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Green synthesis of NPs (Ag & Au) from some plant families (Phyllanthaceae, Lamiaceae, Rutaceae and Euphorbiaceae) and their application in therapeutics: A review

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A B S T R A C T

Plant mediated green synthetic route for silver and gold nanoparticles (AgNPs & AuNPs) from four plant families: *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiaceae* and their therapeutic application of are summarized in the present review article. Silver and gold nanoparticles prepared from the mentioned plant families were visualized with various therapeutic applications *viz*., anti-microbial, ant-bacterial, anti-cancer and anti-oxidant activities etc. Owing to size and shapes, NPs green synthesized from various plants like *Ricinus communis* (Ag), *Tectona grandis* (Ag), *Plectranthus amboinicus* (Ag, Au), *Phyllanthus emblica* (Ag, Au), *Ricinu communis* (Ag), *Leucas aspera* (Ag, Au), *Acalypha indica* Linn . (Ag, Au) were envisioned with innumerable curative applications such as antimicrobial, anticancer, antibacterial, anti-oxidant, cytotoxicity, haemolytic and stimulating effect etc. In the current review, eco-friendly green synthetic itineraries for synthesis of AgNPs and AuNPs are mainly focused. Phyto-components present in plants such as anti-oxidant molecules, terpenes, alkaloids, coumarins like quercetin, D-allose, 1-valine, ocosenamide molecules etc. are the responsible reducing agents for the capping reaction (Ag^+ to Ag^0 and Au^{3+} to Au^0) of nanoparticle from metal precursors like $AgNO_3$ and $HAuCl_4$.

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1. Introduction

Nanotechnology is a rapidly developing area of material science that incorporates many other scientific, engineering, pharmaceutical and technological fields (Santhosh et al., 2022). Nanoparticles are with a diameter ranged from 1 to 100 nm. The properties of nanoparticles might vary depending on their size, structure, and the materials used in their synthesis (Siddiqi et al., 2018). Nanoparticles have several applications in many fields like textiles, electronics and most significantly, healthcare, where these are used for bio sensing, drug delivery, and other human welfare-related purposes (Jain et al., 2021). Metals like copper, silver and gold can be synthesized into nanoparticles that have a variety of medical uses, including antibacterial, anticancer, and anti-diabetic properties (Karmous et al., 2020). The synthesis of silver nanoparticle (AgNPs) and gold nanoparticles (AuNPs) are of great interest to the scientific community due to their special qualities (Popescu et al., 2010), such as chemical stability, catalytic activity, free-radical scavenging, good conductivity and particularly for their antibacterial, antifungal, antiviral, and anti-inflammatory activities (Lateef et al., 2018; Ahmad et al., 2003). Ag NPs are also used in cosmetic products, electronic components, food industry, cryogenic superconducting materials, and composite fibers (Jabeen et al., 2021). These are more effectively used as antibacterial agents, in anticancer medications, in treatment of wounds, nano-coating for bone implants, water disinfecting and in dental surgery etc. (Jain and Mehata, 2017; Hembram et al., 2018). AuNPs have garnered the most attention among the numerous metallic NPs because of their exceptional surface plasmon resonance features, variable sizes, simple synthesis, and multifunctional capabilities with well-characterized attributes (Sarfraz and Khan, 2021). AuNPs are flexible, largely inert, biocompatible, and stable materials. Because of its clearly defined surface chemistry, these can readily be coupled with a variety of molecules, including proteins, medicines, enzymes, dyes, antibodies, and nucleic acids (Santhosh et al., 2022). There are wide range of biological uses for AuNPs functionalized with diverse targeting moieties, imaging therapy, including diagnosis and drug delivery (Tian et al., 2014).

The production of NPs using bio-mediated synthesis is a safe, affordable, and less hazardous process, where it includes all herbal extracts, microbes and biopolymers (Rahuman et al., 2022). The biosynthesis method of NPs using plant extract is a green route and

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more preferable approach than other chemically treated methods. NPs can be synthesized from various parts of plants viz., leaves, bark, roots, stems, flowers, seeds, and fruits. Looking forward the acceptance bio-synthetic route and utility of AgNPs and AuNPs this article aimed to discuss about the production of silver and gold nanoparticles utilizing diverse plant components from four different plant families, including the *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiaceae* as well as their therapeutic uses. Plants belonging to these families have medicinal effects, for instance, *Antidesma acidum Retz*. plant belonging to *Phyllanthaceae* family is used to treat fever, cough and jaundice in traditional medicinal system (Chuakul and Saralamp 2000). *Osimum sanctum* belonging to *Lamiaceae* is commonly known as "Holy basil" and has a long history of being used medicinally in Ayurveda. It has various healing properties and used to treat diseases like malaria, arthritis, cough, dysentery, bronchitis, skin diseases, chronic fever, eye diseases etc.

The *Phyllanthaceae* is a small, shrub, 5–6 m tall and flowering family plant (Mahomoodally et al., 2020). It includes more than 2000 species and widely distributed in tropical and sub-tropical regions (Kathriarachchi et al., 2005; Hoffman et al., 2023). *Phyllanthaceae* family contains various medicinal plants, such as *Antidesma acidum, Antidesma bunius, Arbutus andracene, Cleistanthus collinus, Phyllanthus acidus, Phyllanthus embica, Phyllanthus niruri* and *Sauropus androgynous* etc. These plants have different medicinal properties, which is the part of the oldest traditional medicinal system. Leaves are simple, glabrous and rounded in shape and it is native to tropical and subtropical area of Asia and widely distributed to countries like- India, China, Pakistan, Indonesia and Western Himalaya region (Antidesma acidum Retz., plants of the World Online 2021). Researchers have been reported that phytochemical screening of plant extract shows presence of phenol, flavanones, coumarins, tannin, saponin, xanthoprotein and sugar reducing capacity (Patil and Jadhav Rathod, 2014). *Antidesma bunius* L. *Spreng* is native to Philippines and the leaves are traditionally used to treat snake bites (Fabregas et al., 2021).

Lamiaceae are the mint family, containing around 236 genera and includes 6900–7200 species (Tamokou et al., 2017). These plants are sub-shrubs with many branches that have simple opposing green or purple leaves with intense scents and hairy stalks (Rout et al., 2012). Leaves have petiole and are ovate, up to 5 cm long, usually somewhat toothed. Flowers are purplish in elongate racemes in close whorls, such as *Osimum sanctum, Ocimum canum, Origanum vulgare* L.*, Plectranthus amboinicus, Mentha piperita, Thymus serpyllum* and *Leucas aspera.* These family plants are tiny, shrubby, blooming, and many of them have aromatic properties in all parts and mostly found in India, China, Indonesia, Malaysia, Myanmar, Philippines, Sri Lanka, Africa, South west Asia, Australia, and some of the Arab countries (Ramteke et al., 2013). The *Lamiaceae* family plant shows antidiabetic, anticancer, antimicrobial, analgesic, hepatoprotective, diaphoretic and cardioprotective activities (Stella Sravanthi et al., 2018).

Euphorbiaceae is a largest family of flowering plants containing herbs, trees and cactus like plants (Gillespie and Armbruster, 1997). These plants are widely distributed in Tropical Africa, Asia including India, Yemen, Sri Lanka, Pakistan and south America; which mostly found in temperate or tropical regions gardens, roadside and wastelands (Menon et al., 2017). The leaves have stipules and are alternating, rarely opposite such as *Ricinus communis, Phyllathus, Jatropha curcas, Acalypha hispida, Acalypha indica* and *Croton tiglium* etc. Many of these plants have been utilized medicinally by numerous cultures all over the world. In Ayurvedic medicine, this plant family is used to treat a variety of illnesses, including abdominal pain, jaundice, chronic dysentery, hepatitis, urinary tract infections, constipation, skin ulcer, liver and kidney diseases (Aboulthana et al., 2019; Ghramh et al., 2019; Joseph et al., 2021). These plants contain bio-stabilizers and reductants like Phenolics, flavonoids, polysaccharides, steroids, tannins, saponins and alkaloids (Gul et al., 2021).

The *Rutaceae* family plants are most commonly known as citrus plants, such as *Citrus sinensis, Citrus limon, Citrus tangerina, Citrus maxima, Citrus macroptera and Citrus aurantium. Citrus* plants are native to Southeast Asia, Eastern Himalayas, India, Western China and Myanmar. Citrus plants are shrubs or trees with aromatic smell. Leaves are usually opposite without stipules and contains oil glands. These plants and fruits are notable for their fragrant properties and are commonly used in foods, perfumes, essential oils and other scented items (Gandhi et al., 2020). Most of the citrus fruits are excellent sources of flavanones, vitamin C and contains phytochemicals like alkaloids, phenolic compounds, terpenoids and polyketides etc. Citrus fruits have anti-oxidant, anti-cancer, anti-inflammatory, anti-allergy and anti-microbial properties in along with having neuroprotective, cardiovascular, obesity control, hepatoprotective and other health benefits (Lv et al., 2015).

These four family plants have been successfully utilized by numerous researchers to synthesize Au and Ag NPs. The plants can be extracted using various methods like decoction process, maceration process, digestion, soxhlet extraction etc. These plants can transform metal ions into nanoparticles due to containing valued phytochemicals; such as flavonoids, alkaloids, phenolic compounds, terpenoids, steroids, tannins, saponins and polyketides. It was reported that the phyllanthaceae family plant *A.acidum, C. collinus, A. andrachne, P. emblica* were used to synthesize AgNPs and AuNPs; shows antimicrobial, antioxidant activities (Basumatary et al., 2023; VennilaRaj et al., 2013; Erdoğan et al., 2016; Masum et al., 2019). The *Lamiaceae* plant species *P. amboinicus, O. sanctum, O. canum etc.* are utilized in the biosynthesis of AuNPs and AgNPs with anti-tumor, antibacterial, anticancer, and anti-malaria properties (Reddy et al., 2017; Elumalai et al., 2017; Stella Sravanthi et al., 2018). In a similar way, plants from the *Rutaceae* and *Euphorbiaceae* families are used for the production of nanoparticles and have some therapeutic benefits. The biosynthesized AgNPs and AuNPs exhibit sufficient medical capabilities like antibacterial, anticancer, anti-diabetic, anti-malaria, anti-tumor, and anti-oxidant activity due to the presence of bioactive compounds. Thus, the pharmaceutical industry has a wide range of potential applications for the use of medicinal plants in nanoparticle production. Here, in the present review article, the green synthetic route for the synthesis of Ag and Au NPs from plant extract and their therapeutic applications are concentrated.

2. Methodology based on database

Google Scholar, ScienceDirect, and other online databases (Academia, Research Gate, and Willey Online Library) provide access to a variety of databases. The databases including book chapters, research publications, review articles, and some online data were initially identified. Following methodology and biological activity analysis of silver and gold nanoparticles, 205 records were chosen for further processing. 105 records were included in full-text studies after some records were excluded from selected articles as shown in Fig. 1.

2.1. Green synthesis of nanoparticles

Researchers have employed a variety of techniques to develop nanoparticles, including chemical (sol-gel process, chemical reduction, vapor deposition, etc.), physical (electrochemical, irradiation, ultrasonication, etc.) and biological (using herbal extracts and microbial sources) processes (Jia et al., 2020).

Chemical reduction, microemulsion, photoinduced reduction, UV-initiated photoreduction, electrochemical irradiation, and pyrolysis are the many chemically synthesis processes. Numerous organic and inorganic substances, including polyethylene glycol, sodium hydroxide (NaOH), sodium borohydride ($NaBH_4$), ascorbate, tollens reagent,

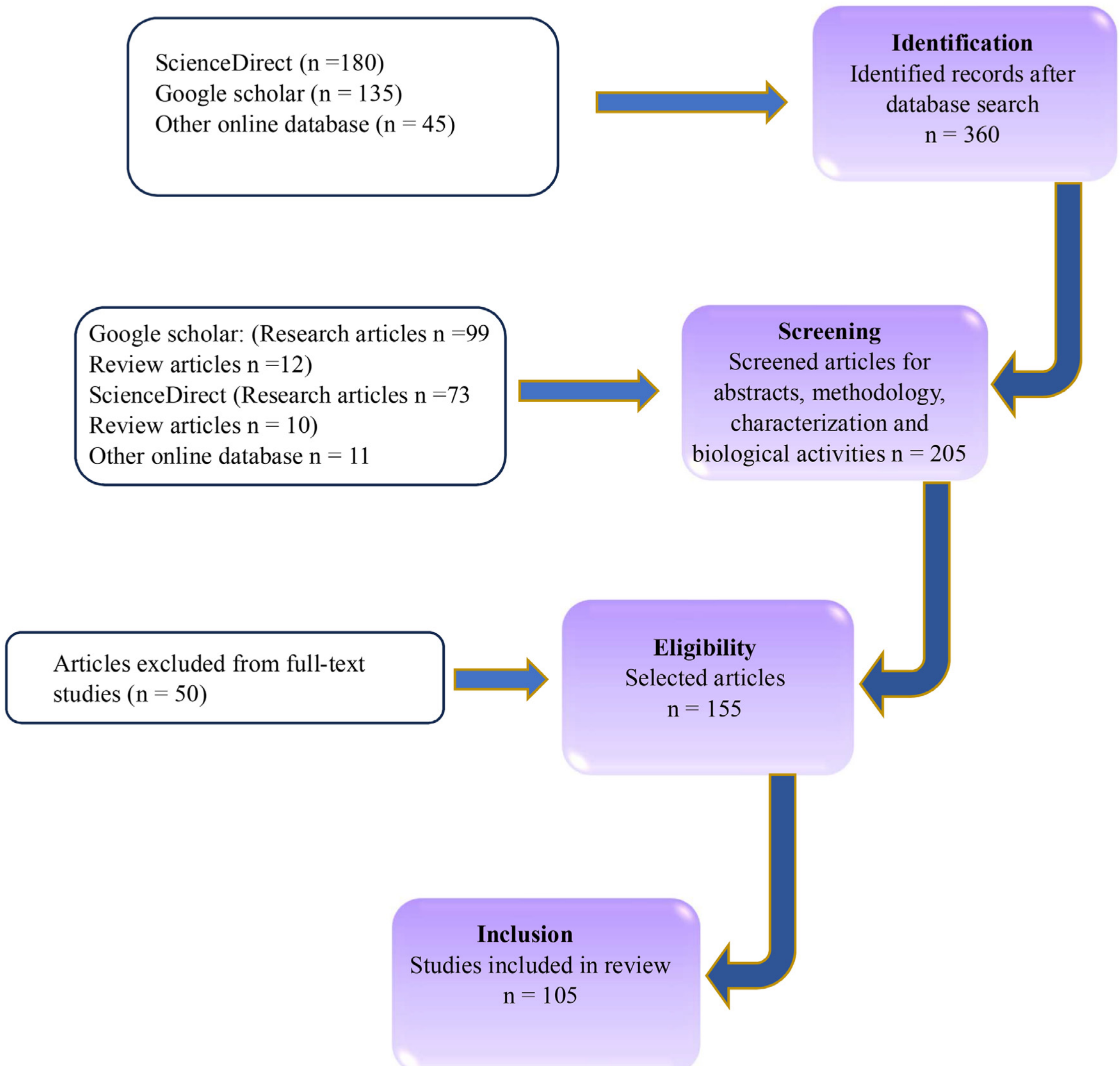

Fig. 1. Database search flow chart.

N-dimethyl formamide (DMF), and tollens reagent, are generally used to reduce the metal ion to create nanoparticles in both aqueous and non-aqueous solutions (Iravani et al., 2014). The biggest advantage of this chemical reduction is the speedy synthesis of a large number of nanoparticles.

In physical approaches, the evaporation-condensation process in a tube furnace at atmospheric pressure is used to produce nanoparticles. The use of radiation as a reducing agent, rapid process and the lack of dangerous chemicals are advantages of physical approaches (Rahuman et al., 2022). Although it is a common practice to create metallic nanoparticles chemically, the use of stabilizing and reducing reagents is restricted due to their hazardous effects, high cost and dangerous side effects.

Biological method is an eco-friendly, cost efficient, non-toxic that doesn't require any sophisticated equipment's or chemicals (Jain et al., 2021). In this approach, nanoparticles have been synthesized using plant extracts, yeast and fungi. Fig. 2 shows the schematic representation of green synthesis of nanoparticles from various plant families. From Fig. 2, various plants parts (leaf, seed, stem etc.) are to be dried and grinded before preparation of aqueous or polar solvent extracts. After extraction, to the filtrate metal precursor solutions are to be added and confirmed by visual color change about the preparation of NPs; followed by UV–vis, XRD, TEM, FESEM etc. analytical methods. This review focused on green synthesis, which is the most ideal way to create nanoparticles through biological processes. Plants are feedstock of various bio-active compounds viz., flavonoids, terpenoids, saponins, alkaloids, phenols, etc. and are used traditionally as a natural source of medicine in both conventional systems and contemporary therapies to enhance human health (Swamy et al., 2017; Jain and Mehata, 2017). Many plant parts, including roots, bark, leaves, and fruits, are utilized in traditional medicine for long time. The use of plants as a source of medication has a significant impact on global health care in traditional medicine system. Since ancient times, wild food plants have been essential to human existence. Ethnic people use them as traditional veggies and also utilize them medicinally (Ramya et al., 2017).

Plants being major source of primary and secondary metabolites like flavonoids, terpenoids, saponins, alkaloids, phenols, nucleic acids, proteins, amino acid and vitamins etc., play a crucial role in the transformation of bulk metals into metal nanoparticles (Ulaeto et al., 2019; Silva et al., 2019) and may operate as a stabilizing and reducing agent for nanoparticle formation (Lee et al., 2016) through capping reaction.

Fig. 3 shows the capping of phyto-compounds present in plant extract for the reduction of metal precursors (M^+, M^{2+} etc.) to metal nanoparticles (M^0 NPs). Plants are free from toxic chemicals and it contains natural reducing agents, which is suitable for environment friendly nanoparticle synthesis (Shaikh et al., 2020). For instance, it

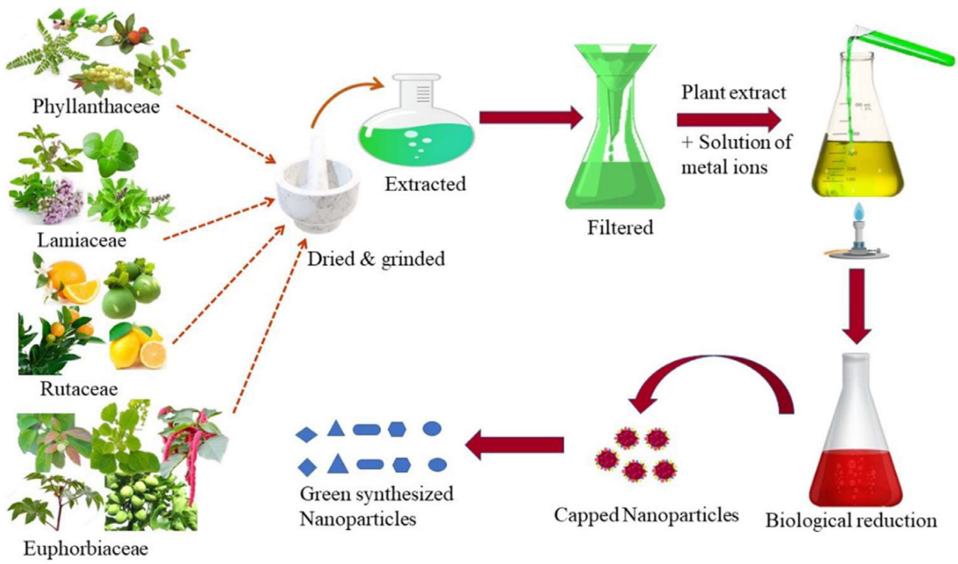

Fig. 2. Green synthesis of nanoparticles: Plant extracts dried, grinded filtered followed by nanoparticle synthesis by biological reduction.

was reported that secondary metabolites of plant extract can stabilize the silver Ag^{+} ions into Ag^{0} and formed with spherical in shape NPs (Masum et al., 2019). Similarly, it is reported that the reduction mechanism of flavonoids and alkaloids present in *M.Lucida* plant extract, with Ag^{+} ions through capping reaction to reduce Ag^{0} (Labula et al., 2022). The -OH and -COOH groups present in phytocompounds involved in reduction of Ag^{+} to Ag^{0}. It has been noticed that metal NPs for example AuNPs and AgNPs can be biosynthesized from variety of plant components; where utilization of leaves in synthesis is most common. The morphology of NPs is significantly influenced by variations in the amounts of metabolites present in various plant sections and even within individual plants. Numerous studies have been demonstrated the efficient synthesis of various kinds of nanoparticles; which can vary in size and shape like spherical, rod, wire, cubic, triangles, hexagonal and pentagonal (Drummer et al., 2021). NPs are coated with plants secondary metabolites such as flavonoids, phenols, terpenoids, tannin, glycosides and functional groups such as ketones, aldehydes, and carboxylic acid. Organic acids (oxalic, malic, and tartaric) and other water-soluble phyto-constituents present in plants, such as flavones and quinones, may have assisted in the rapid reduction of silver ions during the synthesis process (Bose and Chatterjee, 2016). *P. amboinicus* leaf extract act as a reducing and capping agent in production of AgNPs and AuNPs; where bioactive components are capped with nanoparticles and possesses antibacterial activity (Reddy et al., 2017). *C. macroptera* fruit extract reduces the positive ion gold chloride solution Au^{3+} into Au^{0} during the synthesis of AuNPs. Anticancer and anti-biofilm activities of phytochemical-capped Au nanoparticles have been explored (Majumdar et al., 2019). The involvement of various plant metabolites in the preparation of Ag & Au NPs is tabulated in Table 1 based on previous reports.

2.2. *Synthesis and characterization of AgNps and AuNps using plant extracts from* phyllanthaceae*, l*amiaceae, rutaceae and euphorbiaceae

Metallic NPs especially gold and silver have attracted considerable attention in catalysis, optics, sensing, imaging and biomedical devices (Jain et al., 2021). Bio-mediated synthesized silver and gold nanoparticles are well known for its pharmaceutical and biomedical applications (Rauf et al., 2021). Utilization of plant extract in nanoparticle synthesis is one of the easiest, simple and one-step method. In order to start the synthesis of gold and silver nanoparticles, the medicinal plant extract is extracted utilizing the various methods as mentioned above. The freshly prepared $AgNO_3$ and $HAuCl_4$ solution are mixed with plant extracts and then placed on a magnetic stirrer at a constant temperature. When plant extract or active components from plants are added to silver nitrate solution, which acts as a reducing agent, the solution's positive ions (Ag^{+}) change to zero-valent states (Ag^{0}) (Jain and Mehata, 2017). The solution's color changed from light yellow to reddish brown while being continually stirred in a dark environment. The formation of nanoparticles is indicated by the color changing at a particular time (Roy et al., 2019). Later, it is confirmed by monitoring UV–visible spectra around 410–430 nm at different time intervals. After the complete synthesis of AgNPs, the solution mixture is centrifuged at around 10,000 rpm and dried in an air oven (AlSalhi et al., 2016). In the case of AuNPs synthesis, plant extract is injected dropwise to generate nanoparticles by reducing metal ions

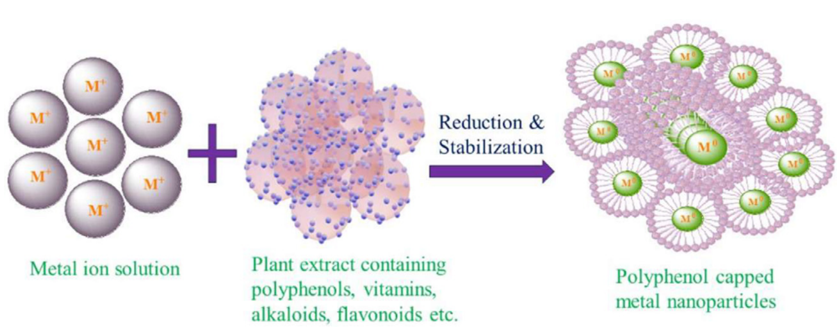

Fig. 3. Capping of phyto-compounds present in plant extracts for nano-particle synthesis.

Table 1
Ag and Au NPs from plant species with possible reducing plant metabolites.

Plant species	Nanoparticles	Possible reducing pyto-chemicals	Ref.
Acalypha hispida	Ag	Phytol, n-Hexadecanoic acid, 1, 2, 3-Benzenetriol, α-D-Mannofuranoside, methyl, D-Allose and Octadecanoic acid	(Selvakumar et al., 2018)
Acalypha indica	Ag	Flavonoids or terpenoids	(Menon et al., 2017)
Ricinus communis	Ag	Quercetin-3−0-p-D-glucopyranoside, indole-3-actetic acid, triethyl citrate and amino acid (1-valine)	(Gul et al., 2021)
Leucas aspera, Hyptis suaveolens	Ag	Tannins, phenols, flavonoids, saponin, quinone, protein, carbohydrates, cyanin and terpenoids	(Elumalai et al., 2017)
Leucas aspera	Ag	Proteins	(Smitha et al., 2022)
Ocimum basilicum and *Ocimum sanctum (L.)*	Ag	Cis-11-Eicosenamide, 8-Methyl-6-nonenamide, 13- Docosenamide and (13z)-N-([(13z)−13-D*ocosenoylamino*]methyl)- 13-docosenamide	(Malapermal et al., 2017)
Plectranthus amboinicus	Ag, Au & Ag-Au	Carboxylic acids, alkaloids, flavones, aldehydes, terpenoids, alkenes, and amines	(Reddy et al., 2017)
Ocimum sanctum	Au	Proteins	(Gautam et al., 2017)
Salvia spinosa	Ag	Carnosic acid and flavonoids	(Pirtarighat et al., 2019)
Tectona grandis	Ag	Proteins	(Rautela et al., 2019)
Ocimum sanctum	Ag	Proteins and terpenoids	(Rout et al., 2012)
Sauropus androgynous	Ag	Enzymes, flavonoids, phenols, alkaloids, terpenoids and tannins	(Abhimannue and Menon, 2021)
Cleistanthus collinus	Ag	Aryl naphthalene lignin	(VennilaRaj et al., 2013)
Phyllanthus emblica	Ag, Au	Proteins, phenols and flavonoids	(Masum et al., 2019) (Wang et al., 2021)
Phyllanthus acidus	Ag	Quercetin	(Sowmya et al., 2018)
Citrus aurantium	Ag	Vitamins, minerals, phenolic compounds, terpenoids, and flavonoids	(Erdoğan et al., 2021)
Citrus tangerina, Citrus sinensis & Citrus limon	Ag	Flavonoids, alkaloids, coumarins, and phenolics	(Niluxsshun et al., 2021)

precursors (Yuan et al., 2017). During the synthesis process, plant extract acts as reducing agent to reduce Au^{3+} ions in metal precursors to Au^0 (Santhosh et al., 2022). The combination solution's color gradually shifts from bright yellow to tomato red over time. Visual observation of color changes is primary indication of nanoparticle production and lastly the mixture is confirmed by recording UV−visible spectra at 550 nm. Then the solution should be centrifuged for around 30 min at 3000 rpm and dried after separating the pellet from the supernatant (Huang et al., 2019). Some plant-mediated green synthesized AgNPs and AuNPs from different family plants based on previous reports are summarized in Table. 2.

Green synthetic details of AgNP and AuNPs from plants belonging to *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiaceae* families are given herewith: *A. acidum, C. collinus, S. androgynous* are some plants falls under ***Phyllanthaceae*** family and green synthetic routes for both AgNPs and AuNPs were reported earlier from these plants. It was reported that the synthesis of AgNPs from *S. androgynous* (L.) aqueous extract; mixture of 10 ml of plant extract and 90 ml of silver nitrate solution at various concentrations was incubated at 90 °C in a water bath for 45 min and maintained overnight at room temperature in a dark place (Abhimannue and Menon, 2021). Again, synthesis of AgNPs from *A. acidum* leaf extract was reported by Basumatary et al. (2023); freshly prepared 10 mM silver nitrate solution and plant extract were mixed in 1:20 ratio and placed on a magnetic stirrer at 70 °C for 90 min. The formation of brown colloidal solution and UV−visible spectra confirmed the complete reduction of $AgNO_3$ (Ag^+ ions to Ag^0) (Basumatary et al., 2023). VennilaRaj et al.; in 2013 reported the green synthesis of AgNPs using *C. collinus* leaf extract. 10 ml of *C. collinus* ethanolic leaf extract was added to 90 ml of freshly prepared 1 mM $AgNO_3$ aqueous solution and stirred for 1 h at 80 °C. The solution's color changed from light brown to dark reddish brown, indicating the reduction of ions. *O. sanctum* leaf, falls under ***Lamiaceae*** family was also reported in synthesis of AgNPs to reduce metal ions and its antibacterial activity was investigated against *E. coli* and *S. aureus* (Ramteke et al., 2013). 10 ml of plant extract and 30 ml of $AgNO_3$ solution was mixed and stirred continuously for two hours to reduce silver nitrate solution. Then the solution was incubated for 12 h in dark at room temperature and it turns to brown in color which indicates the complete formation of nanoparticles. After 12 h, synthesized particles were repeatedly washed by deionized water through centrifugation at 12,000 rpm for 20 min. Similarly, *O. canum* also used in one-step synthesizing method. Where 10 ml of leaf extract was added to 90 ml of $AgNO_3$ solution and stirred at 80 °C for 15 min. The rapid color change of solution from light yellow to brown, indicates that *O. canum* extract showed fast reduction activity due to containing bio-active phytochemicals. The synthesized nanoparticles were separated by centrifugation process and dried. AgNPs antibacterial efficacy evaluated against E. coli bacteria and revealed a maximal inhibition zone at a dose of 30 ppm (Tailor et al., 2020). AuNPs also synthesized as similar process with slight modification, where 10 ml of 1 mM $HAuCl_4$ solution was added to 30 ml of *O. sanctum* leaf extract in a conical flask. The conical flask was placed in a shaker at 37 °C for 24 h and UV-spectra was recorded at different time intervals. Then the solution mixture was centrifuged at 4 °C for 15 min at 11,500 rpm followed by washing with distilled water and final pellet was sonicated. Biosynthesized AuNPs showed anticancer and antitumor activity (Gautam et al., 2017). AuNPs synthesized from herbal plant L. *aspera* extract was evaluated for anticancer, cytotoxic activity and antibacterial activities against *S. epidermidis* and *E. coli* bacterial strains (Prabu et al., 2016). *P. amboinicus* leaf extract was used to successfully synthesis both AgNPs and AuNPs, as well as Au/Ag bimetallic nanoparticles. AgNPs determined for antibacterial activity against the gram-positive pathogens *E. coli* and *Pseudomonas* spp. as well as the gram-negative pathogens *Bacillus* spp. and *Staphylococcus spp* (Reddy et al., 2017). ***Euphorbiaceae*** family includes medicinal plants viz. *Ricinus communis, Phyllathus, Jatropha curcas, Acalypha hispida, Acalypha indica* and *Croton tiglium* etc. are also commonly used for green synthesizing method of AgNPs and AuNPs to reduce metal ions (Ojha et al., 2017). *R. communis* leaf and root extract have been successfully utilized in synthesizing AgNPs. Methanolic root and leaf extracts were mixed with 1 mM $AgNO_3$ solution in different ratio (1:1, 1:2, 1:3, 1:4, 1:5, 1:6, 1:7, 1:8, 1:9, 1:10) mL and stirred for 4 h. AuNPs can be synthesized from *R. communis* ethanolic leaf extract (Ghramh et al., 2019). AuNPs was synthesized by mixing de-oiled Jatropha waste aqueous extract with 120 ml of $HAuCl_4$ solution and stirred continuously. After an hour, the combination solution's color changed from pale yellow to orange, suggesting the formation of AuNPs through the reduction of Au(III) to Au(0) (Kanchi et al., 2014). Similar to the process outlined above, AgNPs and AuNPs were synthesized using an aqueous extract (Krishnaraj et al., 2014). The ***Rutaceae*** family is a group of plants that encompasses a wide range of species such as citrus fruits, *Citrus sinensis, Citrus limon, Citrus tangerina,*

Table 2
Green synthesis of Plant mediated AgNPs and AuNPs from plant families *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiaceae*.

Family	Plant species	Parts	Solvent	NPs	Size & Shape	Reference
Euphorbiaceae	*Acalypha hispida*	Leaf	Methanol	Ag	10–30 nm & Spherical	(Selvakumar et al., 2018)
	Acalypha indica	Leaf	Aqueous	Ag	-	(Ghosh et al., 2018)
	Acalypha indica	Leaf	Aqueous	Ag	34 nm & Spherical	(Menon et al., 2017)
	Acalypha indica Linn.	Leaf	Aqueous	Ag & Au	20–30 nm & Spherical	(Krishnaraj et al., 2014)
	Ricinus communis	Leaf & Root	Methanol	Ag	Root = 29 nm	(Gul et al., 2021)
	Croton tiglium L.	Seeds	Ethyl Alcohol, Petroleum Ether & Aqueous	Ag	Leaf = 38 nm & Spherical	(Aboulthana et al., 2019)
	Ricinus communis	Leaf	Ethanol	Au	5–10 nm & Spherical	(Ghramh et al., 2019)
	Jatropha curcas	Seed	Aqueous	Ag	40–80 nm & Spherical	(Nayak et al., 2019)
	Jatropha	Waste	Aqueous	Au	80–95 nm & Spherical	(Kanchi et al., 2018)
	Jatropha curcas	Leaf	Aqueous	Ag	14 nm & Triangle, hexagonal, spherical	(Chauhan et al., 2016)
	Phyllanthus amarus	Seed	Aqueous	Ag	20–50 nm & Spherical	(Joseph et al., 2021)
	Ricinus communis var. *carmencita*	Leaf	Methanol	Ag	-	(Ojha et al., 2017)
					30–40 nm & Spherical	
Lamiaceae	*Ocimum sanctum*	Leaf	Aqueous	Ag	18 nm & Spherical	(Ramteke et al., 2012)
	Ocimum canum	Leaf	Aqueous	Ag	15.72 nm & Spherical, Rod	(Tailor et al., 2020)
	Leucas aspera	Leaf	Aqueous	Ag	20–40 nm & Spherical	(Sivaramakrishnan et al., 2019)
	Leucas aspera, Hyptis suaveolens	Leaf	Aqueous	Ag	7–22 nm, 5–25 nm & Spherical, hexago-	(Elumalai et al., 2017)
	Leucas aspera	Leaf	Aqueous	Au	nal, triangular.	(Prabu et al., 2016)
	Ocimum sanctum	Leaf	Aqueous	Ag	17 nm & Spherical	(Sravanthi V et al., 2018)
	Origanum vulgare L.	Plant	Aqueous	Ag	24.3 nm & Spherical	(Shaik et al., 2018)
	Plectranthus amboinicus	Leaf	Aqueous	Ag, Au & Ag-Au	12 nm & Spherical	(Reddy et al., 2017)
	Ocimum sanctum	Leaf	Aqueous	Au	28.42 nm, 30.28 nm, 21.54 nm & Spheri-	(Gautam et al., 2017)
	Salvia spinosa	Plant	Aqueous	Ag	cal, anisotropic; Triangular, hexagonal,	(Pirtarighat et al., 2019)
	Tectona grandis	Seed	Aqueous	Ag	spherical; Spherical	(Rautela et al., 2019)
	Ocimum sanctum	Leaf	Methanol	Ag	16 nm & Spherical	(Rout et al., 2012)
					5.13 nm & Spherical, oval	
					10–30 nm & Spherical	
					0–50 nm & Spherical	
Phyllanthaceae	*Sauropus androgynous*	Leaf	Aqueous	Ag	16–55 nm & Spherical	(Abhimannue and Menon, 2021)
	Antidesma bunius L.	Fruit	Aqueous	Ag	-	(Fabregas et al., 2021)
	Arbutus andrachne	Leaf	Aqueous	Ag	107.8 ± 0.8 nm & Spherical	(Erdoğan et al., 2016)
	Cleistanthus collinus	Leaf	Ethanol	Ag	131 nm & Cubic	(VennilaRaj et al., 2013)
	Phyllanthus emblica	Fruit	Aqueous	Ag	39 nm & Spherical	(Masum et al., 2019)
	Phyllanthus emblica	Fruit	Ethanol	Au	5–60 nm & circular, triangular, polygonal	(Wang et al., 2021)
	Phyllanthus niruri	Leaf	Aqueous	Ag	10–50 nm & Cubical, rectangular, trian-	(Amalorpavamary et al., 2019)
	Phyllanthus acidus	Leaf	Aqueous	Ag	gular, Spherical	(Sowmya et al., 2018)
	Phyllanthus emblica	Fruit	Aqueous	Ag	65–250 nm & Spherical, polydisperse	(Renuka et al., 2020)
	Ruellia tuberose & *Phyllanthus acidus*	Leaf & Twig	Aqueous	Au	30 nm & Hexagonal	(Vasantharaj et al., 2018)
	Cleistanthus collinus	Leaf	Aqueous	Ag	88.37 nm, 94.31 nm, 82.23 nm, 81.36 nm	(Mohanta et al., 2018)
					& Spherical	
					Spherical	
Rutaceae	*Citrus aurantium*	Peel	-	Ag	141±3 nm & Irregular	
	Citrus limon	Peel	Aqueous	Ag	59.74 nm & Spherical	(Erdoğan et al., 2021)
	Citrus macroptera	Fruit	-	Au	20 nm & multi-shape, predominantly	(Alkhulaifi et al., 2020)
	Citrus maxima	Peel	Aqueous	Au	pseudo-spherical	(Majumdar et al., 2019)
	Citrus sinensis	Peel	Aqueous	Ag	8–25 nm & Spherical	(Yuan et al., 2016)
	Citrus tangerina, Citrus sinensis & Citrus limon	Peel	Aqueous	Ag	10 nm, 35 nm & Polydisperse, spherical	(Kaviya et al., 2011)
	Citrus limon	Peel	Aqueous	Ag	10–70 nm; 5–80 nm; 10–50 nm &	(Niluxsshun et al., 2021)
	Citrus maxima	Peel	Aqueous	Ag	Spherical, oval; triangular, rod, hexag-	(Nisha et al., 2014)
	Citrus clementina	Peel	Aqueous	Ag	onal	(Huo et al., 2018)
	Citrus limetta	Peel	Aqueous	Ag	17.3–61.2 nm & Spherical	(Saratale et al., 2018)
	Citrus limetta	Peel	Aqueous	Au	18.7 ± 9.5 nm & Spherical	(Dutta et al., 2020)
						(Sivakavinesan et al., 2022)
					15–20 nm & Spherical	
					18 nm & Spherical	
					64 nm & Irregular	

Table 3
Therapeutic applications of AgNPs and AuNPs synthesized from *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiaceae* plant families.

Family	Plant Species	NPs	Biomedical Application	Reference
Euphorbiaceae	*Acalypha indica*	Ag	Antifungal	(Ghosh et al., 2018)
	Acalypha indica Linn.	Ag & Au	Cytotoxic effect	(Krishnaraj et al., 2014)
	Ricinus communis	Ag	Antimicrobial & Cytotoxic	(Gul et al., 2021)
	Croton tiglium L.	Ag	Antioxidant	(Aboulthana et al., 2019)
	Ricinus communis	Au	Cytotoxic, Antimicrobial, Hemolytic & Stimulatory effect	(Ghramh et al., 2019)
	Jatropha curcas	Ag		(Nayak et al., 2019)
	Jatropha	Au	Antibacterial	(Kanchi et al., 2018)
	Jatropha curcas	Ag	-	(Chauhan et al., 2016)
	Phyllanthus amarus	Ag	Antibacterial	(Joseph et al., 2021)
	Ricinus communis var. *carmencita*	Ag	Antibacterial	(Ojha et al., 2017)
			Antibacterial	
Lamiaceae	*Ocimum sanctum*	Ag	Antibacterial	(Ramteke et al., 2013)
	Ocimum canum	Ag	Antibacterial	(Tailor et al., 2020)
	Leucas aspera	Ag	Antimicrobial	(Sivaramakrishnan et al., 2019)
	Leucas aspera, Hyptis suaveolens	Ag	Larvicidal	(Elumalai et al., 2017)
	Leucas aspera	Au	Antibacterial & Anticancer	(Prabu et al., 2016)
	Ocimum sanctum	Ag	Anticancer	(Sravanthi V et al., 2018)
	Origanum vulgare L.	Ag	Antimicrobial	(Shaik et al., 2018)
	Plectranthus amboinicus	Ag, Au & Ag-Au	Antibacterial	(Reddy et al., 2017)
	Ocimum sanctum	Au	Anti-Tumor	(Gautam et al., 2017)
	Salvia spinosa	Ag	Antibacterial	(Pirtarighat et al., 2019)
	Tectona grandis	Ag	Antimicrobial	(Rautela et al., 2019)
	Ocimum sanctum	Ag	Antibacterial & Antifungal	(Rout et al., 2012)
Phyllanthaceae	*Sauropus androgynous*	Ag	Antibacterial & Anti-helminthic	(Abhimannue and Menon, 2021)
	Antidesma bunius L.	Ag	Antimicrobial	(Fabregas et al., 2021)
	Arbutus andrachne	Ag	Antimicrobial	(Erdoğan et al., 2016)
	Cleistanthus collinus	Ag	Antimicrobial & Antioxidant	(VennilaRaj et al., 2013)
	Phyllanthus emblica	Ag	Antimicrobial	(Masum et al., 2019)
	Phyllanthus emblica	Au	Anticancer	(Wang et al., 2021)
	Phyllanthus niruri	Ag	Antibacterial	(Amalorpavamary et al., 2019)
	Phyllanthus acidus	Ag	Antibacterial	(Sowmya et al., 2018)
	Phyllanthus emblica	Ag	Antimicrobial	(Renuka et al., 2020)
	Ruellia tuberose & Phyllanthus acidus	Au	Bionanocatalyst	(Vasantharaj et al., 2018)
	Cleistanthus collinus	Ag	Antibacterial & Anticancer	(Mohanta et al., 2018)
	Citrus aurantium	Ag	Glioblastoma	(Erdoğan et al., 2021)
Rutaceae	*Citrus limon*	Ag	Antibacterial & cytotoxic	(Alkhulaifi et al., 2020)
	Citrus macroptera	Au	Anticancer & Anti-biofilm	(Majumdar et al., 2019)
	Citrus maxima	Au	Antibacterial	(Yuan et al., 2016)
	Citrus sinensis	Ag	Antibacterial	(Kaviya et al., 2011)
	Citrus tangerina, Citrus sinensis & Citrus limon	Ag	Antibacterial	(Niluxsshun et al., 2021)
	Citrus limon	Ag	Antidermatophytic	(Nisha et al., 2014)
	Citrus maxima	Ag	Antioxidant & Antimicrobial	(Huo et al., 2018)
	Citrus clementina	Ag	Antioxidant, Antimicrobial & Anticancer	(Saratale et al., 2018)
	Citrus limetta	Ag	Antibacterial & Antifungal	(Dutta et al., 2020)
	Citrus limetta	Au	Antioxidant	(Sivakavinesan et al., 2022)

Citrus maxima, Citrus macroptera and Citrus aurantium. Citrus plants have a great utilization to form medicine for thousands of years in a number of ancient cultures. Green synthesized nanoparticles using citrus have a wide range of potential pharmaceutical applications due to their antimicrobial properties. They exhibit strong bactericidal and fungicidal activity against various microorganisms. One potential application is in wound dressings, where they can prevent infection and promote healing by killing the microorganisms responsible for the infection (Xu et al., 2020). They have also been used in medical devices such as catheters to prevent bacterial colonization, which can lead to infections. This is particularly important as bacterial infections caused by catheterization are a significant healthcare problem, as it can lead to serious complications (Samrot et al., 2018). 1 mM silver nitrate was reduced by mixing 3 ml of aqueous peel extract of *C. sinensis*. The synthesized AgNPs were evaluated antibacterial properties against both gram-negative bacteria like *E. coli* and gram-positive bacteria like *S. aureus* (Nahar et al., 2021).

The characterization of synthesized nanoparticles are essential to evaluate shape, size, crystallinity, surface charge, surface coating, and biological activities. The synthesized particles are analyzed by using a variety of analytical techniques, such as UV-visible spectroscopy, Fourier transform infra-red spectroscopy (FTIR), transmission electron microscopy (TEM), scanning electron microscopy (SEM), selected area electron diffraction (SAED), energy-dispersive X-ray spectroscopy (EDX) and X-ray diffraction (XRD) analysis. **UV–visible spectrophotometry** is a simple technique for quickly identifying and characterizing nanoparticles. Due to the interaction between light and the moving surface electrons of nanoparticles, it produces a potent absorbance band known as surface plasmon resonance (SPR) in the visible range of 400–600 nm (Usmani et al., 2019). The formation of nanoparticles can be confirmed preliminarily with the help of UV–visible spectroscopy. Many researchers have reported the formation of AgNPs gives sharp and strong absorption band around 420–450 nm. A proportionate association between the size and SPR peaks has been identified by examining the development of brown colloids that were formed using various amounts of plant extract. Selvakumar et al., reported the *A. hispid* a mediated synthesized AgNPs gives SPR peak at 425 nm (Selvakumar et al., 2018). AgNPs synthesized by using *A. acidum* leaf extract is verified its formation with absorbance peak at 430 nm. The color of the solution was shown to vary from a clear solution to a bright yellow, yellow to a yellowish brown, a yellowish brown to a reddish brown, and lastly to a colloidal brown (Basumatary et al., 2023). The **FTIR spectroscopy** is characterized to identify the reducing, stabilizing agents and possible biomolecules connected to the metal and surface atoms of the capping agents of the nanoparticles. The involvement of polyphenols during the synthesis of nanoparticles can be confirmed with the help of FTIR spectra. The presence of peaks indicates the participation of functional groups like aldehydes, carboxylic acid, ketones (Niraimathi et al., 2013). Greenly synthesized silver nanoparticles from L. aspera leaf extract reveals the shift of major peaks in FTIR spectra. L. *aspera* extract shows peak between 3420 and 3371 (assigned to N—H stretching, amides), 1635 and 1650 (related to C=O stretching, amides), and 1000 and 1320 cm^{-1} (typical of a C—O stretch, carboxylic acids). Synthesized AgNPs exhibited peaks at 1826, 1521, and 1247 cm^{-1}, respectively, corresponding to C=O stretching, N—O stretching of aromatic nitro compounds and C—N stretching aromatic amine. These peaks indicate the presence of functional groups on surface of AgNPs (Sivaramakrishnan et al., 2019). The FTIR spectra of *O. sanctum* leaf extract loaded synthesized AuNPs showed bands at 1630, 1526, 1670 and 1239 cm^{-1} were assigned to C=O stretching vibrations, stretching vibrations of N—O compounds, -C=C stretching vibrations, C—N stretching vibrations of aliphatic amine groups respectively (Gautam et al., 2017). **Scanning electron microscopy (SEM)** is a technique to analyze the generated surface topography and size of plant mediated synthesized silver and gold nanoparticles. Utilizing electron microscopy for structural characterization of AgNPs and AuNPs reveals qualitative and quantitative data regarding the size, shape, size distribution, and dry diameter distribution (Noah et al., 2019). SEM image of *Jatropha curcas* plant mediated AgNPs showed spherical shape of AgNPs with size around nm around 80–95 nm and revealed monodispersed aggregated form (Nayak et al., 2019). L. *aspera* leaf extract mediated AuNPs revealed spherical shape of particles around 100 nm (Prabu et al., 2016). **Transmission electron microscopy (TEM)** is a microscopy technique where high resolution image is formed through transmission of electron beam. It provides the nanoparticles structure and chemical behavior with the help of image. SAED is an additional helpful imaging technique for analyzing the crystalline structure of nanoparticles. The crystalline nature of the particles as well as their size, shape, and distribution could be determined by SAED (Rahuman et al., 2022). The magnified TEM image of L. *aspera* leaf extract mediated synthesized AgNPs clearly shows the spherical shape of nanoparticles in 20–40 nm size (Sivaramakrishnan et al., 2019). *A. indica Linn* based prepared AuNPs revealed spherical shape with size less than 30 nm (Krishnaraj et al., 2014). The SAED image of AgNPs synthesized from *A. acidum* leaf extract shows crystalline nature as FCC lattice (Basumatary et al., 2023). The elemental purity of biosynthesized nanoparticles can be confirmed with the help of EDS analysis, where **energy-dispersive X-ray spectroscopy** gives information about contamination of samples. The energy dispersive X-ray (EDX) spectrum of *C. aurantium* extract based prepared AgNPs resulted the presence of carbon and oxygen with 25.17 % major peak for Ag (Erdoğan et al., 2021). **X-ray diffraction (XRD)** is a technique to evaluate crystallographic structure of metallic nanoparticles. When atoms interact with the crystal's surface XRD and are exposed to x-rays, it provides data showing diffraction patterns. XRD analysis of *C. macroptera* fruit extract mediated AuNPs confirmed the crystalline nature with FCC lattice. The graph reveals four peaks at 38.160, 43.620, 64.160 and 77.250 assigned to the (111), (200), (220), and (311) planes corresponding to standard Bragg reflections. These four planes and diffraction peaks are well agreed with SAED pattern (Majumdar et al., 2019). Once the synthesized nanoparticles have been successfully characterized, confirming their size and morphology, they can be evaluated for different applications, such as industrial activities, medicinal purposes, and environmental remediation.

2.3. Applications in therapeutics

This study explores the therapeutic potential of silver and gold nanoparticles synthesized through green methods using four plant families. Following a comprehensive characterization process, the synthesized nanoparticles undergo evaluation for various biological activities like antibacterial, antidiabetic, anticancer, antioxidant, and cytotoxicity activities. Numerous studies have been conducted on plant-mediated AgNPs and AuNPs; have provided promising leads for the development of innovative antibacterial applications. The small size of these nanoparticles provides them with the ability to penetrate bacterial cell membranes, leading to enhanced membrane permeability. This increased permeability can ultimately results in the destruction of bacteria and fungi (Ahmed and Mustafa, 2019). It is well-accepted that, AgNPs have a destructive effect on bacterial cell walls by disrupting the cell respiration chain and cell nucleic acid (DNA or RNA) due to larger surface-to-volume ratio than their bulk equivalent (Klasen et al., 2000; Rai et al., 2009). Silver nanoparticles (AgNPs) have been extensively investigated for their antibacterial activities against human pathogens through disc diffusion method, namely *Pseudomonas aeruginosa, Escherichia coli, Haemophilus influenza, Staphylococcus aurous, Klebsiella pneumoniae* etc. (Rasheed et al., 2017). Gold nanoparticles (AuNPs) also exhibit antibacterial activity, although they are often less potent compared to silver nanoparticles. *S. androgynous and C. collinus* mediated AgNPs were showed antibacterial activities against *Staphylococcus aureus, E. coli, Enterobacter cloaca* and *Pseudomonas sp* (Abhimannue and Menon, 2021; VennilaRaj et al., 2013). *O. sanctum* leaf extract induced AgNPs was investigated antibacterial activity against *E. coli* and *S. aureus* (Ramteke et al., 2013). AgNPs synthesized from *P. amboinicus* leaf extract was showed strong activity against the gram-positive pathogens *E. coli* and *Pseudomonas* spp. as well as the gram-negative pathogens *Bacillus* spp. and *Staphylococcus* spp. (Reddy et al., 2017). Table 3 shows some therapeutic applications of plant mediated AgNP and AuNPs.

AuNPs synthesized from herbal plant L. *aspera* extract was showed remarkable results in antibacterial activities against *S. epidermidis* (63 %) and *E. coli* (37 %) bacterial strains (Prabu et al., 2016). *C. sinensis* mediated AgNPs were shown to possess strong antibacterial properties against both gram-negative bacteria like *E. coli* and gram-positive bacteria like *S. aureus* (Nahar et al., 2021). AgNPs produced using the extract of *C. limon zest* have been proven to be efficient in preventing the growth of certain types of bacteria such as *E. coli*, a gram-negative pathogen, and *S. aureus*, a gram-positive bacterium (Kalimuthu et al., 2020).

The biosynthesized nanoparticles from the indigenous plants are commonly utilized in medical procedures and are essential in the treatment of many different types of human diseases (Santhosh et al., 2022). There are certain medicinal herbs that have potent anti-diabetic properties such as *A. Bunius, O. basilicum, O. sanctum, Thymus serpyllum etc.* (Wahab et al., 2022; Malapermal et al., 2017). Diabetes is a long term a chronic metabolic disease characterized by high blood glucose levels in human body that affects over 100 million people worldwide. It occurs when the body cannot generate enough insulin or can't utilize it properly. Insulin is mostly responsible for allowing glucose to enter cells and function as an energy source. As a result, diabetes develops when the body's cells are unable to use the created insulin or the pancreas is unable to produce enough insulin to control blood sugar levels (Ojo et al., 2021). Antidiabetic activity can be tested through inhibiting carbohydrate-digesting enzymes; such as α-amylase inhibitory test and α-Glucosidase inhibitory test (Rahuman et al., 2022). AgNPs derived from *T. serpyllum* have showed improvement in glucose tolerance and insulin release as well as α-amylase inhibition activity. AgNPs are more effective at lowering hyper-glycaemia and improving IRS1 (reduced insulin receptor substrate-1) and AMPK (adenosine monophosphate protein kinase) genes expression for the treatment of diabetes, which helps in receiving glucose and insulin resistance (Wahab et al., 2022]. *O. basilicum* and *O. sanctum* plant based synthesized AgNPs has revealed greater inhibitory action against α-amylase than acarbose. The AgNps synthesized from *O. sanctum* (89.31 ± 5.319 %) and *O. basilicum* (79.74 ± 9.51 %) inhibited *B. stearothermophilus* aglucosidase, demonstrating that their activity was significantly higher than that of acarbose. Excellent enzymatic activity inhibition and more favourable treatment for preventing diabetic-related problems have been demonstrated by AgNPs (Malapermal et al., 2017).

Cancer is a serious and life threatening disease that afflict millions of people all over the world (Jabeen et al., 2021). It is characterized by the body's aberrant cells growing and spreading out of control (Hollstein et al., 2016). There are many modern anticancer therapies available, including chemotherapy, anticancer medications, and various radiations. Chemotherapy and radiation treatments have a number of negative side effects that cause human beings to become weak and to suffer socially and economically (Rahuman et al., 2022). The development of innovative therapeutics that are both affordable and biocompatible is therefore desperately required (Krishnaraj et al., 2014). Numerous medicinal plants with active ingredients that have antitumor, anticancer, and anti-inflammatory properties are being researched as potential medicines globally. Several plants are used in traditional folk medicine for their potential health advantages. The bioactive substances found in plants are 1000 times more potent and superior to chemotherapy. Thus, plant based synthesized nanoparticles. Consequently, plant-based synthetic silver and gold nanoparticles are emerging to efficiently fight cancer (Jain et al. 2021). The use of indigenous plants has created new opportunities and possibilities for the treatment of cancer. Due to containing valued secondary metabolites in plants, they serve as a source of novel compounds found through phytochemical screening and aid in the development of innovative cancer treatment approaches like the green fabrication of AgNPs and AuNPs (Klefenz, 2004). *P. emblica* leaf extract derived AgNPs revealed anticancer activity against Hepatocellular carcinoma (HCC) (Singh et al., 2019). Hela and HepG2 cell lines were significantly (p 0.05) inhibited by *R. communis* leaf extract-mediated AuNPs (Ghramh et al., 2019). AgNPs and AuNPs produced by A. indica leaf extract have shown excellent cytotoxic activity against MDA-MB-231 and breast cancer cells; the toxic effects on MDA-MB-231 cells from gold nanoparticle treatment were marginally higher than from silver nanoparticle treatment (Krishnaraj et al., 2014). Biosynthesized AuNPs from *Phyllanthus emblica L.* extract exhibited anticancer efficacy against gastric cancer (GC), demonstrating an enhanced cytotoxicity against AGS cells (Wang et al., 2021). Bio-reduced AgNPs by *O. sanctum* leaf extract was investigated in-vitro cytotoxicity activity utilizing MTT colorimetric method against non-cancerous (HEK-293) and cancerous cell lines (MCF-7 and MDA-MB-231 cells). AgNPs shown substantial cytotoxicity action; their IC50 values against MCF-7 and MDA-MB-231 are 32.86 g/ml and 26.23 g/ml, respectively (Stella Sravanthi et al., 2018). The anticancer activity of *C. macroptera* based AuNPs showed significant result against three human cancer cell lines such as MDA-MB 468, A549 and HepG2 (Majumdar et al., 2019). The results indicate that medicinal plant induced synthesized silver and gold nanoparticles can be exploited as brand-new anticancer drugs for the treatment of cancer.

Antioxidants are the constituents that play a crucial role in defending cells against the harmful effects of free radicals. Free radicals are unstable chemicals that can harm cells and produce oxidative stress in biological systems. Cells release reactive oxygen species (ROS) during immunological function, which are extremely reactive and capable of destroying cellular compounds (Bhuiyan et al., 2009). Which can lead to a number of health problems, including heart diseases, chronic illnesses, including cancer and ageing. The antioxidant capabilities of bio-mediated nanoparticle synthesis are the result of the capped functional groups in the extracts of medicinal plants (Chang et al., 2012; Ahmed and Mustafa, 2019). Antioxidant activity can be evaluated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, ABTS radical scavenging assay, ferric reducing antioxidant power (FRAP) assay and H_2O_2 scavenging assay. Numerous research work has examined the antioxidant properties of AgNPs derived from several medicinal plants, such as *A. indica (*Menon et al., 2017*), Croton tiglium* L. (Aboulthana et al., 2019), *Thymus serpyllum* (Wahab et al., 2022), *S. androgynous* (Abhimannue and Menon, 2021) and *R. communis* (Ojha et al., 2017). The IC_{50} value for bio-induced Ag nanoparticles is 5 mg/ml, indicating stronger antioxidant properties (Menon et al., 2017). Nanoparticles derived from medicinal plants have demonstrated strong antioxidant activity as well as numerous other biological features, including antibacterial, anti-inflammatory, antifungal, antiviral, and anti-aging effects. It should be well agreed that, these biological activities are due to the capping of phytochemicals during the synthesis of nanoparticles. Carbohydrates, alkaloids, phenolic chemicals, flavonoids, glycosides, saponins, and tannins are the primary and secondary metabolites of plant extracts that are responsible for the reduction of metals to nanoparticles and biological activity (Rahuman et al., 2022).

Cytotoxicity of AgNPs and AuNPs depends on the plant bio-components used in their synthesis as well as their morphological characteristics, such as size and shape. Some chemicals have the ability to directly harm cell membranes, causing cytotoxicity and the destruction of cells or the release of their contents. Others could obstruct vital biological functions including protein synthesis, DNA synthesis, or mitochondrial function, which would cause cell malfunction and ultimately cell death (Panda et al., 2011). Researchers usually use cytotoxicity assays to investigate substance's potential toxicity. Bharathi, V. et al., reported on 2017, that *M. piperita* induced silver nanoparticles was investigated for one of the most significant neurological enzymes (acetylcholinesterase). The activity was assessed through the execution of enzyme kinetic tests, which showed that plant mediated synthesized AgNPs has ability of binding to both the free AChE enzyme and to the enzyme−substrate (AChE-AChI) complex and can cause neurotoxicity via inhibiting AChE activity (Bharathi et al., 2017). Cytotoxicity of *R. communis* root and leaf extract mediated AgNPs has evaluated through hemolytic assay. The result revealed good biocompatibility up to 12 μg/mL (R-Ag NPs: 5.3 %, L-Ag NPs: 5.01 %) but beyond this limit, the percent hemolysis exceeded the permissible limit as 5 % hemolysis is permitted for biomaterials, according to ASTM-E252408 (Gul et al., 2021). Silver nanoparticles formed with the peel extract of *C. limon* have been found to have the ability to promote cytotoxicity against human colon carcinoma cell lines (HCT-116) and human breast cancer cell lines (MCF-7) (Alkhulaifi et al., 2020). As a result, *C. tiglium* plant mediated AgNPs showed increased cytotoxicity against the development of human colon cancer cells in comparison to crude extracts (Aboulthana et al., 2019).

3. Conclusion

The present review assembles the synthesis of AgNPs and AuNPs from plants of four plant families *Phyllanthaceae, Lamiaceae, Rutaceae* and *Euphorbiacea* for first time as per our knowledge. The various therapeutic applications of NPs such as antibacterial agent, antidiabetic, anticancer, biosensors in medicine and in drug delivery system are also summarized herein. The bio-mediated synthesis process is one of the most convenient, affordable and green approach for the creation of nanoparticles. Therefore, the present review will provide an elaborate information of the family plants and their various utility in the field of nanotechnology. NPs therapeutic properties vary depending on their size, shape, and synthesis materials. Both AuNPs and AgNPs have remarkable antibacterial properties against gram-positive and gram-negative microorganisms, as well as cytotoxic, anticancer, and anti-diabetic properties. Plant-based NPs have excellent biological activity due to presence of phyto-constituents like alkaloids, phenolic compounds, flavonoids, terpenoids, tannin, glycosides and functional groups (ketones, aldehydes, and carboxylic acid). The research on new compounds of the plants, could replace current chemotherapeutic and many other therapeutic applications using green synthesized AuNPs and AgNPs may be a good aspect of research in near future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abhimannue, A.P., Menon, A., 2021. Green synthesis of silver nanoparticles using *Sauropus androgynous* leaf extract with potential biological properties. *Int. J. Res. Pharm. Sci*. Res 12 (8), 4267–4274. https://doi.org/10.13040/IJPSR.0975-8232.12(8).4267-74.

Aboulthana, W.M., Youssef, A.M., El-Feky, A.M., Ibrahim, N.E., Seif, M.M., Hassan, A.K., 2019. Evaluation of antioxidant efficiency of *Croton tiglium L.* seeds extracts after incorporating silver nanoparticles. Egypt. J. Chem. 62, 181–200. https://doi.org/10.21608/ejchem.2018.4960.1442.

Ahmad, A., Mukherjee, P., Senapati, S., Mandal, D., Khan, M.I., Kumar, R., Sastry, M., 2003. Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Colloids Surf. B: Biointerfaces 28, 313–318. https://doi.org/10.1016/S0927-7765(02)00174-1.

Ahmed, R.H., Mustafa, D.E., 2019. Green synthesis of silver nanoparticles mediated by traditionally used medicinal plants in Sudan. Int. Nano Lett. 10, 1–14. https://doi.org/10.1007/s40089-019-00291-9.

Alkhulaifi, M.M., Alshehri, J.H., Alwehaibi, M.A., Awad, M.A., Al-Enazi, N.M., Aldosari, N.S., Hatamleh, A.A., Abdel- Raouf, N., 2020. Green synthesis of silver nanoparticles using Citrus limon peels and evaluation of their antibacterial and cytotoxic properties. Saudi J. Biol. Sci. 27 (12), 3434–3441. https://doi.org/10.1016/j.sjbs.2020.09.031.

AlSalhi, M.S., Devanesan, S., Alfuraydi, A.A., Vishnubalaji, R., Munusamy, M.A., Murugan, K., Nicoletti, M., Benelli, G., 2016. Green synthesis of silver nanoparticles using *Pimpinella anisum* seeds: antimicrobial activity and cytotoxicity on human neonatal skin stromal cells and colon cancer cells. Int. J. Nanomed. 11, 4439–4449.

Antidesma acidum Retz., plants of the World Online. Royal Botanic Gardens, Kew, 2021. https://powo.science.kew.org.

Basumatary, S., Kumar, K.J., Daimari, J., Mondal, A., Kalita, S., Dey, K.S., Deka, A.K., 10.1016/j.enmm.2022.100769, 2023. Biosynthesis of silver nanoparticles using *Antidesma acidum* leaf extract: its application in textile organic dye degradation. Environ. Nanotechnol. Monit. Manag. 19, 100769, 1-11.

Bharathi, V., Jannathul, F., Noorzaid, M., Resni, M., 2017. Green synthesis of *Mangifera indica* silver nanoparticles and its analysis using Fourier transform infrared and scanning electron microscopy. Natl. J. Physiol. Pharm. Pharmacol. https://doi.org/10.5455/njppp.2017.7.0725428082017.

Bhuiyan, M.A.R., Hoque, M.Z., Hossain, S.J., 2009. Free radical scavenging activities of *Zizyphus mauritiana*. World J. Agric. Sci. 5 (3), 318–322.

Bose, D., Chatterjee, S., 2016. Biogenic synthesis of silver nanoparticles using guava (*Psidium guajava*) leaf extract and its antibacterial activity against *Pseudomonas aeruginosa*. Appl. Nanosci. 6 (6), 895–901. https://doi.org/10.1007/s13204-015-0496-5.

Chang, C.L., Lin, C.S., Lai, G.H., 2012. Phytochemical characteristics, free radical scavenging activities, and neuroprotection of five medicinal plant extracts. Evid. Complem. Altern. Med. 2012, 984295, 1-8 https://doi.org/10.1155/2012/984295.

Chauhan, N., Tyagi, A.K., Kumar, P., Malik, A., 2016. Antibacterial potential of *Jatropha curcas* synthesized silver nanoparticles against food borne pathogens. Front. Microbiol. 7, 1748. https://doi.org/10.3389/fmicb.2016.01748.

Chuakul, W., Saralamp, P., 2000. Medicinal plants used in Phu Khieo wildlife sanctuary area, Chaiyaphum province (Thailand). Jpn. Soc. Plant Syst. 51 (1), 67–98.

Drummer, S., Madzimbamuto, T., Chowdhury, M., 2021. Green synthesis of transition-metal nanoparticles and their oxides: a review. Materials 14, 2700.

Dutta, T., Ghosh, N.N., Das, M., Adhikar, R., Mandal, V., Chattopadhyay, A.P., 2020. Green synthesis of antibacterial and antifungal silver nanoparticles using *Citrus limetta* peel extract: experimental and theoretical studies. J. Environ. Chem. Eng. 8, 104019 .

Elumalaia, D., Hemavathic, M., Deepaad, C.V., Kaleena, P.K., 2017. Evaluation of phytosynthesised silver nanoparticles from leaf extracts of *Leucas aspera* and *Hyptis suaveolens* and their larvicidal activity against malaria, dengue and filariasis vectors. Parasite Epidemiol. Control 2, 15–26.

Erdoğan, Ö., Abbak, M., Demirbolat, G.M., Aksel, M., Paşa, S., Dönmez yalçin, G., Çevik, Ö., 2021. Treatment of glioblastoma by photodynamic therapy with the aid of synthesized silver nanoparticles by green chemistry from *Citrus aurantium*. J. Res. Pharmacy 25 (5), 641–652. https://doi.org/10.29228/jrp.56.

Erdoğan, T., Yılmaz, F.F., Kıvçak, B., Özyazıcı, M., 2016. Green synthesis of silver nanoparticles using *Arbutus andrachne* leaf extract and its antimicrobial activity. Trop. J. Pharm. Res. 15 (6), 1129–1136.

Fabregas, A.J.E., Bercilla, D.J.P.S., Guzman, J.C.D., Diaz, C.D.C., Dinglasan, R.E., Sandoval, S.S., Dumaoal, O.S.R., Fajarillo, D.K.F., 2021. Antimicrobial property of bio-reduced silver nanoparticle prepared using aqueous fruit extract of *Antidesma bunius L.* Spreng against Methicillin resistant and susceptible *Staphylococcus aureus*. Asia Pacific J. Allied Health Sci. 4, 8–17.

Gandhi, G.R., Vasconcelos, A.B.S., Wu, D.T., Li, H.B., Antony, P.J., Li, H., Geng, F., Gurgel, R.Q., Narain, N., Gan, R.Y., 2020. Citrus flavonoids as promising phytochemicals targeting diabetes and related complications: a systematic review of in vitro and in vivo studies. Nutrients 12 (10), 1–32. https://doi.org/10.3390/nu12102907.

Gautam, P.K., Kumar, S., Tomar, M.S., Singh, R.K., Acharya, A., Shyanti, Ritis, Anita, K., Swaroop, S., Kumar, S., Ram, B., 2017. Biologically synthesized gold nanoparticles using *Ocimum sanctum* (Tulsi Leaf Extract) induced anti-tumor response in a T cell daltons Lymphoma. J. Cell Sci. Ther. 8, 1–9. https://doi.org/10.4172/2157-7013.1000278.

Ghosh, R., Dutta, S., Bhattacharyya, S., 2018. Green synthesis of silver nanoparticle by *acalypha indica* and its antifungal effect against *Phytopathogen Colletotrichum capsica*. Acta Sci. Agric. 2, 27–38.

Ghramh, H.A., Khan, K.A., Ibrahim, E.H., Setzer, W.N., 2019. Synthesis of gold nanoparticles (AuNPs) using *Ricinus communis* leaf ethanol extract, their characterization, and biological applications. Nanomaterials 9, 765. https://doi.org/10.3390/nano9050765.

Gillespie L.J., Armbruster, K.S., 1997. A Contribution to the Guianan Flora: *dalechampia, Haematostemon Omphalea, Pera, Plukenetia*, and *Tragia* (Euphorbiaceae) with Notes on Subfamily Acalyphoideae.

Gul, A., Fozia, Shaheen, A., Ahmad, I., Khattak, B., Ahmad, M., Ullah, R., Bari, A., Ali, S.S., Alobaid, A., Majid, M., Asmari, M.M., Mahmood, H.M., 2021. Green synthesis, characterization, enzyme inhibition, antimicrobial potential, and cytotoxic activity of plant mediated silver nanoparticle using *Ricinus communis* leaf and root extracts. Biomolecules 11 (206). https://doi.org/10.3390/biom11020206.

Gurumallesh Prabu, H.G., Ganesan, R.M., Poorani, G., 2016. Synthesis of gold nanoparticles using *Leucas aspera* extract for multifunctional applications. Int. J. Adv. Sci. Eng. Technol. 16–19.

Hembram, K.C., Kumar, R., Kandha, L., Parhi, P.K., Kundu, C.N., Bindhani, B.K., 2018. Therapeutic prospective of plant-induced silver nanoparticles: application as antimicrobial and anticancer agent. Artif. Cells, Nanomed. Biotechnol. 46, 1–14. https://doi.org/10.1080/21691401.2018.1489262.

Hoffman, P., 2023. “Phyllanthaceae” Flowering plant Families of the World. Firefly BooksISBN, Ontario, Canada. 978-1-55407-206-4.

Hollstein, M., Alexandrov, L., Wild, C., Ardin, M., Zavadil, J., 2016. Base changes in tumour DNA have the power to reveal the causes and evolution of cancer. Oncogene 36, 158–167.

Huang, Q., Luo, A., Jiang, L., Zhou, Y., Yang, Y., Liu, Q., Zhang, C., 2019. Disinfection efficacy of green synthesized gold nanoparticles for medical disinfection applications. Afr. Health Sci. 19 (1), 1441–1458. https://doi.org/10.4314/ahs.v19i1.

Huo, C., Khoshnamvand, M., Liu, P., Yuan, C.-G., Cao, W., 2018. Eco-friendly approach for biosynthesis of silver nanoparticles using *Citrus maxima* peel extract and their characterization, catalytic, antioxidant and antimicrobial characteristics. Mater. Res. Express Accept 27, 0−31.

Iravani, S., Korbekandi, H., Mirmohammadi, S.V., Zolfaghari, B., 2014. Synthesis of silver nanoparticles: chemical, physical and biological methods. Res. Pharm. Sci. 9 (6), 385–406.

Jabeen, S., Qureshi, R., Munazir, M., Maqsood, M., Munir, M., Shah, S.S.H., Rahim, B.Z., 2021. Application of green synthesized silver nanoparticles in cancer treatment—a critical review. Mater. Res. Express. 8, 1–18. https://doi.org/10.1088/2053-1591/ac1de3.

Jain, N., Jain, P., Devyani Rajput, D., Patil, U.K., 2021. Green synthesized plant-based silver nanoparticles: therapeutic prospective for anticancer and antiviral activity. Micro Nano Syst. Lett. 9, 1–24. https://doi.org/10.1186/s40486-021-00131-6.

Jain, S., Mehata, M.S., 2017. Medicinal plant leaf extract and pure flavonoid mediated green synthesis of silver nanoparticles and their enhanced antibacterial property. Sci. Rep. 15867, 1–13. https://doi.org/10.1038/s41598-017-15724-8.

Jia, Y.P., Shi, K., Liao, J.F., Peng, J.R., Hao, Y., Qu, Y., Chen, L.J., Liu, L., Yuan, X., Qian, Z.Y., Wei, X.W., 2020. Effects of cetyltrimethylammonium bromide on the toxicity of gold nanorods both in vitro and in vivo: molecular origin of cytotoxicity and inflammation. Small Methods 1–11. https://doi.org/10.1002/smtd.201900799.

Joseph, J., Deborah, K., Raghavi, R., Shamya, M., Aruni, W., 2021. Green synthesis of silver nanoparticles using *Phyllanthus amarus* seeds and their antibacterial activity assessment. Biomed. Biotechnol. Res. J. 5, 35–38.

Kalimuthu, K., Cha, B.S., Kim, S., Park, K.S., 2020. Eco-friendly synthesis and biomedical applications of gold nanoparticles: a review. Microchem. J. 104296. https://doi.org/10.1016/j.microc.2019.104296.

Kanchi, S., Kumar, G., Lo, A.-Y., Tseng, C.-M., Chen, S.-K., Lin, C.-Y., Chin, T.-S., 2014. Exploitation of de-oiled jatropha waste for gold nanoparticles synthesis: a green approach. Arab. J. Chem. 11, 247–255. https://doi.org/10.1016/j.arabjc.2014.08.006 .

Karmous, I., Pandey, A., Haj, K.B., Chaoui, A., 2020. Efciency of the green synthesized nanoparticles as new tools in cancer therapy: insights on plant-based bioengineered nanoparticles, biophysical properties, and anticancer roles. Biol. Trace Elem. Res. 196, 330–342.

Kathriarachchi, H., Hoffmann, P., Samuel, R., Wurdack, K.J., Chase, M.W., 2005. Molecular phylogenetics of Phyllanthaceae inferred from Wve genes (plastid atpB, matK, 3'ndhF, rbcL, and nuclear PHYC). Mol. Phylogenet. Evol. 36, 112–134.

Kaviyaa, S., Santhanalakshmi, J., Viswanathan, B., Muthumary, J., Srinivasan, K., 2011. Biosynthesis of silver nanoparticles using *Citrus sinensis* peel extract and its antibacterial activity. Spectrochim. Acta Part A: Mol. Biomol. Spectrosc. 79, 594–598.

Klasen, H., 2000. A historical review of the use of silver in the treatment of burns. II. Renewed interest for silver. Burns 26 (2), 131–138. https://doi.org/10.1016/S0305-4179(99)00116-3.

Klefenz, H., 2004. Nanobiotechnology: from molecules to systems. Eng. Life Sci. 4 (3), 211–218. https://doi.org/10.1002/elsc.200402090.

Krishnaraj, C., Muthukumaran, P., Ramachandran, R., Balakumaran, M.D., Kalaichelvan, P.T., 2014. *Acalypha indica Linn*: biogenic synthesis of silver and gold

nanoparticles and their cytotoxic effects against MDA-MB-231, human breast cancer cells. Biotechnol. Rep. 4, 42–49. https://doi.org/10.1016/j.btre.2014.08.002.
Labula, A.H., David, O.A., Terna, A.D., 2022. Green synthesis and characterisation of silver nanoparticles using *Morinda lucida* leaf extract and evaluation of its anti-oxidant and anti-microbial activities. Chem. Pap. 76, 7313–7325. https://doi.org/10.1007/s11696-022-02392-0.
Lateef, A., Folarin, B.I., Oladejo, S.M., Akinola, P.O., Beukes, L.S., Gueguim-Kana, E.B., 2018. Characterization, antimicrobial, antioxidant, and anticoagulant activities of silver nanoparticles synthesized from *Petiveria alliacea L.* leaf extract. Prep. Biochem. Biotechnol. 48, 1–7. https://doi.org/10.1080/10826068.2018.1479864.
Lee, K.X., Shameli, K., Miyake, M., Kuwano, N., Ahmad Khairudin, N.B.B., Mohamad, S.E.B., Yew, Y.P., 2016. Green synthesis of gold nanoparticles using aqueous extract of *Garcinia mangostana* fruit peels. J. Nanomater. 2016, 8489094,1-7. https://doi.org/10.1155/2016/8489094.
Lv, X., Zhao, S., Ning, Z., Zeng, H., Shu, Y., Tao, O., Xiao, C., Lu, C., Liu, Y., 2015. Citrus fruits as a treasure trove of active natural metabolites that potentially provide benefits for human health. Chem. Cent. J. 9 (68). https://doi.org/10.1186/s13065-015-0145-9.
Mahomoodally, M.F., Kissoon, B.N., Pudaruth, S., 2020. *Phyllanthus phillyreifolius*. Underexplored Medicinal Plants from Sub-Saharan Africa. *Phyllanthus phillyreifolius*. Underexplored Medicinal Plants from Sub-Saharan Africa, pp. 217–221. https://doi.org/10.1016/B978-0-12-816814-1.00033-8.
Majumdar, M., Biswas, S.C., Choudhury, R., Upadhyay, P., Adhikary, A., Roy, D.N., Misra, T.K., 2019. Synthesis of gold nanoparticles using *Citrus macroptera* fruit extract: anti-biofilm and anticancer activity. ChemistrySelect 4 (19), 5714–5723.
Malapermal, V., Botha, I., Krishna, S.B.N., Mbatha, J.N., 2017. Enhancing antidiabetic and antimicrobial performance of *Ocimum basilicum*, and *Ocimum sanctum (L.)* using silver nanoparticles. Saudi J. Biol. Sci. 24, 1294–1305.
Masum, M.M.I., Siddiqa, M.M., Ali, K.A., Zhang, Y., Abdallah, Y., Ibrahim, E., Qiu, W., Yan, C., Li, B., 2019. Biogenic synthesis of silver nanoparticles using *Phyllanthus emblica* fruit extract and its inhibitory action against the pathogen acidovorax oryzae strain RS-2 of rice bacterial brown stripe. Front. Microbiol. 10 (820). https://doi.org/10.3389/fmicb.2019.00820.
Menon, S., Agarwal, H., Kumar, S.R., Kumar, S.V., 2017. Green synthesis of silver nanoparticles using medicinal plant *Acalypha indica* leaf extracts and its application as an antioxidant and antimicrobial agent against foodborne pathogens. Int. J. Appl. Pharm. 9, 42–50.
Mohanta, Y.K., Panda, S.K., Syed, A., Ameen, F., Bastia, A.K., Mohanta, T.K., 2018. Bio-inspired synthesis of silver nanoparticles from leaf extracts of *Cleistanthus collinus (Roxb.)*: its potential antibacterial and anticancer activities. IET Nanobiotechnol. 12, 343–348.
Nahar, K., Rahaman, M.H., Khan, G.A., Islam, M.K., Al-Reza, S.M., 2021. Green synthesis of silver nanoparticles from *Citrus sinensis* peel extract and its antibacterial potential. Asian J. Green Chem. 5 (1), 135–150.
Nayak, S., Sajankila, S.P., Rao, C.V., Hegde, A.R., Mutalik, S., 2019. Biogenic synthesis of silver nanoparticles using *Jatropha curcas* seed cake extract and characterization: evaluation of its antibacterial activity. Energy Sources, Part A: Recov., Utiliz. Environ. Effects. 43, 1–9. https://doi.org/10.1080/15567036.2019.1632394.
Niluxsshun, M.C.D., Masilamani, K., Mathiventhan, U., 2021. Green synthesis of silver nanoparticles from the extracts of fruit peel of *Citrus tangerina, Citrus sinensis*, and *Citrus limon* for antibacterial activities. Bioinorg. Chem. Appl. 6695734, 1–8. https://doi.org/10.1155/2021/6695734.
Niraimathi, K., Sudha, V., Lavanya, R., Brindha, P., 2013. Biosynthesis of silver nanoparticles using *Alternanthera sessilis (Linn.)* extract and their antimicrobial, antioxidant activities. Colloids Surf. B Biointerfaces 102, 288–291.
Nisha, N.S., Aysha, O.S., Rahaman, J.S.N., Kumar, P.V., Valli, S., Nirmala, P., Reena, A., 2014. Lemon peels mediated synthesis of silver nanoparticles and its antidermatophytic activity. Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 124, 194–198.
Noah, N., 2019. Green synthesis: characterization and application of silver and gold nanoparticles. Nanoparticles 53, 111–135.
Ojha, S., Sett, A., Bora, U., 2017. Green synthesis of silver nanoparticles by *Ricinus communis var. carmencita* leaf extract and its antibacterial study. Adv. Nat. Sci.: Nanosci. Nanotechnol. 8, 1–8. https://doi.org/10.1088/2043-6254/aa724b.
Ojo, O.A., Olayide, I., Akalabu, M.C., Basiru, A., 2021. Nanoparticles and their biomedical applications. Biointerface Res. Appl. Chem. 11, 8431–8445. https://doi.org/10.33263/BRIAC111.84318445.
Panda, K.K., Achary, V.M.M., Krishnaveni, R., Padhi, B.K., Sarangi, S.N., Sahu, S.N., Panda, B.B., 2011. In vitro biosynthesis and genotoxicity bioassay of silver nanoparticles using plants. Toxicol. Vitro 25, 1097–1105.
Patil, P., Jadhav (Rathod), V., 2014. Pharamacognostical Evaluation of *Antidesma Acidum Retz*. Leaf: a wild edible plant. J. Adv. Sci. Res. 5 (1), 28–31.
Pirtarighat, S., Ghannadnia, M., Baghshahi, S., 2019. Green synthesis of silver nanoparticles using the plant extract of *Salvia spinosa* grown in vitro and their antibacterial activity assessment. J. Nanostruct. Chem. 9, 1–9. https://doi.org/10.1007/s40097-018-0291-4.
Popescu, M., Velea, A., Lorinczi, A., 2010. Biogenic production of nanoparticles. Dig. J. Nanomater. Biostruct. 5 (4), 1035–1040.
Rahuman, H.B.H., Dhandapani, R., Narayanan, S., Palanivel, V., Paramasivam, R., Subbarayalu, R., Thangavelu, S., Muthupandian, S., 2022. Medicinal plants mediated the green synthesis of silver nanoparticles and their biomedical applications. IET Nanobiotechnol. 16, 115–144. https://doi.org/10.1049/nbt2.12078.
Rai, M., Yadav, A., Gade, A., 2009. Silver nanoparticles as a new generation of antimicrobials. Biotechnol. Adv. 27, 76–83.
Ramteke, C., Chakrabarti, T., Sarangi, B.K., Pandey, R.-A., 2013. Synthesis of silver nanoparticles from the aqueous extract of leaves of *Ocimum sanctum* for enhanced antibacterial activity. J. Chem. 278925, 1–7. https://doi.org/10.1155/2013/278925.
Ramya, B., Seetharaman, S., Indra, V., Sheela, D., Perinbam, K., Augustainet, G., 2017. Phytochemical profiling of aqueous extracts of selected medicinal plants. J. Pharm. Sci. Innov. 6 (1), 14–16.
Rasheed, T., Bilal, M., Iqbal, H.M.N., Li, C., 2017. Green biosynthesis of silver nanoparticles using leaves extract of *Artemisia vulgaris* and their potential biomedical applications. Colloids Surf. B: Biointerfaces. 158, 408–415. https://doi.org/10.1016/j.colsurfb.2017.07.020.
Rauf, A., Ahmad, T., Khan, A., Maryam, Uddin, G., Ahmad, B., Mabkhot, Y.N., Bawazeer, S., Riaz, N., Malikovna, B.K., Almarhoon, Z.M., Al-Harrasi, A., 2021. Green synthesis and biomedicinal applications of silver and gold nanoparticles functionalized with methanolic extract of *Mentha longifolia*. Artif. Cells Nanomed. Biotechnol. 49, 194–203. https://doi.org/10.1080/21691401.2021.1890099.
Rautela, A., Rani, J., Debnath (Das), M., 2019. Green synthesis of silver nanoparticles from *Tectona grandis* seeds extract: characterization and mechanism of antimicrobial action on different microorganisms. J. Anal. Sci. Technol. 10 (5), 1–10.
Reddy, B.P., Mallikarjuna, K., Narasimha, G., Park, S.-H., 2017. *Plectranthus amboinicus*-mediated silver, gold, and silver-gold nanoparticles: phyto-synthetic, catalytic, and antibacterial studies. Mater. Res. Express 4, 1–8. https://doi.org/10.1088/2053-1591/aa80a2.
Renuka, R., Devi, K.R., Sivakami, M., Thilagavathi, T., Uthrakumar, R., Kaviyarasu, K., 2020. Biosynthesis of silver nanoparticles using *Phyllanthus emblica* fruit extract for antimicrobial application. Biocatal. Agric. Biotechnol. 24 (8), 1–22. https://doi.org/10.1016/j.bcab.2020.101567.
Rout, Y., Behera, S., Ojha, A.K., Nayak, P.L., 2012. Green synthesis of silver nanoparticles using *Ocimum sanctum* (Tulashi) and study of their antibacterial and antifungal activities. J. Microbiol. Antimicrob. 4 (6), 103–109. https://doi.org/10.5897/JMA11.060.
Roy, A., Bulut, O., Some, S., Mandal, A.K., Yilmaz, M.D., 2019. Green synthesis of silver nanoparticles: biomolecule-nanoparticle organizations targeting antimicrobial activity. RSC Adv. 9, 2673–2702. https://doi.org/10.1039/c8ra08982e.
Samrot, A.V., Raji, P., Selvarani, A.J., Nishanthini, P., 2018. Antibacterial activity of some edible fruits and its green synthesized silver nanoparticles against uropathogen – Pseudomonas aeruginosa SU 18. Biocatal. Agric. Biotechnol. 253–270. https://doi.org/10.1016/j.bcab.2018.08.014.
Santhosh, P.B., Genova, J., Chamati, H., 2022. Green synthesis of gold nanoparticles: an eco-friendly approach. Chemistry (Easton) 4, 345–369. https://doi.org/10.3390/chemistry4020026.
Saratale, R.G., Shin, H.-S., Kumar, G., Benelli, G., Ghodake, G.S., Jiang, Y.Y., Kim, D.S., Saratale, G.D., 2018. Exploiting fruit byproducts for eco-friendly nanosynthesis: *citrus × clementina* peel extract mediated fabrication of silver nanoparticles with high efficacy against microbial pathogens and rat glial tumor C6 cells. Environ. Sci. Pollut. Res. 25, 10250–10263.
Sarfraz, N., Khan, I., 2021. Plasmonic gold nanoparticles (AuNPs): properties, synthesis and their advanced energy, environmental and biomedical applications. Chem. Asian J. 16, 720–742.
Selvakumar, P., Sithara, R., Viveka, K., Sivashanmugam, P., 2018. Green synthesis of silver nanoparticles using leaf extract of *Acalypha hispida* and its application in blood compatibility. J. Photochem. Photobiol. B, Biol. 182, 52–61. https://doi.org/10.1016/j.jphotobiol.2018.03.018.
Shaik, M.R., Khan, M., Kuniyil, M., Al-Warthan, A., Alkhathlan, H.Z., Siddiqui, M.R.H., Shaik, J.P., Ahamed, A., Mahmood, A., Khan, M., Adil, S.F., 2018. Plant-extract-assisted green synthesis of silver nanoparticles using *Origanum vulgare L.* extract and their microbicidal activities. Sustainability 10, 913. https://doi.org/10.3390/su10040913.
Shaikh, W., Chakraborty, S., Islam, R., 2020. Photocatalytic degradation of rhodamine B under UV irradiation using *Shorea robusta* leaf extract- mediated bio-synthesized silver nanoparticles. Int. J. Environ. Sci. Technol. 17 (4), 2059–2072.
Siddiqi, K.S., Husen, A., Rao, R.A.K., 2018. A review on biosynthesis of silver nanoparticles and their biocidal properties. Nanobiotechnology 16 (14), 1–28. https://doi.org/10.1186/s12951-018-0334-5.
Silva, L.P., Pereira, T.M., Bonatto, C.C., 2019. Frontiers and perspectives in the green synthesis of silver nanoparticles. Green Synthesis, Characterization and Applications of Nanoparticles. Micro and nano technologies. Elsevier, pp. 137–163. 10.1016/B978-0-08-102579-6.00007-1.
Singh, D., Yadav, E., Falls, N., Kumar, V., Singh, M., Verma, A., 2019. Phytofabricated silver nanoparticles of *Phyllanthus emblica* attenuated diethyl-nitrosamine-induced hepatic cancer via knock-down oxidative stress and infammation. Infammopharmacology 27, 1037–1054.
Sivakavinesan, M., Vanaja, M., Lateef, R., Alhadlaq, H.A., Mohan, R., Annadurai, G., Ahamed, M., 2022. *Citrus limetta* Risso peel mediated green synthesis of gold nanoparticles and its antioxidant and catalytic activity. J. King Saud Univ. Sci. 34, 102235.
Sivaramakrishnan, M., Sharavanan, V.J., Govindarajan, D.K., Meganathan, Y., Devaraj, B.S., Natesan, S., Kothandan, R., Kandaswamy, K., 2019. Green synthesized silver nanoparticles using aqueous leaf extracts of *Leucas aspera* exhibits antimicrobial and catalytic dye degradation properties. SN Appl. Sci. 1 208, 1–8. https://doi.org/10.1007/s42452-019-0221-1.
Sowmya, C., Lavakumar, V., Venkateshan, N., Ravichandiran, V., Saigopal, D.V.R., 2018. Exploration of *Phyllanthus acidus* mediated silver nanoparticles and its activity against infectious bacterial pathogen. Chem. Cent. J. 12, 1–9. https://doi.org/10.1186/s13065-018-0412-7.
Stella Sravanthi, V., Mohan, K.V., Periyasamy, L., 2018. Green synthesis of silver nanoparticles using *Ocimum sanctum* leaf extract and its anti-cancer activity against breast cancer cell line. Int. J. Res. Anal. Rev. 5, 1–8.
Swamy, M.K., Arumugam, G., Kaur, R., Ghasemzadeh, A., Yusoff, M.M., Sinniah, U.R., 2017. GCMS– based metabolite profiling, antioxidant and antimicrobial properties

of different solvent extracts of Malaysian *Plectranthus amboinicus* leaves. Evid. Complement. Altern. Med. 1517683, 1–10. https://doi.org/10.1155/2017/1517683.

Tailor, G., Yadav, B.L., Chaudhary, J., Joshi, M., Suvalka, C., 2020. Green synthesis of silver nanoparticles using *Ocimum canum* and their anti-bacterial activity. Biochem. Biophys. 24, 100848. https://doi.org/10.1016/j.bbrep.2020.100848.

Tamokou, J.D.D., Mbaveng, A.T., Kuete, V., 2017. Chapter 8 - antimicrobial activities of African medicinal spices and vegetables, medicinal spices and vegetables from Africa. 207–237. 10.1016/B978-0-12-809286-6.00008-X

Tian, F., Bonnier, F., Casey, A., Shanahan, A.E., Byrne, H.J., 2014. Surface enhanced Raman scattering with gold nanoparticles: effect of particle shape. Anal. Methods 6, 9116–9123.

Ulaeto, S.B., Mathew, G.M., Pancrecious, J.K., Nair, J.B., Rajan, T.P.D., Maiti, K.K., Pa, B.C., 2019. Biogenic Ag nanoparticles of Neem extract; its structural evaluation and antimicrobial effects against *Pseudomonas nitroreducens* and *Aspergillus unguis* -NII 08123. ACS Biomater. Sci. Eng. 6 (1), 235–245.

Usmani, A., Mishra, A., Jafri, A., Arshad, M., Siddiqui, M.A., 2019. Green synthesis of silver nanocomposites of *Nigella sativa* seeds extract for hepatocellular carcinoma. Curr. Nanomater. 4, 191–200. https://doi.org/10.2174/2468187309666190906130115.

Vasantharaj, S., Sripriya, N., Shanmugavel, M., Manikandan, E., Gnanamani, A., Senthilkumar, P., 2018. Surface active gold nanoparticles biosynthesis by new approach for bionanocatalytic activity. J. Photochem. Photobiol. B, Biol. 1–17. https://doi.org/10.1016/j.jphotobiol.2018.01.007.

VennilaRaj, R., Palanisamy, K., Arthanareeswari, M., Bitragunta, S., 2013. Green synthesis of silver nanoparticles from *Cleistanthus collinus* leaf extract and their biological effects. Int. J. Chem. 34, 1103–1107.

Wahab, M., Bhatti, A., John, P., 2022. Evaluation of antidiabetic activity of biogenic silver nanoparticles using *Thymus serpyllum* on streptozotocin-induced diabetic BALB/c mice. Polymers (Basel) 14, 3138. https://doi.org/10.3390/polym14153138.

Wang, R., Xu, X., Puja, A.M., Perumalsamy, H., Balusamy, S.R., Kim, H., Kim, Y.-J., 2021. Gold nanoparticles prepared with *Phyllanthus emblica* fruit extract and *Bifidobacterium animalis subsp*. lactis can induce apoptosis via mitochondrial impairment with inhibition of autophagy in the human gastric carcinoma cell line AGS. Nanomaterials 11, 1260. https://doi.org/10.3390/nano11051260.

Xu, L., Wang, Y.Y., Huang, J., Chen, C.Y., Wang, Z.X., Xie, H., 2020. Silver nanoparticles: synthesis, medical applications and biosafety. Theranostics 10 (20), 8996–9031. https://doi.org/10.7150/thno.45413.

Yuan, C.-G., Huo, C., Gui, B., Cao, W.-P., 2017. Green synthesis of gold nanoparticles using *Citrus maxima* peel extract and their catalytic/antibacterial activities. IET Nanobiotechnol. 11, 523–530. https://doi.org/10.1049/iet-nbt.2016.0183.