, they are less stable. In addition, the smaller a particle, the larger fraction of atoms on the surface, and the higher the bonding energy per atom causing a high surface area and volume ratio rate, allowing them to react much faster. Also, are due to density of states, where groups of atoms tend to form bands, and the greater the number, the higher the state density; here a gap called "forbidden" is created, which is the energy that is occupied for an electron crosses a state from lower to higher energy. These vary as the density change, being able to modify the electrical, magnetic, biological properties of the materials, among others (Roduner, 2006).

The future of nanoparticles lies in synthesizing them using greenways, living beings such as plants, microorganisms, or fungi, and seeking their effectiveness in the market (Hoseinpour and Ghaemi, 2018). There are already products with nanoscale materials in their formulations, among them are Doxorubicin (Doxil), also known as Caelyx, a cancer treatment drug. The agent mixture is inside unilaminar liposomes coated with PEG (polyethylene glycol) and is called "PEGylated liposomes". Their size varies between 80 and 90 nm (Abdellatif and Alsowinea, 2021). Additionally, Remington Nano Silver Dryer, Infinity 230 Nano Silver Tourmaline Ceramic Folding Styler by Conair, and Zazen Professional Nano-Silver Ionic Hair-dryer are hair dryers with silver nanoparticles (Taylor *et al*., 2017). Furthermore, Ostim is a calcium hydroxyapatite paste $[Ca_{10}(PO_4)_6(OH)_2]$ that has osteoconduction skills, with crystals of 20 nm in diameter (Farjadian *et al*., 2019). Sea Hawk Cukote Biocide Plus Red-3541 is a paint with biocidal capacity with copper oxide nanoparticles whose average size is 220 nm (Adeleye *et al*., 2016). Nemozin is a burn ointment with zinc oxide nanoparticles of 200 nm (Swathi *et al*., 2013). There are more than 1814 products whose ingredients include nanoparticles, the most predominant being silver (Vance *et al*., 2015).

There are two methods for synthesizing nanoparticles: Top-Down and Bottom Up. Top-Down processes convert the bulk material into nano-sized particles by mechanical milling, laser ablation, or sputtering. For Botton Up methods, nanoparticles are formed from smaller molecules created by the union of atoms or molecules. It can be made through solid state methods (physical vapor deposition, chemical vapor deposition), liquid state methods (Sol-gel, chemical reduction, hydrothermal), gas phase methods (pyrolysis spray, laser ablation), biological methods (bacteria, fungi, plants), among others (microwaves, supercritical fluids, ultrasound) (Jamkhande *et al*., 2019). Unfortunately, many of these methods need a lot of energy to operate or pollute substances, making them unattractive for industrial use. Social responsibility emphasizes the search for alternatives that are economical and take care of the environment. The biological synthesis of nanomaterials has been put into practice since it uses temperature, pH, and pressures considered mild conditions. In addition, it has advantages over other synthesis methods, including higher productivity and lower costs (Kalimuthu *et al*., 2019; Sign *et al*., 2018).

Biological synthesis uses microorganisms and plants (or their extracts). There is a particular interest in using plants because they have many phytochemicals including ketones, aldehydes, flavonoids, amides, terpenoids, carboxylic acids, phenols, and ascorbic acids. These components are known to reduce metal salts and create metal nanoparticles. However, although there are several studies on nanoparticles, the exact mechanism involved in this process remains uncertain (Singh *et al*., 2018). Therefore, this review aims to present a current overview of the fundamentals of the synthesis of nanoparticles using the components found in plant extracts, the effect of reaction conditions, and the biological applications of these nanoparticles.

Fundamentals of Green Synthesis of Nanoparticles using Plant Extracts

Although the nanoparticle synthesis mechanisms are still under investigation, the formation of metal complexes is present in all reactions, so it is possible to consider the theory of the effective atomic number proposed by Lewis. This rule establishes that for coordination compounds, the summary of the electrons from the metal plus those donated by the ligands must be equal to the number of electrons present in the next noble gas, according to the period of the metal involved (Tolman, 1972).

During the synthesis of nanoparticles using natural extracts, the metal ions from precursors are captured and immobilized by different biological elements that function as ligands. Reduction and sintering processes are carried out to obtain the final product. The characteristics of nanoparticles depend on reaction conditions, being able to vary morphology, dispersion, performance, and size when modifying temperature, pH, and concentrations of precursors, among others (He *et al*., 2017; Skandalis *et al*., 2017; Ahmed *et al*., 2017). Temperature, for example, influences nanoparticle size, reaction rate, and shape of nanoparticles. In ZnO nanoparticles synthesis using *Cherry* fruit extracts, studied at 25 °C, 60 °C and 90 °C, researchers observed that as the temperature increased, the nanoparticle size increased. This explains that the extract is rich in ascorbic acid, which becomes unstable with increasing temperature leading to an uncontrolled reduction process and particle aggregation (Malek-Mohammadi *et al*., 2018). In an alternative study for silver nanoparticles synthesis using *Mangifera indica* leaf extract, the temperature was varied from ambient conditions to 80 °C, the intensity of SPR from ambient conditions to 40 °C was increased. This was due to the increase in reaction speed; between 60 °C and 80 °C, an increase in the amplitude of the peak was found accompanied by a decrease in the intensity of SPR, demonstrating that the ability to act as a reducing agent of the extract decreased and caused agglomerates of nanoparticles (Samari *et al*., 2018). The temperature was also shown to affect the synthesis of silver nanoparticles using extracts of *Piper retrofractum* fruit, where the temperature was increased from 25 °C to 80 °C, and is associated with larger particle sizes due to their agglomeration. In addition, high temperatures can denature compounds in the extracts, making them unavailable to react and forming longer nanoparticles (Amaliyah *et al*., 2022).

The pH of the synthesis process also effects nanoparticle size. In synthesizing silver nanoparticles using *Thymus algeriensies* extracts, pH from 3 to 11 was tested during the synthesis process. The resulting nanoparticles had a change in absorption length from 425 nm to 418 nm and an increase in signal intensity, indicating a decrease in size and that the alkaline environment favors the reducing and stabilizing capacity of the antioxidants present in the extract (Beldjilali *et al*., 2020). It has been seen that pH affects the nucleation stage in *Piper chava* extracts used to form silver nanoparticles. As the pH increases from 5 to 9, the absorption in SPR increases and is accompanied by a shift towards blue. This is because at low pH the aggregation of nanoparticles is induced, instead of nucleation to form new ones. At more alkaline pH, the anionic functional groups in the extract are favored to bind with silver ions and increase the nucleation sites, resulting in smaller sizes (Mahuiddin *et al*., 2020). The same effect is observed on silver and gold nanoparticles synthesized using *Opuntia dillenii* extract. When varying the pH from 1 to 13, it is observed that at low pH, there is a broadening in the bands from UV-Vis spectrum, indicating the formation of large nanoparticles. While at more alkaline pH, a narrowing of the band is observed at 400 nm indicating smaller nanoparticles (Ahmed *et al*., 2022).

Synthesis Using Natural Plant Extracts

Plants are autotrophic organisms, biochemically additional to the primary metabolites necessary for the organisms' life. They synthesize secondary metabolites, also known as natural products, which are not essential for plant growth, but are compounds that help with adaptive processes, defense against predators or pathogens, ecological interactions, symbiosis, metal transport, and competition, among others. Secondary metabolites are classified into four categories according to the "British Nutrition Foundation": Terpenoids, Phenols, Nitrogen Compounds, and Sulfide Compounds (Mera *et al.*, 2019; E. Ahmed *et al.*, 2017). A representative structure of each category is shown in Figure 1. Secondary or phytochemical metabolites can act as reducing and stabilizing agents responsible for the synthesis of nanoparticles (Ovais *et al.*, 2018).

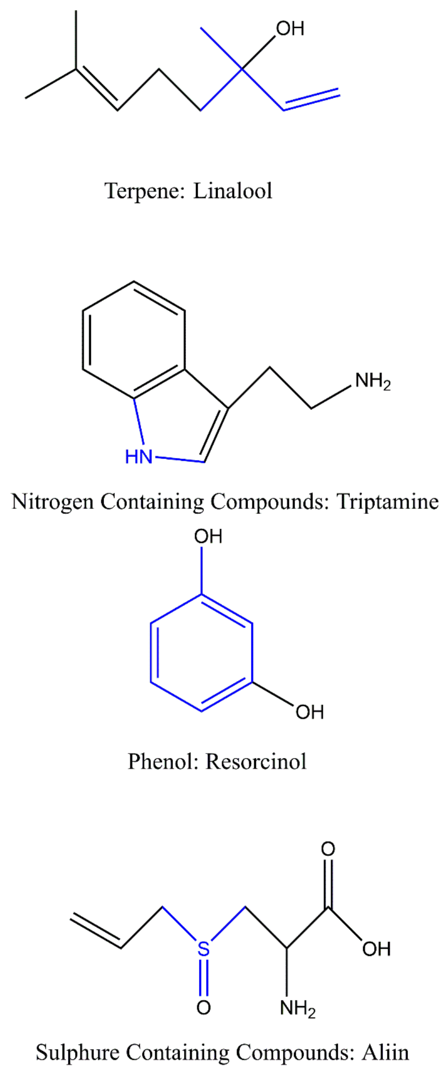

Figure 1. Representative structure of each group of secondary metabolites (The key structure is shown in blue).
Figura 1. Estructura representativa de cada grupo de metabolito secundarios (La estructura representativa se muestra en azul).

In general, nanoparticle synthesis involves mixing plant extracts with metal precursor salts. They can interact under different reaction conditions (pH, temperature, concentrations, etc.). Here, the formation of nanoparticles takes place in stages. It begins with the set of species equilibrium; once dissolved, the extracts and the precursor salt coordination complexes are formed between the metal ion and the phytochemicals of the extract. The sites where the nanoparticles will grow are created at the second nucleation stage. At the third stage of growth and adsorption, small adjacent nanoparticles come together to form particles of a larger size. Finally, during termination, the final shape of the nanoparticles occurs. The general synthesis mechanism is shown in Figure 2. The following operations consist of purification by centrifugation and washing until the impurities present are removed (Naikoo *et al.*, 2021; Behzad *et al.*, 2021; Bouttier-

Figueroa *et al*., 2019a). As expected, results in the synthesis of nanoparticles show that the extract and its concentration affect the size and morphology of the nanoparticles, while temperature and pH affect the agglomeration process (Erjaee *et al*., 2017; Koshy, 2017).

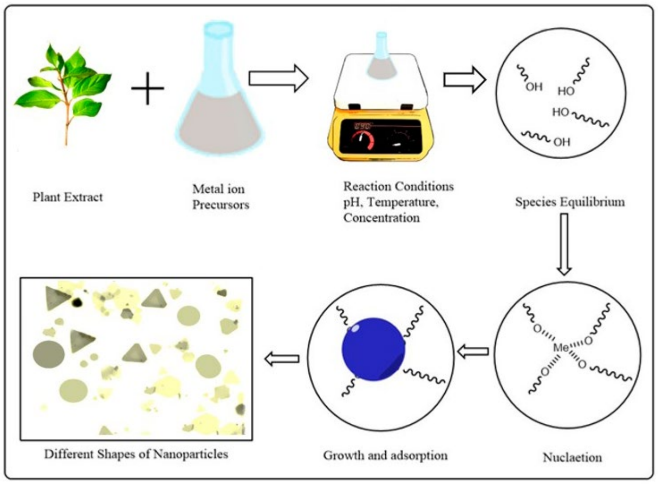

Figure 2. General mechanism for nanoparticles synthesis utilizing plant extracts (Me = metallic ion).
Figura 2. Mecanismo general para la síntesis de nanopartículas utilizando extractos de plantas (Me = ion metálico).

A list of plants used for the synthesis of nanoparticles between 2017 and 2022 is presented in Table 1. It is observable that the main phytochemicals involved in the synthesis of nanoparticles are phenolic compounds, flavonoids, carboxylic acids, carbohydrates, terpenoids, alkaloids, and proteins. They contain functional groups capable of coordinating with, and reduce, metal ions. Extracts of *Azadirachta indica*, *Hibiscus rosa-sinensis*, *Murraya koenigii*, *Moringa oleifera*, *Tamarindus indica*, and *Spinacea oleracea* contain phenolic compounds and flavonoids that act as covering agents, preventing agglomeration and stabilizing the formation of copper oxide nanoparticles (Rehana *et al*., 2017; Al-Jawjari *et al*., 2022). Extracts of *Aloe vera*, *Hibiscus sabdariffa*, *Atalantia monophylla*, *Punica granatum*, *Ocimum americanum*, *Beta vulgaris*, *Cinnamomum tamala*, *Cinnamomum verum*, *Brassica oleracea var. Itálica*, *Acalypha fruticosa L.*, *Alchornea laxiflora*, and *Syzygium Cumini* contain phenolic compounds, flavonoids, tannins, organic acids, and terpenoids that can trigger the reduction of zinc salts and control the size of zinc oxide nanoparticles (Mahendiran *et al*., 2017; Vijayakumar *et al*., 2017; Mohamad *et al*., 2019; Narendra *et al*., 2019; Mohanan *et al*., 2020; Vijayakumar *et al*., 2019; Ekennia *et al*., 2020; Rafique *et al*., 2022). *Origanum vulgare L*. contains phenolic and carbohydrate compounds that play a vital role in the reduction of Pd^{2+} ions and act as stabilizing agents for palladium nanoparticles (Rafi *et al*., 2017). *Moringa oleifera* leaves contain amino acids, alkaloids, flavonoids, and phenolic compounds that facilitate the synthesis of iron nanoparticles (Katata-Seru *et al*., 2018). The extracts of *Annona muricata*, *Coleus aromaticus*, *Tasmannia lanceolata*, *Backhousia citriodora* and *Tecoma capensis* have flavonoids, terpenoids and proteins responsible for the reduction of gold ions. In addition, they help in the formation and stabilization of synthesized nanoparticles (Folorunso *et al*., 2019; Boomi *et al*., 2018; Khandanlou *et al*., 2020; Hosny *et al*., 2022). *Tecoma stans L*. contains hydroxyl groups, alkenes, alkynes, flavonoids, carbohydrates, amines, and phosphates that act in the synthesis and formation of magnesium oxide nanoparticles (Nguyen *et al*., 2021). *Atriplex halimus* contains glycosides, terpenoids, flavonoids, and alkaloids involved in reducing and stabilizing palladium nanoparticles (Eltaweil *et al*., 2022). The synthesis of silver nanoparticles has been the favorite of several research groups. Several plant extracts have been used among them: *Buddleja globosa hope*, *Lantana camara L.*, *Viscous cleome L.*, *Sida cordifolia*, *Psidium guajava L.*, *Amaranthus cruentus*, *Achillea millefolium L.*, *Phyllanthus urinaria*, *Pouzolzia zeylanica*, *Scoparia dulcis*, *Piper colubrinum*, *Phoenix dactylifera L.*, and *Camellia sinensis*. These have in common the presence of carboxylic, hydroxyl, carbonyl, and phenolic groups that are responsible for the reduction of Ag^{+} ions to Ag^{0} and act as a coating on the synthesized nanoparticles (Carmona *et al*., 2017; Shriniwas *et al*., 2017; Lakhmanan *et al*., 2018; Naga *et al*., 2017; Wang *et al*., 2018; Baghani *et al*., 2020; Yousaf *et al*., 2020; Nguyen *et al*., 2020; Santhoshkumar *et al*., 2021; Laouini *et al*., 2021).

Secondary metabolites for nanoparticle synthesis

The extracts used for nanoparticle synthesis have a wide variety of secondary metabolites involved in nanoparticle reduction, formation, and stabilization. Phytochemicals in the extracts include phenols, flavonoids, alkaloids, terpenoids, proteins, carbohydrates, and amino acids.

Phenols

Phenols are chemical compounds that contain a hydroxyl group (-OH) attached to an aromatic hydrocarbon. In plants, the term polyphenol is usually used for secondary metabolites from the biochemical pathways of shikimic acid. They may have more than one phenolic ring and do not contain functional groups based on nitrogen in their structure (Cirkovic *et al*., 2018). Below are reaction mechanisms for the synthesis of nanoparticles involving phenols. Gallic acid has been shown to interact with Au^{+3} ions by releasing electrons and reduce them to gold atoms. It has been proposed to form an intermediate complex during reduction that oxidizes to form quinones and gold nanoparticles. Quinones are inferred to remain on the surface of the nanoparticles, preventing their aggregation for prolonged periods (Ahmad *et al*., 2019). The proposed mechanism is shown in Figure 3a. In the case of silver nanoparticles, gallic acid causes the reduction of Ag ions. After reduction, it is oxidized to its quinone form and the carboxylic group (-C = O) present in the oxidized form coordinates with the surface of the nanoparticles to stabilize them (Bhutto *et al*., 2018). The schematic representation is shown in Figure 3b. Combining these molecules with metallic copper salts gives a polyphenolic complex with the Cu^{2+} ion, whose reduction generates nanoparticles of Cu^{0}. The

Table 1. Characteristics of nanoparticles synthesized with natural extracts from different plants species.
Tabla 1. Características de las nanopartículas sintetizadas con extractos naturales de diferentes especies de plantas.

Plant Species	Origin of the Extract	Nanoparticle	Nanoparticle Size (nm)	Functional Group Involved on Synthesis	Effect	Reference
Azadirachta indica, *Hibiscus rosa-sinensis*, *Murraya koenigii*, *Moringa oleifera* and *Tamarindus indica*	Leaves	CuO	Average size of 12	Phenolic compounds and flavanoids	Anticancer	(Rehana *et al.*, 2017)
Aloe vera and *Hibiscus sabdariffa*	Leaves	ZnO	9 to 18	Phenolic compounds and flavonoids	Antibacterial, antioxidant, and anticancer	(Mahendiran *et al.*, 2017)
Buddleja globosa hope	Leaves	Ag	1 to 53	Phenols and carboxylic groups	-	(Carmona *et al.*, 2017)
Lantana camara L.	Leaves	Ag	410 to 450	Carboxylic, hydroxyl, carbonyl, and phenyl groups	Antioxidant, antibacterial, and cytotoxic on Brine shrimp	(Shriniwas *et al.*, 2017a)
Origanum vulgare L.	Leaves	Pd	2 to 20	Phenolic compounds and glycoside	Catalytic activity	(Rafi *et al.*, 2017)
Atalantia monophylla	Leaves	ZnO	30	Tannin, organic acids, terpenoids, aromatic dicarboxylic acid, and amides	Antibacterial	(Vijayakumar *et al.*, 2018)
Moringa oleifera	Seeds	Fe	2.6 to 7.4	Amino acids, alkaloids, flavonoids, and phenolic compounds	Antibacterial and coagulant	(Katata *et al.*, 2018)
Cleome viscosa L.	Fruit	Ag	5 to 30	Alkaloids, phenolic compounds, amino acids, carbohydrates, and tannins	Antibacterial and anticancer	(Lakshmanan *et al.*, 2018)
Sida cordifolia	Whole plant	Ag	3 to 8	Alkaloids, carbohydrates, proteins, glycosides, flavonoids, and tannins	Antibacterial	(Naga *et al.*, 2018)
Psidium guajava L.	Leaves	Ag	Average size of 25	Flavonoids and polyphenolic groups	Antibacterial	(Wang *et al.*, 2018)
Annona muricata	Leaves	Au	27 to 32	Flavonoids, terpenoids, and proteins	Antibacterial and antifungal	(Folorunso *et al.*, 2019)
Punica granatum	Peel	ZnO	32.98 to 81.84	Pinucalagin, ellagic acid, caffeic acid, chlorogenic acid, and gallic acid	Antibacterial and anticancer	(Mohamad *et al.*, 2019)
Coleus aromaticus	Leaves	Au	Average size of 80	Phenolic hydroxyl, aromatic amines, and polyphenol groups	Antibacterial and anticancer	(Boomi *et al.*, 2019)
Ocimum americanum	Whole plant	ZnO	Average size of 21	Phenol, hydroxyl, and carboxyl groups	Antibacterial and anticancer	(Narendra *et al.*, 2019)
Amaranthus cruentus	Flowering shoot parts	Ag	Average size of 15	Aromatic compound, proteins, hydroxyl groups, and carboxylic acids	Antibacterial and anticancer	(Baghani *et al.*, 2020)
Tasmannia lanceolata and *Backhousia citriodora*	Leaves	Au	Average size of 7.10	Terpenoids, flavonoids, and phenolic compounds	Anticancer	(Khandanlou *et al.*, 2020)
Achillea millefolium L.	Whole plant	Ag	14.27 to 20.77	Proteins, flavonoids, and phenols such as tannic acid	Antibacterial and antioxidant	(Yousaf *et al.*, 2020)
Beta vulgaris, *Cinnamomum tamala*, *Cinnamomum verum, and Brassica oleracea var. italica*	Whole plant	ZnO	20 to 47	Hydroxil groups, proteins, aldehydes, alkanes, alkenes, ketones, and alcohol	Antibacterial and antifungal	(Mohanan *et al.*, 2020)
Phyllanthus urinaria, *Pouzolzia zeylanica*, and *Scoparia dulcis*	Leaves	Ag	4 to 52	Tannins, flavonoids, phenolics, and terpenoids compounds	Antifungal	(Nguyen *et al.*, 2020)
Acalypha fruticosa L.	Leaves	ZnO	Average size of 50	Flavonoids	Antibacterial	(Vijayakumar *et al.*, 2019)
Piper colubrinum	Leaves	Ag	10 to 50	Compunds with with OH and CO groups	Antibacterial	(Santhoshkumar *et al.*, 2021)
Tecoma stans L.	flower, bark, and leaves	MgO	20 to 50	Hydroxyl/amino groups, alkene or alkyne, flavonoids or carboxylic compounds, saturated primary alcohol, carbohydrates, amines, and phosphates	Treatment of hazardous dyes from the wastewater	(Nguyen *et al.*, 2021)

Plant Species	Origin of the Extract	Nanoparticle	Nanoparticle Size (nm)	Functional Group Involved on Synthesis	Effect	Reference
Alchornea laxiflora	Leaves	ZnO	Average size of 200	Polyphenols, flavonoids, tanins, alkaloids, and saponins	Photocatalyst	(Ekennia *et al.*, 2021)
Citrus limon	Fruit	Cu	5 to 28	Alcohols, phenols, carboxylic acids, and amino groups	Antibacterial	(Amer *et al.*, 2021)
Phoenix dactylifera L.	Leaves	Ag/Ag_2O	37.71 to 28.66	Carboxyl, carbonyls, amides, and phenols	Photocatalytic activity for azo dye degradation	(Laouini *et al.*, 2021)
Syzygium Cumini	Leaves	ZnO	64 to 78	Hydroxyl and amide groups	Fertilizer in agriculture and catalyst for dye removal from polluted water	(Rafique *et al.*, 2022)
Tecoma capensis	Leaves	Au	20 to 25	Alkaloids, flavonoids, glycosides, terpenoids, tannins, and phenolic compounds	Photocatalytic, anticancer and antioxidant	(Hosny *et al.*, 2022)
Spinacea oleracea	Leaves	CuO	13 to 17	Phenols and flavonoids	Antioxidant and anticancer	(Al-Jawhari *et al.*, 2022)
Atriplex halimus	Leaves	Pt	1 to 3	Glycosides, terpenoids, flavonoids, and alkaloids	Antibacterial, antioxidant, and catalytic	(Eltaweil *et al.*, 2022)
Camellia sinensis	Leaves	Ag	15 to 33	Polyphenols, proteins, flavonoids, saponins, and glycosides	Antibacterial	(Widatalla *et al.* 2022)

ions can subsequently be oxidized with oxygen to form stable CuO nanoparticles (Veisi *et al*., 2021). The mechanism of biogenesis is shown in Figure 3c. The general mechanism for the synthesis of nanoparticles using phenols is described by Malapermal *et al.* (2017), who speculate that the conversion of biomolecules with C-OH groups to C=O groups is responsible for the reduction of ions, in the case of their study Ag^+ to Ag^0, leaving as a result a keto compound. The proposed mechanism is illustrated in Figure 3d.

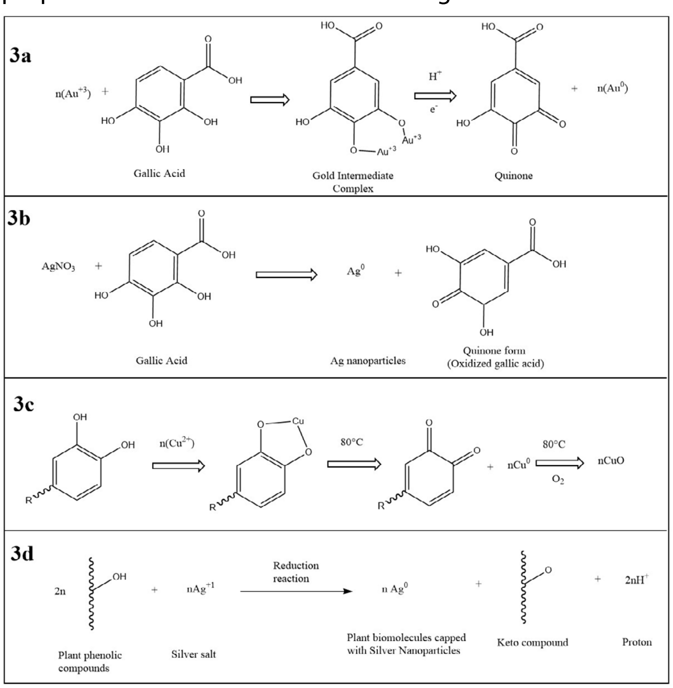

Figure 3. Proposed mechanisms for nanoparticle synthesis from phenols compounds. Adapted from references [Cirkovic *et al.*, 2018; Ahmad *et al.*, 2019; Bhutto *et al.*, 2018; Veisi *et al.*, 2021; Malapermal *et al.*, 2017].
Figura 3. Mecanismos propuestos para la síntesis de nanopartículas a partir de compuestos fenólicos. Adaptado de referencias [Cirkovic *et al.*, 2018; Ahmad *et al.*, 2019; Bhutto *et al.*, 2018; Veisi *et al.*, 2021; Malapermal *et al.*, 2017].

Flavonoids

They are hydroxylated phenolic substances synthesized by plants in response to microbial infections. The chemical structure is a propane diphenyl skeleton with fifteen carbon atoms in its primary nucleus: two six-membered rings linked with a three-carbon unit, which may or may not be a part of a third ring. In addition, two benzene rings (rings A and B) are linked through a third heterocyclic oxygen-containing pyrene ring (Karak, 2019). Flavonoids have hydroxyl and carbonyl groups that can bind metal ions through a chelating effect. This chelating ability is associated with a nucleophilic character of the aromatic ring. The antioxidant property of flavonoids is related to their ability to donate electrons and hydrogen atoms. Trivalent gold ions can form complexes in aqueous solutions with flavonoids when they oxidize to ketone groups and form the nucleus of nanoparticles (Irfan *et al*., 2017). The proposed mechanism is shown in Figure 4a.

The flavonoid orientin contains an aromatic hydroxyl group capable of adhering to nickel ions by forming complexes with each other. Subsequently, an annealing process is applied to break down the complex and form NiO nanoparticles (Mayedwa *et al*., 2018). The proposed mechanism of orientin with nickel ions is shown in Figure 4b. Quercetin contains hydroxyl groups with high reductive activity. It has been used to reduce Ag^+ ions by forming complex intermediates, followed by oxidation by hydrogen abstraction forming a hydrate (Kobylinska *et al*., 2020). The schematic is shown in Figure 4c. A general proposal for the formation of nanoparticles with flavonoids, taking silver as an example, is given by Sherin *et al*. (2020). They indicated that hydroxyl groups are strong ligands that can reduce ions from Ag^+ to Ag^0. They suggested that if sodium hydroxide is added to the reaction medium, the reducing power of these phytomolecules is improved, and the formation can be accelerated at room temperature. The possible proposed mechanism is illustrated in Figure 4d.

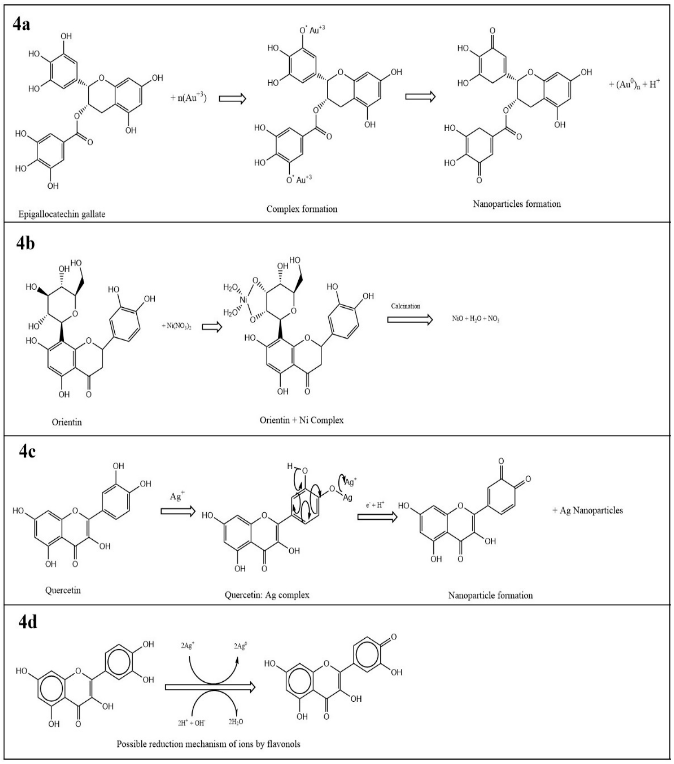

Figure 4. Proposed mechanisms for nanoparticle synthesis from flavonoids compounds. Adapted from references [Irfan et al., 2017; Mayedwa et al., 2018; Kobylinska et al., 2020; Sherin et al., 2020].
Figura 4. Mecanismos propuestos para la síntesis de nanopartículas a partir de compuestos flavonoides. Adaptado de referencias [Irfan et al., 2017; Mayedwa et al., 2018; Kobylinska et al., 2020; Sherin et al., 2020].

Alkaloids

These are molecules present in plants with a nitrogen at any position of the molecule but must not belong to an amide or a peptide bond (Rios *et al.*, 1989). They have demonstrated participation in the formation of platinum and palladium nanoparticles; alkaloids of *Peganum harmala* seeds showed rearrangement and deprotonation in their O-H and C-O groups, indicating the participation in the bioreduction of nanoparticles (Fahmy *et al.*, 2021). In another study, this same plant was used to reduce silver nanoparticles. In this case, five main alkaloids, Harmine, Harmaline, Harmalol, Vasicine, and Vasicinone were identified, indicating the participation of the same groups in the reduction of nanoparticles (Almadiy *et al.*, 2018). *Conocarpus lancifolius* presents two alkaloids, Scopolamin and Hyoscine, that can act as metal chelators and participate in silver nanoparticle formation (Raheema *et al.*, 2020). *Terminalia catappa* has alkaloids involved in Nd_2O_3 nanoparticles formation, acting as essential sources for obtaining $Nd(OH)_3$ complexes in hydrolysis processes necessary for the formation of nanoparticles (Lembang *et al.*, 2018). Although it is known that alkaloids participate in the formation of nanoparticles, there are still few publications on the subject, and there is a lack of deepening in the reaction mechanism of the formation process. Hence, further research in this area is necessary.

Terpenoids

They are metabolites of plants with different atomic carbon units, where C = 5, 10, 15, 20, …, n > 40, and are thus classified as hemiterpenes (C5), monoterpenes (C10), sesquiterpenes (C15), diterpenes (C20), triterpenes (C30), tetraterpenes or carotenoids (C40), and polyterpenes (Cn, n > 40) (Proshkina *et al.*, 2020). Extracts of only terpenes from *Lantana chamber* plant have been used to synthesize silver nanoparticles; these participate in reducing Ag^+ ions to Ag^0 ions (Shriniwas *et al.*, 2017b). *Withania coagulans* has poly-oxygenated biomolecules called withanolides (C28 - steroidal lactone triterpenoids), which are involved in synthesizing silver nanoparticles (Tripathi *et al.*, 2019). The Terpenoids present in *Annona squamosa* help in the synthesis of gold nanoparticles; their hydroxyl and carbonyl groups are complexed with Au^3 ions and reduced to Au^0 by the oxidation of carbonyl and carboxyl groups (Gangapuram *et al.*, 2018). Pentacyclic terpenoids (lupeol and β-sitosterol) of *Euclea natalensis* participate in forming zirconium oxide nanoparticles, and the –OH groups are responsible for the reduction. The tautomeric transformation of enol compounds to keto is thought to release hydrogen atoms, accountable for removing the zirconium molecule (Da Silva et *al.*, 2019). The proposed mechanism is shown in Figure 5a. In this aspect, research has begun to offer reaction mechanisms, but it is still necessary to understand the process in detail.

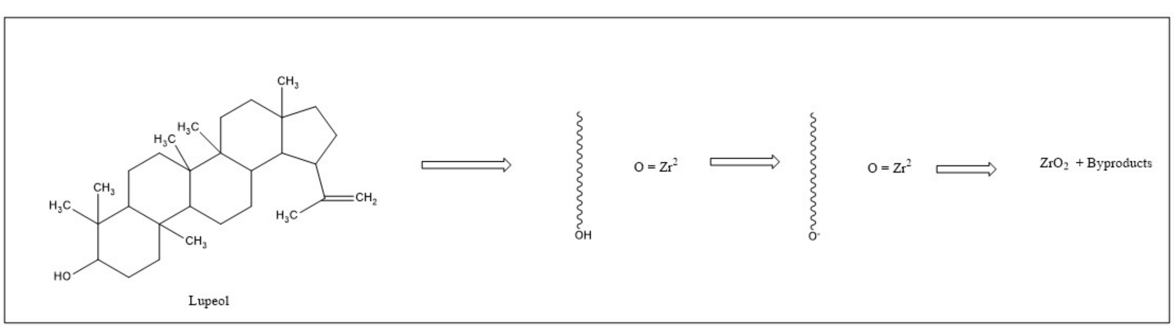

Figure 5. Proposed mechanism for nanoparticle synthesis from terpenoid compounds. Adapted from Gangapuram *et al.* (2018).
Figura 5. Mecanismo propuesto para la síntesis de nanopartículas a partir de compuestos terpenoides. Adaptado de Gangapuram *et al.* (2018).

Amino acids and proteins

Proteins are biomolecules constructed from the covalent polymerization of amino acids (Mora *et al.*, 2020). *Camellia sinensis* extracts have been used for the synthesis of zinc oxide nanoparticles. These contain amino acids that are not directly involved in the formation of nanoparticles but stabilize the nanoparticles in suspension (Dhanemozhi *et al.*, 2017). Ajwa and Barni were used for the synthesis of platinum nanoparticles. As a result, it was found that amino acids and proteins participate in coating the nanoparticles (Al-Radadi, 2019). *Carissa carandas* proteins coat and stabilize nanoparticles, as demonstrated by being employed to synthesize silver nanoparticles. Hydroxyl, carbonyl, and other functional groups in amino acids and peptides (C=O, -OCH, C-O) can bind metals, forming a coating around the metal nanoparticle. Also, the presence of the -OH group in benzenes contained in the extract participate in the formation of nanoparticles since they can release a proton, change to its anionic form, stabilize itself by its resonance structure, provide electrons that function as reducing agents, and oxidize the metallic salt (Joshi *et al.*, 2018). *Moringa oleifera* extract proteins also function as coating agents of nanoparticles, in this case confirmed by Transmission Electron Microscopy (TEM) (Mateus *et al.*, 2018). The participation of these biomolecules is not directly related to the process of nanoparticle formation but to their stabilization.

Carbohydrates

These molecules composed of carbon and hydrogen atoms, have different monomeric units and degrees of polymerization; glycosidic bonds join them and in nature, they are found together with proteins, lipids, amino acids, etc. The binding of various carbohydrates is called a polysaccharide (Mena-García *et al.*, 2019). Carbohydrates present in *Astragalus membranaceus* possess weak reducing activity, and have been used for the synthesis of silver nanoparticles due to the electron-accepting nature of Ag^+ ions and the electron-donating nature of hydroxyl groups in polysaccharides (Ma *et al.*, 2017). *Acacia* gum and pectin have been used for the synthesis of palladium nanoparticles. They have reduced sugars in their structure, which coordinates metal ions in their carbonyl groups, allowing the synthesis of metal nanoparticles (Emam *et al.*, 2020). A representative schematic is shown in Figure 6. *Castanea mollissima* has glucans with a large number of OH groups that have been used to synthesize selenium nanoparticles (Li *et al.*, 2019). Galactomannans in *Prosopis spp* can function as nanoreactors to synthesize zinc oxide nanoparticles by coordinating the OH groups present in these polysaccharides (Bouttier-Figueroa *et al.*, 2019b).

Nanoparticles applications

Recently, nanotechnology has emerged as a science with a wide range of applications. Nanoparticles formed using nanotechnology have qualities that have allowed them to be used in different fields, such as food, agriculture, medicine, catalysis, and water treatment.

Food

Silver nanoparticles synthesized from *Madhuca latifolia* L. extracts can inhibit bacterial growth and be used in food packaging. Nanoparticles act as molecules that can penetrate the bacterial cell wall and affect their metabolic pathways. They can destabilize ribosomal function and DNA, causing cell death (Biswal and Misra, 2020).

Agriculture

Aqueous extract of *Ulva lactuca* allows the synthesizing of silver nanoparticles capable of inhibiting the proliferation of bacteria and fungi of agricultural importance by functioning as pesticides. Nanoparticles come into contact with bacteria entering their cell wall and interrupt cell permeability by interacting with enzymatic cofactors, sulfur, and phosphorous groups of DNA. In the case of fungi, the nanoparticles form pits on the cell surface, which causes changes in morphology and prevents proliferation (Amin, 2020). The extract of *Cornus mas* fruits has been used to synthesize Fe_2O_3 nanoparticles to improve the growth of barley seedlings serving as fertilizers. Nanoparticles work as an iron source; when absorbed by plants they change the concentrations of reactive oxygen species, causing a stimulus in the plant's growth (Rostamizadeh *et al.*, 2020).

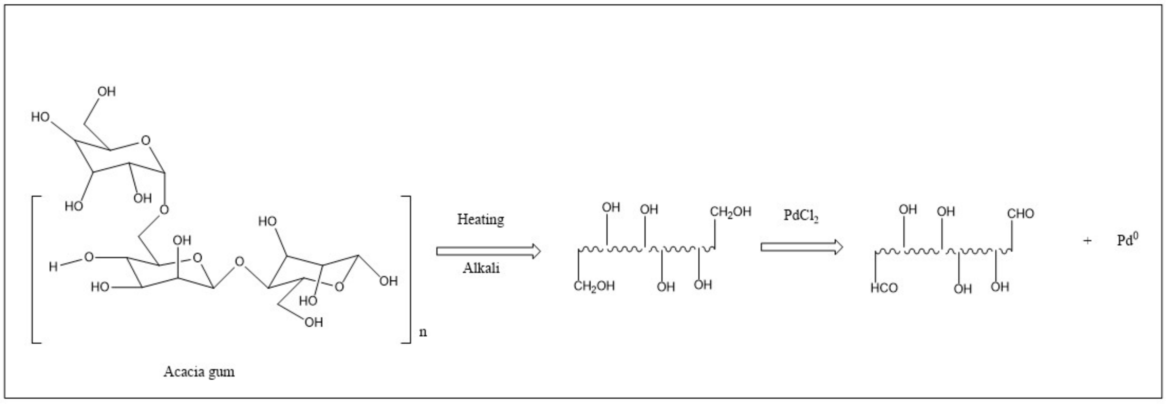

Figure 6. Proposed mechanism for nanoparticle synthesis from a polysaccharide compound. Adapted from Emam et al. (2020).
Figura 6. Mecanismo propuesto para la síntesis de nanopartículas a partir de polisacáridos. Adaptado de Emam et al. (2020).

Water treatment

Ficus benjamina leaves have been used to obtain extracts to form silver nanoparticles that can remove Cd(II) from contaminated water, functioning as ionic or elemental removers. Their results indicated that nanoparticles behave according to a Freundlich model, where Cd(II) adsorption occurs due to multiple layers of heterogeneity of the adsorbent surface (Al-Qahtani, 2017). *Fumariae herba* has been used to synthesize platinum nanoparticles, which can perform catalysis activities to remove organic dyes. This ability is attributed to their relatively large surface-to-volume ratios. Platinum nanoparticles showed enhanced catalytic activity for the degradation of organic dyes (Dobrucka, 2019).

Medicine

The leaves of *Coptis chinensis* allow the synthesis of silver nanoparticles with anticancer activity against lung cancer cells. Nanoparticles interact with cells, affecting the metabolic pathways of mitochondria causing apoptosis and destruction of the mitochondrial membrane. Nanoparticles alter the production of Bcl2 family proteins, altering cell susceptibility to promote the production of caspase 3 and Bax proteins that cause apoptosis (Pei *et al.*, 2019). *Andrographis paniculata*, *Phyllanthus niruri*, and *Tinospora cordifolia* have in their extracts agents capable of synthesizing silver nanoparticles with antiviral activity against the chikungunya virus. Nanoparticles interfere with the virus binding to the host cell, preventing it from entering, but the exact mechanism of action still needs to be studied (Sharma *et al.*, 2019). Zinc oxide synthesized with *Urtica dioica* extract has been employed in rats to lower insulin levels, functioning as an antidiabetic agent. Zinc present in nanoparticles acts by mimicking the activity of insulin, the fundament being that the pancreas of a healthy person contains a greater amount of zinc than a person with diabetes (Bayrami *et al.*, 2020).

Paeonia emodi has been used to synthesize gold nanoparticles essential for cardiovascular diseases treatment. Nanoparticles are loaded with drugs since they can enter tissues and release them directly at the site of action. They decreased the levels of alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, and creatine phosphokinase, which cause heart damage (Ibrar *et al.*, 2018). Zinc oxide nanoparticles have been synthesized with *Aloe socotrin* leaf extracts, allowing the distribution of antimicrobial agents. The nanoparticles eliminated microorganisms that cause urinary infections by destroying their membrane due to the formation of reactive oxygen species (Fahimmunisha *et al*., 2020). Extracts of *Rose indica L* petals can synthesize zinc oxide nanoparticles, which can be used in nail paint with antifungal activity. Understanding of ZnO mechanism of action in fungi needs to be better developed. It is known that H_2O_2 is formed, and the creation of bonds between cellulose molecules in their hydroxyl groups and oxygen atoms leads to the inhibition of fungal growth (Tiwari *et al*., 2017).

Electronic

Titanium oxide, synthesized from lemon peels, has optical and photocatalytic properties that allow its potential use in electronic devices. It is capable of degrading rhodamine B due to its high photocatalytic activity created by the rapid detachment capacity between the photogenerated electrons and holes (Nabi *et al.*, 2022).

Nanoparticles Packaging

Recent research avoids mentioning the materials used to store the synthesized nanoparticles. It is essential to consider an appropriate type of material to store the nanoparticles, preserve their properties, and allow transport in safe conditions. The U.S. Food and Drug Administration (FDA) has a section that regulates materials used to store food, drugs, and cosmetics. It can be extrapolated to nanoparticle storage. Permitted materials include (Marsh *et al*., 2007):

Glass: It does not have aroma, is chemically inert, impermeable to gases, allows good insulation from the outside, can be produced in different ways, and being transparent, allows observation of the stored product.

Metal: Focuses on aluminum and steel. These provide excellent barriers to moisture, air, odors, light, and microorganisms; they are ductile, easily recyclable, and highly accepted by the consumers.

Plastics: They are chemically resistant and cheap to manufacture. In industrial applications, they can be heat-sealed, printed, and stored on-site. The main disadvantage is that they are permeable to light and gases.

Paper and cardboard: This material mainly stores and transports product-filled containers.

Nanoparticles characterization

After synthesizing nanoparticles, it is important to know their morphological and physicochemical properties since, depending on their size, shape, surface morphology, structure, and homogeneity, their properties can vary. The most used characterization techniques are: Uv-vis, XRD, FTIR, DLS, EDAX, SEM and TEM (Gour *et al*., 2019).

- UV-visible: It is used to know the wavelength at which nanoparticles absorb, which is related to their Surface plasmon reverberation, providing information about their size.
- XRD: It is used to know the crystalline structure of nanoparticles.
- FT-IR: It is used to study the functional groups present on nanoparticles surface, which are responsible for the reduction and stabilization.
- DLS: Provides information about the surface charge of nanoparticles.
- EDAX: Estimates the abundance of elements present over nanoparticles surface.
- SEM and TEM: They provide information about nanoparticle morphology, size, and homogeneity.

Other techniques less used, include condensation particle counter, photon correlation spectroscopy, and field emission scattering electron microscopy. Authors such as Mourdikoudis *et al.* (2018) have already described more details about the characterization techniques.

CONCLUSIONS

This review presented information on nanoparticle synthesis using different plant extracts with a particular interest in the reaction mechanisms involved in the formation. The synthesis using natural plant extracts has allowed the elaboration of materials greenly (friendly to the environment, cost reduction, easy obtaining of raw material, and use of non-toxic solvents). The biomolecules present in the extracts are directly related to the reduction of metal ions, participation in the capture of ions, formation of complexes, and finally, the protection of the synthesized material. The development of nanotechnology has allowed applications in different areas such as electronics, medicine, chemistry, physics, engineering, environment, etc. These materials are synthesized invitro and participate in many secondary metabolites in their formation, including alkaloids, carbohydrates, phenols, and Terpenoids. Recent research focuses on specific metabolites for their role in nanoparticle formation. Further studies on the role of selected metabolites in the formation of nanoparticles are needed. The current overview of nanoparticle storage needs to be described in the literature, and there is a research opportunity to study the effects on packaging. This review addresses the characterization techniques, emphasizing the role of each of them in order to introduce their fundamentals. In this way, it will be possible to understand their physical and chemical properties better and subsequently standardize production processes at the industrial level.

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CONFLICTS OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Abdellatif, Ahmed A. H., and Abdullah Fahad Alsowinea. 2021. "Approved and Marketed Nanoparticles for Disease Targeting and Applications in COVID-19." *Nanotechnology Reviews* 10 (1): 1941–77. https://doi.org/10.1515/ntrev-2021-0115.

Adeleye, Adeyemi S., Ekene A. Oranu, Mengya Tao, and Arturo A. Keller. 2016. "Release and Detection of Nanosized Copper from a Commercial Antifouling Paint." *Water Research* 102: 374–82. https://doi.org/10.1016/j.watres.2016.06.056.

Ahmed Anees, Rauf A., Hemed H. A., Qureshi M. N., Sharma R., Aljojani A. S. M., Alhumaydhi F. A., Khan I., Alam A. and Rahman Md. M. 2022. "Green Synthesis of Gold and Silver Nanoparticles Using *Opuntia dillenii* Aqueous Extracts: Characterization and Their Antimicrobial Assessment." *Journal of Nanomaterials*. Article ID 4804116, 17 pages. https://doi.org/10.1155/2022/4804116.

Ahmad, Tausif, Mohamad Azmi Bustam, Muhammad Irfan, Muhammad Moniruzzaman, Hafiz Muhammad Anwaar Asghar, and Sekhar Bhattacharjee. 2019. "Mechanistic Investigation of Phytochemicals Involved in Green Synthesis of Gold Nanoparticles Using Aqueous *Elaeis guineensis* Leaves Extract: Role of Phenolic Compounds and Flavonoids." *Biotechnology and Applied Biochemistry* 66 (4): 698–708. https://doi.org/10.1002/bab.1787.

Ahmed, Ejaz, Muhammad Arshad, Muhammad Zakriyya Khan, Muhammad Shoaib Amjad, Huma Mehreen Sadaf, Iqra Riaz, Pakistan Sidra Sabir, et al. 2017. "Secondary Metabolites and Their Multidimensional Prospective in Plant Life." *Journal of Pharmacognosy and Phytochemistry* 6 (2): 205–14.

Ahmed, Shakeel, Annu, Saif Ali Chaudhry, and Saiqa Ikram. 2017. "A Review on Biogenic Synthesis of ZnO Nanoparticles Using Plant Extracts and Microbes: A Prospect towards Green Chemistry." *Journal of Photochemistry and Photobiology B: Biology* 166: 272–84. https://doi.org/10.1016/j.jphotobiol.2016.12.011.

Al-Jawhari, Hala, Hanan Bin-Thiyab, and Nihal Elbialy. 2022. "In Vitro Antioxidant and Anticancer Activities of Cupric Oxide Nanoparticles Synthesized Using Spinach Leaves Extract." *Nano-Structures and Nano-Objects* 29: 100815. https://doi.org/10.1016/j.nanoso.2021.100815.

Almadiy, Abdulrhman A., Gomah E. Nenaah, and Dalia M. Shawer. 2018. "Facile Synthesis of Silver Nanoparticles Using Harmala Alkaloids and Their Insecticidal and Growth Inhibitory Activities against the Khapra Beetle." *Journal of Pest Science* 91 (2): 727–37. https://doi.org/10.1007/s10340-017-0924-2.

Al-Qahtani, Khairia M. 2017. "Cadmium Removal from Aqueous Solution by Green Synthesis Zero Valent Silver Nanoparticles with Benjamina Leaves Extract." *Egyptian Journal of Aquatic Research* 43 (4): 269–74. https://doi.org/10.1016/j.ejar.2017.10.003.

Al-Radadi, Najlaa S. 2019. "Green Synthesis of Platinum Nanoparticles Using Saudi's Dates Extract and Their Usage on the Cancer Cell Treatment." *Arabian Journal of Chemistry* 12 (3): 330–49. https://doi.org/10.1016/j.arabjc.2018.05.008.

Amaliyah S., Sabarudin A., Masruri M. and Sumitro S. B. 2022. "Characterization and antibacterial application of biosynthesized silver nanoparticles using *Piper retrofractum* Vahl fruit extract as bioreductor". *Journal of Applied Pharmaceutical Science*. 12 (03): 103-114. DOI: 10.7324/JAPS.2022.120311.

Amer, Mohammad W., and Akl M. Awwad. 2021. "Green Synthesis of Copper Nanoparticles by *Citrus limon* Fruits Extract, Characterization and Antibacterial Activity." *International Scientific Organization* 7 (1): 1–8.

Amin, Hadear Hanie. 2020. "Biosynthesized Silver Nanoparticles Using *Ulva lactuca* as a Safe Synthetic Pesticide (in Vitro)." *Open Agriculture* 5 (1): 291–99. https://doi.org/10.1515/opag-2020-0032.

Baghani, Mohsen, and Ali Es-Haghi. 2020. "Characterization of Silver Nanoparticles Biosynthesized Using *Amaranthus cruentus*." *Bioinspired, Biomimetic and Nanobiomaterials* 9 (3): 129–36. https://doi.org/10.1680/jbibn.18.00051.

Bayrami, Abolfazl, Shirin Haghgooie, Shima Rahim Pouran, Farid Mohammadi Arvanag, and Aziz Habibi-Yangjeh. 2020. "Synergistic Antidiabetic Activity of ZnO Nanoparticles Encompassed by *Urtica dioica* Extract." *Advanced Powder Technology* 31 (5): 2110–18. https://doi.org/10.1016/j.apt.2020.03.004.

Behzad, Farahnaz, Seyed Morteza Naghib, Mohammad Amin Jadidi kouhbanani, Seyede Nafise Tabatabaei, Yasser Zare, and Kyong Yop Rhee. 2021. "An Overview of the Plant-Mediated Green Synthesis of Noble Metal Nanoparticles for Antibacterial Applications." *Journal of Industrial and Engineering Chemistry* 94: 92–104. https://doi.org/10.1016/j.jiec.2020.12.005.

Beldjilali M., Mekhissi K., Khane Y., Chaibi W., Belarbi L. and Bousalem S. 2020. "Antibacterial and Antifungal Efficacy of Silver Nanoparticles Biosynthesized Using Leaf Extract of *Thymus algeriensis*." *Journal of Inorganic and Organometallic Polymers and Materials*. 30: 2126–2133. https://doi.org/10.1007/s10904-019-01361-3

Bhutto, Aijaz A., Şaban Kalay, S. T.H. Sherazi, and Mustafa Culha. 2018. "Quantitative Structure–Activity Relationship between Antioxidant Capacity of Phenolic Compounds and the Plasmonic Properties of Silver Nanoparticles." *Talanta* 189: 174–81. https://doi.org/10.1016/j.talanta.2018.06.080.

Biswal, Achyuta Kumar, and Pramila Kumari Misra. 2020. "Biosynthesis and Characterization of Silver Nanoparticles for Prospective Application in Food Packaging and Biomedical Fields." *Materials Chemistry and Physics* 250 (January): 123014. https://doi.org/10.1016/j.matchemphys.2020.123014.

Boomi, P., R. M. Ganesan, G. Poorani, H. Gurumallesh Prabu, S. Ravikumar, and J. Jeyakanthan. 2019. "Biological Synergy of Greener Gold Nanoparticles by Using *Coleus aromaticus* Leaf Extract." *Materials Science and Engineering C* 99 (May 2018): 202–10. https://doi.org/10.1016/j.msec.2019.01.105.

Bouttier-Figueroa, D. C., and M. Sotelo-Lerma. 2019. "Fabrication and Characterization of an Eco-Friendly Antibacterial Nanocomposite of Galactomannan/ZnO by in Situ Chemical Co-Precipitation Method." *Composite Interfaces* 26 (2): 83–95. https://doi.org/10.1080/09276440.2018.1472457.

Carmona, Erico R., Noelia Benito, Tanya Plaza, and Gonzalo Recio-Sánchez. 2017. "Green Synthesis of Silver Nanoparticles by Using Leaf Extracts from the Endemic *Buddleja globosa* Hope." *Green Chemistry Letters and Reviews* 10 (4): 250–56. https://doi.org/10.1080/17518253.2017.1360400.

Cirkovic Velickovic, Tanja D., and Dragana J. Stanic-Vucinic. 2018. "The Role of Dietary Phenolic Compounds in Protein Digestion and Processing Technologies to Improve Their Antinutritive Properties." *Comprehensive Reviews in Food Science and Food Safety* 17 (1): 82–103. https://doi.org/10.1111/1541-4337.12320.

Dhanemozhi, A. Clara, V. Rajeswari, and S. Sathyajothi. 2017. "Green Synthesis of Zinc Oxide Nanoparticle Using Green Tea Leaf Extract for Supercapacitor Application." *Materials Today: Proceedings* 4 (2): 660–67. https://doi.org/10.1016/j.matpr.2017.01.070.

Dobrucka, Renata. 2019. "Biofabrication of Platinum Nanoparticles Using *Fumariae herba* Extract and Their Catalytic Properties." *Saudi Journal of Biological Sciences* 26 (1): 31–37. https://doi.org/10.1016/j.sjbs.2016.11.012.

Ekennia, Anthony, Dickson Uduagwu, Olawale Olowu, Obianuju Nwanji, Obinna Oje, Blessing Daniel, Sandra Mgbii, and Chimerem Emma-Uba. 2021. "Biosynthesis of Zinc Oxide Nanoparticles Using Leaf Extracts of *Alchornea laxiflora* and Its Tyrosinase Inhibition and Catalytic Studies." *Micron* 141 (October 2020): 102964. https://doi.org/10.1016/j.micron.2020.102964.

Eltaweil, Abdelazeem S., Manal Fawzy, Mohamed Hosny, Eman M. Abd El-Monaem, Tamer M. Tamer, and Ahmed M. Omer. 2022. "Green Synthesis of Platinum Nanoparticles Using *Atriplex halimus* Leaves for Potential Antimicrobial, Antioxidant, and Catalytic Applications." *Arabian Journal of Chemistry* 15 (1): 103517. https://doi.org/10.1016/j.arabjc.2021.103517.

Emam, Hossam E., Nourhan M. Saad, Amira E.M. Abdallah, and Hanan B. Ahmed. 2020. "Acacia gum versus Pectin in Fabrication of Catalytically Active Palladium Nanoparticles for Dye Discoloration." *International Journal of Biological Macromolecules* 156: 829–40. https://doi.org/10.1016/j.ijbiomac.2020.04.018.

Fahimmunisha, Basheer Ahmed, Ramachandran Ishwarya, Mohamad S. AlSalhi, Sandhanasamy Devanesan, Marimuthu Govindarajan, and Baskaralingam Vaseeharan. 2020. "Green Fabrication, Characterization and Antibacterial Potential of Zinc Oxide Nanoparticles Using *Aloe socotrina* Leaf Extract: A Novel Drug Delivery Approach." *Journal of Drug Delivery Science and Technology* 55 (November 2019): 101465. https://doi.org/10.1016/j.jddst.2019.101465.

Fahmy, Sherif Ashraf, Iten M. Fawzy, Basma M. Saleh, Marwa Y. Issa, Udo Bakowsky, and Hassan Mohamed El Said Azzazy. 2021. "Green Synthesis of Platinum and Palladium Nanoparticles Using *Peganum harmala* L. Seed Alkaloids: Biological and Computational Studies." *Nanomaterials* 11 (4): 1–15. https://doi.org/10.3390/nano11040965.

Farjadian, Fatemeh, Amir Ghasemi, Omid Gohari, Amir Roointan, Mahdi Karimi, and Michael R. Hamblin. 2019. *Nanopharmaceuticals and Nanomedicines Currently on the Market: Challenges and Opportunities*. *Nanomedicine*. Vol. 14. https://doi.org/10.2217/nnm-2018-0120.

Folorunso, Aderonke, Sunday Akintelu, Abel Kolawole Oyebamiji, Samuel Ajayi, Babawale Abiola, Ibrahim Abdusalam, and Adetoun Morakinyo. 2019. "Biosynthesis, Characterization and Antimicrobial Activity of Gold Nanoparticles from Leaf Extracts of *Annona muricata*." *Journal of Nanostructure in Chemistry* 9 (2): 111–17. https://doi.org/10.1007/s40097-019-0301-1.

Gangapuram, Bhagavanth Reddy, Rajkumar Bandi, Madhusudhan Alle, Ramakrishna Dadigala, Girija Mangatayaru Kotu, and Veerabhadram Guttena. 2018. "Microwave Assisted Rapid Green Synthesis of Gold Nanoparticles Using *Annona squamosa* L Peel Extract for the Efficient Catalytic Reduction of Organic Pollutants." *Journal of Molecular Structure* 1167: 305–15. https://doi.org/10.1016/j.molstruc.2018.05.004.

Gehr, Peter. 2018. "Interaction of Nanoparticles with Biological Systems." *Colloids and Surfaces B: Biointerfaces* 172 (August): 395–99. https://doi.org/10.1016/j.colsurfb.2018.08.023

Gour A. and Jain N. K. 2019. "Advances in green synthesis of nanoparticles." *Artificial cells, nanomedicine and biotechnology*. 47(1): 844-851. DOI:10.1080/21691401.2019.1577878

Goutam, Surya Pratap, Gaurav Saxena, Varunika Singh, Anil Kumar Yadav, Ram Naresh Bharagava, and Khem B. Thapa.

2018. "Green Synthesis of TiO2 Nanoparticles Using Leaf Extract of *Jatropha curcas* L. for Photocatalytic Degradation of Tannery Wastewater." *Chemical Engineering Journal* 336 (December 2017): 386–96. https://doi.org/10.1016/j.cej.2017.12.029.

Hamers, Robert J. 2017. "Nanomaterials and Global Sustainability." *Accounts of Chemical Research* 50 (3): 633–37. https://doi.org/10.1021/acs.accounts.6b00634.

He, Yangqing, Fenfei Wei, Zhanying Ma, Hao Zhang, Qian Yang, Binghua Yao, Zhengrui Huang, Jie Li, Cun Zeng, and Qian Zhang. 2017. "Green Synthesis of Silver Nanoparticles Using Seed Extract of: *Alpinia katsumadai*, and Their Antioxidant, Cytotoxicity, and Antibacterial Activities." *RSC Advances* 7 (63): 39842–51. https://doi.org/10.1039/c7ra05286c.

Hernández-Morales, Liliana, Heriberto Espinoza-Gómez, Lucía Z. Flores-López, Erika Lis Sotelo-Barrera, Alfredo Núñez-Rivera, Rubén Darío Cadena-Nava, Gabriel Alonso-Núñez, and Karla Alejandra Espinoza. 2019. "Study of the Green Synthesis of Silver Nanoparticles Using a Natural Extract of Dark or White *Salvia hispanica* L. Seeds and Their Antibacterial Application." *Applied Surface Science* 489 (June): 952–61. https://doi.org/10.1016/j.apsusc.2019.06.031.

Hoseinpour, Vahid, and Nasser Ghaemi. 2018. "Green Synthesis of Manganese Nanoparticles: Applications and Future Perspective–A Review." *Journal of Photochemistry and Photobiology B: Biology* 189 (August): 234–43. https://doi.org/10.1016/j.jphotobiol.2018.10.022.

Hosny, Mohamed, Manal Fawzy, Yaser A. El-Badry, Enas E. Hussein, and Abdelazeem S. Eltaweil. 2022. "Plant-Assisted Synthesis of Gold Nanoparticles for Photocatalytic, Anticancer, and Antioxidant Applications." *Journal of Saudi Chemical Society* 26 (2): 101419. https://doi.org/10.1016/j.jscs.2022.101419.

Ibrar, Muhammad, Mir Azam Khan, Abdullah, and Muhammad Imran. 2018. "Evaluation of *Paeonia emodi* and Its Gold Nanoparticles for Cardioprotective and Antihyperlipidemic Potentials." *Journal of Photochemistry and Photobiology B: Biology* 189 (May): 5–13. https://doi.org/10.1016/j.jphotobiol.2018.09.018.

Idrees, Muhammad, Saima Batool, Tanzila Kalsoom, Sadaf Raina, Hafiz Muhammad Adeel Sharif, and Summera Yasmeen. 2019. "Biosynthesis of Silver Nanoparticles Using *Sida acuta* Extract for Antimicrobial Actions and Corrosion Inhibition Potential." *Environmental Technology (United Kingdom)* 40 (8): 1071–78. https://doi.org/10.1080/09593330.2018.1435738.

Irfan, Muhammad, Muhammad Moniruzzaman, Tausif Ahmad, Pradip Chandra Mandal, Sekhar Bhattacharjee, and Bawadi Abdullah. 2017. "Ionic Liquid Based Extraction of Flavonoids from *Elaeis guineensis* Leaves and Their Applications for Gold Nanoparticles Synthesis." *Journal of Molecular Liquids* 241: 270–78. https://doi.org/10.1016/j.molliq.2017.05.151.

Jamkhande, Prasad Govindrao, Namrata W. Ghule, Abdul Haque Bamer, and Mohan G. Kalaskar. 2019. "Metal Nanoparticles Synthesis: An Overview on Methods of Preparation, Advantages and Disadvantages, and Applications." *Journal of Drug Delivery Science and Technology* 53 (July 2018): 101174. https://doi.org/10.1016/j.jddst.2019.101174.

Joshi, Neha, Neha Jain, Abhishek Pathak, Jai Singh, Ram Prasad, and Chandrama Prakash Upadhyaya. 2018. "Biosynthesis of Silver Nanoparticles Using *Carissa carandas* Berries and Its Potential Antibacterial Activities." *Journal of Sol-Gel Science and Technology* 86 (3): 682–89. https://doi.org/10.1007/s10971-018-4666-2.

Kalimuthu, Kalishwaralal, Byung Seok Cha, Seokjoon Kim, and Ki Soo Park. 2020. "Eco-Friendly Synthesis and Biomedical Applications of Gold Nanoparticles: A Review." *Microchemical Journal* 152 (September 2019). https://doi.org/10.1016/j.microc.2019.104296.

Karak, Prithviraj. 2019. "BIOLOGICAL ACTIVITIES OF FLAVONOIDS: AN OVERVIEW Prithviraj Karak Department of Physiology, Bankura Christian College, Bankura - 722101, West Bengal, India." *International Journal of Pharmaceutical Sciences and Research* 10 (4): 1567–74. https://doi.org/10.13040/IJPSR.0975-8232.10(4).1567-74.

Katata-Seru, Lebogang, Tshepiso Moremedi, Oluwole Samuel Aremu, and Indra Bahadur. 2018. "Green Synthesis of Iron Nanoparticles Using *Moringa oleifera* Extracts and Their Applications: Removal of Nitrate from Water and Antibacterial Activity against *Escherichia coli*." *Journal of Molecular Liquids* 256: 296–304. https://doi.org/10.1016/j.molliq.2017.11.093.

Khandanlou, Roshanak, Vinuthaa Murthy, and Hao Wang. 2020. "Gold Nanoparticle-Assisted Enhancement in Bioactive Properties of Australian Native Plant Extracts, *Tasmannia lanceolata* and *Backhousia citrio*dora." *Materials Science and Engineering C* 112 (March): 110922. https://doi.org/10.1016/j.msec.2020.110922.

Kobylinska, Natalia, Anatolij Shakhovsky, Olena Khainakova, Dmytro Klymchuk, Liliya Avdeeva, Yakiv Ratushnyak, Volodymyr Duplij, and Nadiia Matvieieva. 2020. "'Hairy' Root Extracts as Source for 'Green' Synthesis of Silver Nanoparticles and Medical Applications." *RSC Advances* 10 (65): 39434–46. https://doi.org/10.1039/d0ra07784d.

Kolahalam, Lalitha A., I. V. Kasi Viswanath, Bhagavathula S. Diwakar, B. Govindh, Venu Reddy, and Y. L.N. Murthy. 2019. "Review on Nanomaterials: Synthesis and Applications." *Materials Today: Proceedings* 18: 2182–90. https://doi.org/10.1016/j.matpr.2019.07.371.

Lakshmanan, G., A. Sathiyaseelan, P. T. Kalaichelvan, and K. Murugesan. 2018. "Plant-Mediated Synthesis of Silver Nanoparticles Using Fruit Extract of *Cleome viscosa* L.: Assessment of Their Antibacterial and Anticancer Activity." *Karbala International Journal of Modern Science* 4 (1): 61–68. https://doi.org/10.1016/j.kijoms.2017.10.007.

Laouini, Salah Eddine, Abderrhmane Bouafia, Alexander V. Soldatov, Hamed Algarni, Mohammed Laid Tedjani, Gomaa A.M. Ali, and Ahmed Barhoum. 2021. "Green Synthesized of Ag/Ag_2O Nanoparticles Using Aqueous Leaves Extracts of *Phoenix dactylifera* L. And Their Azo Dye Photodegradation." *Membranes* 11 (7). https://doi.org/10.3390/membranes11070468.

Lebaschi, Sadaf, Malak Hekmati, and Hojat Veisi. 2017. "Green Synthesis of Palladium Nanoparticles Mediated by Black Tea Leaves (*Camellia sinensis*) Extract: Catalytic Activity in the Reduction of 4-Nitrophenol and Suzuki-Miyaura Coupling Reaction under Ligand-Free Conditions." *Journal of Colloid and Interface Science* 485: 223–31. https://doi.org/10.1016/j.jcis.2016.09.027.

Lembang, M. S., Y. Yulizar, S. Sudirman, and D. O.B. Apriandanu. 2018. "A Facile Method for Green Synthesis of Nd_2O_3 Nanoparticles Using Aqueous Extract of *Terminalia catappa* Leaf." *AIP Conference Proceedings* 2023 (October 2018): 1–7. https://doi.org/10.1063/1.5064090.

Li, Hongyan, Dandan Liu, Shenghui Li, and Changhu Xue. 2019. "Synthesis and Cytotoxicity of Selenium Nanoparticles Stabilized by α-D-Glucan from *Castanea mollissima* Blume." *International Journal of Biological Macromolecules* 129: 818–26. https://doi.org/10.1016/j.ijbiomac.2019.02.085.

Ma, Yihua, Congyan Liu, Ding Qu, Yan Chen, Mengmeng Huang, and Yuping Liu. 2017. "Antibacterial Evaluation of Sliver Nanoparticles Synthesized by Polysaccharides from *Astragalus membranaceus* Roots." *Biomedicine and Pharmacotherapy* 89: 351–57. https://doi.org/10.1016/j.biopha.2017.02.009.

Mahendiran, D., G. Subash, D. Arumai Selvan, Dilaveez Rehana, R. Senthil Kumar, and A. Kalilur Rahiman. 2017. "Biosynthesis of Zinc Oxide Nanoparticles Using Plant Extracts of *Aloe vera* and *Hibiscus sabdariffa*: Phytochemical, Antibacterial, Antioxidant and Anti-Proliferative Studies." *BioNanoScience* 7 (3): 530–45. https://doi.org/10.1007/s12668-017-0418-y.

Mahiuddin Md., Saha P and Ochiai B. 2020. "Green Synthesis and Catalytic Activity of Silver Nanoparticles Based on *Piper chaba* Stem Extracts." *Nanomaterials* 10: 1777. doi:10.3390/nano10091777

Malapermal, Veshara, Izel Botha, Suresh Babu Naidu Krishna, and Joyce Nonhlanhla Mbatha. 2017. "Enhancing Antidiabetic and Antimicrobial Performance of *Ocimum basilicum*, and *Ocimum sanctum* (L.) Using Silver Nanoparticles." *Saudi Journal of Biological Sciences* 24 (6): 1294–1305. https://doi.org/10.1016/j.sjbs.2015.06.026.

Malek Mohammadi F. and Ghasemi N. 2018. "Ingluence of Temperature and Concentration on Biosynthesis and Characterization of Zinc Oxide Nanoparticles using *Cherry* Extract." *Journal of Nanostructure in Chemistry* 8: 93-102. https://doi.org/10.1007/s40097-018-0257-6

Marsh K. and Bugusu B. 2007. "Food Packaging—Roles, Materials, and Environmental Issues." Journal of food science 72(3): R39-R55. https://doi.org/10.1111/j.1750-3841.2007.00301.x

Mateus, Gustavo Affonso Pisano, Michele Putti Paludo, Tássia Rhuna Tonial Dos Santos, Marcela Fernandes Silva, Leticia Nishi, Márcia Regina Fagundes-Klen, Raquel Guttieres Gomes, and Rosângela Bergamasco. 2018. "Obtaining Drinking Water Using a Magnetic Coagulant Composed of Magnetite Nanoparticles Functionalized with *Moringa oleifera* Seed Extract." *Journal of Environmental Chemical Engineering* 6 (4): 4084–92. https://doi.org/10.1016/j.jece.2018.05.050.

Matinise, N., K. Kaviyarasu, N. Mongwaketsi, S. Khamlich, L. Kotsedi, N. Mayedwa, and M. Maaza. 2018. "Green Synthesis of Novel Zinc Iron Oxide ($ZnFe_2O_4$) Nanocomposite via *Moringa oleifera* Natural Extract for Electrochemical Applications." *Applied Surface Science* 446: 66–73. https://doi.org/10.1016/j.apsusc.2018.02.187.

Mayedwa, Noluthando, Nametso Mongwaketsi, Saleh Khamlich, Kasinathan Kaviyarasu, Nolubabalo Matinise, and Malik Maaza. 2018. "Green Synthesis of Nickel Oxide, Palladium and Palladium Oxide Synthesized via *Aspalathus linearis* Natural Extracts: Physical Properties & Mechanism of Formation." *Applied Surface Science* 446: 266–72. https://doi.org/10.1016/j.apsusc.2017.12.116.

Mena-García, A., A. I. Ruiz-Matute, A. C. Soria, and M. L. Sanz. 2019. "Green Techniques for Extraction of Bioactive Carbohydrates." *TrAC - Trends in Analytical Chemistry* 119: 115612. https://doi.org/10.1016/j.trac.2019.07.023.

Mera, Irina Francesca González, Daniela Estefanía González Falconí, and Vivian Morera Córdova. 2019. "Secondary Metabolites in Plants: Main Classes, Phytochemical Analysis and Pharmacological Activities." *Revista Bionatura* 4 (4). https://doi.org/10.21931/RB/2019.04.04.11.

Mody, VickyV, Rodney Siwale, Ajay Singh, and HardikR Mody. 2010. "Introduction to Metallic Nanoparticles." *Journal of Pharmacy and Bioallied Sciences* 2 (4): 282. https://doi.org/10.4103/0975-7406.72127.

Mohamad Sukri, Siti Nur Amalina, Kamyar Shameli, Magdelyn Mei-Theng Wong, Sin Yeang Teow, Jactty Chew, and Nur Afini Ismail. 2019. "Cytotoxicity and Antibacterial Activities of Plant-Mediated Synthesized Zinc Oxide (ZnO) Nanoparticles Using *Punica granatum* (Pomegranate) Fruit Peels Extract." *Journal of Molecular Structure* 1189: 57–65. https://doi.org/10.1016/j.molstruc.2019.04.026.

Mohanan, Akhilash, Vishnu Sankar, Abbas Rahdar, Jithu Joseph, Fardin Sadeghfar, Ronaldo Anuf A, K Rajesh, and George Z Kyzas. 2020. "Green Synthesis and Characterization of Zinc Oxide Nanoparticles with Antibacterial and Antifungal Activity." *Journal of Molecular Structure* 1211: 128107. https://doi.org/10.1016/j.molstruc.2020.128107.

Mora, Marc, Andrew Stannard, and Sergi Garcia-Manyes. 2020. "The Nanomechanics of Individual Proteins." *Chemical Society Reviews* 49 (19): 6816–32. https://doi.org/10.1039/d0cs00426j.

Mourdikoudis S., Pallares R. M. and Thanh T. K. 2018. "Characterization techniques for nanoparticles: comparison and complementary upon studying nanoparticle properties." *Nanoscale* 10 12871-12934. DOI: 10.1039/c8nr02278

Nabi, Ghulam, Qurat Ul Ain, M. Bilal Tahir, Khalid Nadeem Riaz, Tahir Iqbal, Muhammad Rafique, Sajad Hussain, Waseem Raza, Imran Aslam, and Muhammad Rizwan. 2022. "Green Synthesis of TiO2 Nanoparticles Using Lemon Peel Extract: Their Optical and Photocatalytic Properties." *International Journal of Environmental Analytical Chemistry* 102 (2): 434–42. https://doi.org/10.1080/03067319.2020.1722816.

Naga, Panduranga, Vijay Kumar, Shameem Ummey, and Lakshmi Kalyani. 2018. "Microbial Pathogenesis Ultra Small, Mono Dispersed Green Synthesized Silver Nanoparticles Using Aqueous Extract of *Sida cordifolia* Plant and Investigation of Antibacterial Activity." *Microbial Pthogenesis* 124 (December 2017): 63–69. https://doi.org/10.1016/j.micpath.2018.08.026.

Naikoo, Gowhar A., Mujahid Mustaqeem, Israr U. Hassan, Tasbiha Awan, Fareeha Arshad, Hiba Salim, and Ahsanulhaq Qurashi. 2021. "Bioinspired and Green Synthesis of Nanoparticles from Plant Extracts with Antiviral and Antimicrobial Properties: A Critical Review." *Journal of Saudi Chemical Society* 25 (9): 101304. https://doi.org/10.1016/j.jscs.2021.101304.

Narendra Kumar, H. K., N. Chandra Mohana, B. R. Nuthan, K. P. Ramesha, D. Rakshith, N. Geetha, and Sreedharamurthy Satish. 2019. "Phyto-Mediated Synthesis of Zinc Oxide Nanoparticles Using Aqueous Plant Extract of *Ocimum americanum* and Evaluation of Its Bioactivity." *SN Applied Sciences* 1 (6): 1–9. https://doi.org/10.1007/s42452-019-0671-5.

Nguyen, Dai Hai, Jung Seok Lee, Ki Dong Park, Yern Chee Ching, Xuan Thi Nguyen, V H Giang Phan, Thai Thanh, and Hoang Thi. n.d. "Green Silver Nanoparticles Formed by *Phyllanthus urinaria*, *Pouzolzia zeylanica*, and *Scoparia dulcis* Leaf Extracts and the Antifungal Activity."

Nguyen, Duyen Thi Cam, Huy Hoang Dang, Dai Viet N. Vo, Long Giang Bach, Trinh Duy Nguyen, and Thuan Van Tran. 2021. "Biogenic Synthesis of MgO Nanoparticles from Different Extracts (Flower, Bark, Leaf) of *Tecoma stans* (L.) and Their Utilization in Selected Organic Dyes Treatment." *Journal of Hazardous Materials* 404 (PA): 124146. https://doi.org/10.1016/j.jhazmat.2020.124146.

Opris, Razvan, Corina Tatomir, Diana Olteanu, Remus Moldovan, Bianca Moldovan, Luminita David, Andras Nagy, Nicoleta Decea, Mihai Ludovic Kiss, and Gabriela Adriana Filip. 2017. "The Effect of *Sambucus nigra* L. Extract and Phytosinthesized Gold Nanoparticles on Diabetic Rats." *Colloids and Surfaces B: Biointerfaces* 150: 192–200. https://doi.org/10.1016/j.colsurfb.2016.11.033.

Ovais, Muhammad, Ali Talha Khalil, Nazar Ul Islam, Irshad Ahmad, Muhamamd Ayaz, Muthupandian Saravanan, Zabta Khan Shinwari, and Sudip Mukherjee. 2018. "Role of Plant Phytochemicals and Microbial Enzymes in Biosynthesis of Metallic Nanoparticles." *Applied Microbiology and Biotechnology* 102 (16): 6799–6814. https://doi.org/10.1007/s00253-018-9146-7.

P., Patil Shriniwas, and Kumbhar Subhash T. 2017a. "Antioxidant, Antibacterial and Cytotoxic Potential of Silver Nanoparticles Synthesized Using Terpenes Rich Extract of *Lantana camara* L. Leaves." *Biochemistry and Biophysics Reports* 10 (October 2016): 76–81. https://doi.org/10.1016/j.bbrep.2017.03.002.

Pei, Junwen, Binfan Fu, Lifeng Jiang, and Taizhen Sun. 2019. "Biosynthesis, Characterization, and Anticancer Effect of Plant-Mediated Silver Nanoparticles Using *Coptis chinensis*." *International Journal of Nanomedicine* 14: 1969–78. https://doi.org/10.2147/IJN.S188235.

Proshkina, Ekaterina, Sergey Plyusnin, Tatyana Babak, Ekaterina Lashmanova, Faniya Maganova, Liubov Koval, Elena Platonova, Mikhail Shaposhnikov, and Alexey Moskalev. 2020. "Terpenoids as Potential Geroprotectors." *Antioxidants* 9 (6): 1–51. https://doi.org/10.3390/antiox9060529.

Rafi Shaik, Mohammed, Zuhur Jameel Qandeel Ali, Mujeeb Khan, Mufsir Kuniyil, Mohamed E. Assal, Hamad Z. Alkhathlan, Abdulrahman Al-Warthan, Mohammed Rafiq H. Siddiqui, Merajuddin Khan, and Syed Farooq Adil. 2017. "Green Synthesis and Characterization of Palladium Nanoparticles Using *Origanum vulgare* L. Extract and Their Catalytic Activity." *Molecules* 22 (1). https://doi.org/10.3390/molecules22010165.

Rafique, Muhammad, Rabbia Tahir, S. S.A. Gillani, M. Bilal Tahir, M. Shakil, T. Iqbal, and M. O. Abdellahi. 2022. "Plant-Mediated Green Synthesis of Zinc Oxide Nanoparticles from *Syzygium cumini* for Seed Germination and Wastewater Purification." *International Journal of Environmental Analytical Chemistry* 102 (1): 23–38. https://doi.org/10.1080/03067319.2020.1715379.

Raheema, Rana Hussein, and Roaa M H Shoker. 2020. "Phytochemicals Screening and Antibacterial Activity of Silver Nanoparticles, Phenols and Alkaloids Extracts of *Conocarpus lancifolius*." *EurAsian Journal of BioSciences Eurasia J Biosci* 14 (October): 4829–35.

Rehana, Dilaveez, D. Mahendiran, R. Senthil Kumar, and A. Kalilur Rahiman. 2017. "Evaluation of Antioxidant and Anticancer Activity of Copper Oxide Nanoparticles Synthesized Using Medicinally Important Plant Extracts." *Biomedicine and Pharmacotherapy* 89: 1067–77. https://doi.org/10.1016/j.biopha.2017.02.101.

Rios, J. L., S. Simeon, and A. Villar. 1989. "Pharmacological Activity of Aporphinoid Alkaloids. A Review." *Fitoterapia* 60 (5): 387–412. https://doi.org/10.63019/ajb.v1i2.467.

Roduner, Emil. 2006. "Size Matters: Why Nanomaterials Are Different." *Chemical Society Reviews* 35 (7): 583–92. https://doi.org/10.1039/b502142c.

Rostamizadeh, Elham, Alireza Iranbakhsh, Ahmad Majd, Sedigheh Arbabian, and Iraj Mehregan. 2020. "Green Synthesis of Fe_2O_3 Nanoparticles Using Fruit Extract of *Cornus mas* L. and Its Growth-Promoting Roles in Barley." *Journal of Nanostructure in Chemistry* 10 (2): 125–30. https://doi.org/10.1007/s40097-020-00335-z.

Samari, Fayezeh, Hossein Salehipoor, Ebrahim Eftekhar, and Saeed Yousefinejad. 2018. "Low-Temperature Biosynthesis of Silver Nanoparticles Using Mango Leaf Extract: Catalytic Effect, Antioxidant Properties, Anticancer Activity and Application for Colorimetric Sensing." *New Journal of Chemistry* 42 (19): 15905–16. https://doi.org/10.1039/C8NJ03156H.

Santhoshkumar, R., A. Hima Parvathy, and E. V. Soniya. 2021. "Phytosynthesis of Silver Nanoparticles from Aqueous Leaf Extracts of *Piper colubrinum*: Characterisation and Catalytic Activity." *Journal of Experimental Nanoscience* 16 (1): 295–309. https://doi.org/10.1080/17458080.2021.1970140.

Sharma, Vikrant, Sulochana Kaushik, Pooja Pandit, Divya Dhull, Jaya Parkash Yadav, and Samander Kaushik. 2019. "Green Synthesis of Silver Nanoparticles from Medicinal Plants and Evaluation of Their Antiviral Potential against Chikungunya Virus." *Applied Microbiology and Biotechnology* 103 (2): 881–91. https://doi.org/10.1007/s00253-018-9488-1.

Sherin, Lubna, Ayesha Sohail, Um e.Salma Amjad, Maria Mustafa, Riffat Jabeen, and Anwar Ul-Hamid. 2020. "Facile Green Synthesis of Silver Nanoparticles Using *Terminalia bellerica* Kernel Extract for Catalytic Reduction of Anthropogenic Water Pollutants." *Colloids and Interface Science Communications* 37 (May): 100276. https://doi.org/10.1016/j.colcom.2020.100276.

Silva, Anderson Felipe Viana da, Ana Paula Fagundes, Domingos Lusitâneo Pier Macuvele, Elita Fontanele Urano de Carvalho, Michelangelo Durazzo, Natan Padoin, Cíntia Soares, and Humberto Gracher Riella. 2019. "Green Synthesis of Zirconia Nanoparticles Based on *Euclea natalensis* Plant Extract: Optimization of Reaction Conditions and Evaluation of Adsorptive Properties." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 583 (August): 123915. https://doi.org/10.1016/j.colsurfa.2019.123915.

Singh, Hina, Juan Du, Priyanka Singh, and Tae Hoo Yi. 2018. "Ecofriendly Synthesis of Silver and Gold Nanoparticles by *Euphrasia officinalis* Leaf Extract and Its Biomedical Applications." *Artificial Cells, Nanomedicine and Biotechnology* 46 (6): 1163–70. https://doi.org/10.1080/21691401.2017.1362417.

Singh, Jagpreet, Tanushree Dutta, Ki Hyun Kim, Mohit Rawat, Pallabi Samddar, and Pawan Kumar. 2018. "'Green' Synthesis of Metals and Their Oxide Nanoparticles: Applications for Environmental Remediation." *Journal of Nanobiotechnology* 16 (1): 1–24. https://doi.org/10.1186/s12951-018-0408-4.

Skandalis, Nicholas, Anastasia Dimopoulou, Anthie Georgopoulou, Nikolaos Gallios, Dimitrios Papadopoulos, Dimitrios Tsipas, Ioannis Theologidis, Nikolaos Michailidis, and Maria Chatzinikolaidou. 2017. "The Effect of Silver

Nanoparticles Size, Produced Using Plant Extract from Arbutus Unedo, on Their Antibacterial Efficacy." *Nanomaterials* 7 (7). https://doi.org/10.3390/nano7070178.

Swathi, Vottikuti, Maravajhala Vidyavathi, T. N.V.K.V. Prasad, and R. V.Suresh Kumar. 2013. "Comparison of Different Nano Biocomposites of Neomycin with Marketed Ointment by In-Vitro and in-Vivo Evaluations." *International Journal of Drug Delivery* 5 (4): 438–48. https://doi.org/10.5138/ijdd.v5i4.1171.

Taylor, Alicia A., M. Yusuf Khan, Jennifer Helbley, and Sharon L. Walker. 2017. "Safety Evaluation of Hair-Dryers Marketed as Emitting Nano Silver Particles." *Safety Science* 93: 121–26. https://doi.org/10.1016/j.ssci.2016.11.021.

Tiwari, Nikita, Raksha Pandit, Swapnil Gaikwad, Aniket Gade, and Mahendra Rai. 2017. "Biosynthesis of Zinc Oxide Nanoparticles by Petals Extract of Rosa Indica L., Its Formulation as Nail Paint and Evaluation of Antifungal Activity against Fungi *Causing onychomycosis*." *IET Nanobiotechnology* 11 (2): 205–11. https://doi.org/10.1049/iet-nbt.2016.0003.

Tolman, C. A. 1972. "The 16 and 18 Electron Rule in Organometallic Chemistry and Homogeneous Catalysis." *Chemical Society Reviews* 1 (3): 337–53. https://doi.org/10.1039/CS9720100337.

Tripathi, Deepika, Arusha Modi, Gopeshwar Narayan, and Shashi Pandey Rai. 2019. "Green and Cost Effective Synthesis of Silver Nanoparticles from Endangered Medicinal Plant *Withania coagulans* and Their Potential Biomedical Properties." *Materials Science and Engineering C* 100 (February): 152–64. https://doi.org/10.1016/j.msec.2019.02.113.

Vance, Marina E., Todd Kuiken, Eric P. Vejerano, Sean P. McGinnis, Michael F. Hochella, and David Rejeski Hull. 2015. "Nanotechnology in the Real World: Redeveloping the Nanomaterial Consumer Products Inventory." *Beilstein Journal of Nanotechnology* 6 (1): 1769–80. https://doi.org/10.3762/bjnano.6.181.

Veisi, Hojat, Bikash Karmakar, Taiebeh Tamoradi, Saba Hemmati, Malak Hekmati, and Mona Hamelian. 2021. "Biosynthesis of CuO Nanoparticles Using Aqueous Extract of Herbal Tea (*Stachys lavandulifolia*) Flowers and Evaluation of Its Catalytic Activity." *Scientific Reports* 11 (1): 1–13. https://doi.org/10.1038/s41598-021-81320-6.

Vijayakumar, S., P. Arulmozhi, N. Kumar, B. Sakthivel, S. Prathip Kumar, and P. K. Praseetha. 2019. "*Acalypha Fruticosa* L. Leaf Extract Mediated Synthesis of ZnO Nanoparticles: Characterization and Antimicrobial Activities." *Materials Today: Proceedings* 23: 73–80. https://doi.org/10.1016/j.matpr.2019.06.660.

Vijayakumar, S., S. Mahadevan, P. Arulmozhi, S. Sriram, and P. K. Praseetha. 2018. "Green Synthesis of Zinc Oxide Nanoparticles Using *Atalantia monophylla* Leaf Extracts: Characterization and Antimicrobial Analysis." *Materials Science in Semiconductor Processing* 82 (November 2017): 39–45. https://doi.org/10.1016/j.mssp.2018.03.017.

Wang, Lu, Yanan Wu, Jia Xie, Sheng Wu, and Zhenqiang Wu. 2018. "Characterization, Antioxidant and Antimicrobial Activities of Green Synthesized Silver Nanoparticles from *Psidium guajava* L. Leaf Aqueous Extracts." *Materials Science and Engineering C* 86 (February): 1–8. https://doi.org/10.1016/j.msec.2018.01.003.

Widatalla, Hiba Abbas, Layla Fathi Yassin, Ayat Ahmed Alrasheid, Shimaa Abdel Rahman Ahmed, Marvit Osman Widdatallah, Sahar Hussein Eltilib, and Alaa Abdulmoneim Mohamed. 2022. "Green Synthesis of Silver Nanoparticles Using Green Tea Leaf Extract, Characterization and Evaluation of Antimicrobial Activity." *Nanoscale Advances* 4: 911–15. https://doi.org/10.1039/d1na00509j.

Yousaf, Huma, Ansar Mehmood, Khawaja Shafique Ahmad, and Muhammad Raffi. 2020. "Green Synthesis of Silver Nanoparticles and Their Applications as an Alternative Antibacterial and Antioxidant Agents." *Materials Science and Engineering C* 112 (February): 110901. https://doi.org/10.1016/j.msec.2020.110901.