HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

الجمعية السعودية لعلوم الحياة
SAUDI BIOLOGICAL SOCIETY

Review green synthesis of silver nanoparticles by using plant extracts and their antimicrobial activity

Emad Abada, Abdullah Mashraqi, Yosra Modafer, Mohamed A. Al Abboud, A. El-Shabasy *

Biology Department/ College of Science, Jazan University, Jazan City 82817, Saudi Arabia

ARTICLE INFO

Keywords:
AgNPs
Antimicrobial activity
Plants parts

ABSTRACT

Interest in the biosynthesis of nanoparticles has increased in the last era by researchers. Nanoparticles have several applications in different fields like optoelectronics, magnetic devices, drug delivery, and sensors. Nanoparticle synthesis by green methods is safe for the environment and should be explored and encouraged popularly since various plants' have the high extent to form these nanoparticles. Worldwide, UV spectroscopy, X-ray diffraction, Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Dynamic Light Scattering (DLS), Atomic Force Microscopy (AFM) besides Fourier Transform Infrared Spectroscopy (FTIR) are used in many ways for characterize nanoparticles. The most advantageous use of AgNPs is their great attribution to be used as antimicrobial agents. Finally, concept of AgNPs synthesis is deserved to be the modern technical and medical concern. The current review shows a complete comprehensive and analytical survey of the biosynthesis of AgNPs with a particular focus on their activities as antimicrobials and the possible theories of their effect on the microbial cell and all influenced secondary metabolites.

1. Introduction

The Nanotechnology field has protruded as a breakthrough technology in the twenty-first century. It is an integrative field that includes creating, processing, and deploying materials smaller than 100 nm scaling size. It deals with materials on molecular basis and has recently joined diversed broad field of applications (Mansoori, 2005).

Nowadays, many promising technologies that depend heavily on nanotechnology have emerged, such as biomedical science, optics, mechanics, the chemical industry, drug-gene distribution, optoelectronic systems, catalysis, energy science, photoelectrochemical, and space industries applications. A particular concern is directed to nanoparticles owing to their exceedingly small size with higher surface/ volume ratios which cause physical and chemical variations in their property instead of the bulk of similar chemical structures and functions (Ray, 2010). Green Synthesis nanotechnology is used to be more safe to the environments by utilizing plants bacteria and other different bioresources (Lateef et al., 2016).

Also, several studies have been conducted to synthesize metal nanoparticles by using bacteria such as *Bacillus subtilis*, and fungi such as *Fusarium oxysporum,* and *Penicillium* sp. (Du et al., 2011).

This review focused on using extracts from different plants to

Abbreviations: AgNPs, Silver Nanoparticles; EDAX, Energy Dispersion Analysis of X-ray; FTIR, Fourier Transform Infrared Spectroscopy; MIC, Minimum Inhibitory Concentration; mg, Milligram; nm, Nanometer; PL, Photoluminescence Analysis; SEM, Scanning Electron Microscopy; TEM, Transmission Electron Microscopy; XRD, X-ray Diffractometer; XPM, X-ray Photoelectron Microscopy; ZOI, Zone of Inhibition; DLS, Dynamic Light Scattering; AFM, Atomic Force Microscopy; A1, *Acinetobacter baumannii*; A2, *Aeromonas hydrophila*; A3, *Agrobacterium tumefaciens*; B1, *Bacillus cereus*; B2, *Bacillus licheniformis*; B3, *Bacillus luteus*; B4, *Bacillus pumilus*; B5, *Bacillus subtilis*; C1, *Candida albicans*; C2, *Candida krusei*; C3, *Chromobacterium violaceum*; C4, *Citrobacter frurdii*; C5, *Citrobacter koseri*; C6, *Citrobacter* sp.; E1, *Enterobacter aerogenes*; E2, *Enterococcus faecalis*; E3, *Enterococcus hirae*; E4, *Escherichia coli*; K1, *Klebsiella aerogenes*; K2, *Klebsiella oxytoca*; K3, *Klebsiella planticola*; K4, *Klebsiella pneumonia*; L1, *Listeria monocytogenes*; M1, *Micrococcus avus*; P1, *Prevotella brevis*; P2, *Proteus mirabilis*; P3, *Proteus vulgaris*; P4, *Pseudomonas aeruginosa*; P5, *Pseudomonas putida*; P6, *Pseudomonas* sp.; P7, *Pseudomonas syringae*; S1, *Salmonella enterica*; S2, *Salmonella paratyphi*; S3, *Salmonella typhimurium*; S4, *Serratia marcescens*; S5, *Shigella dysenteriae*; S6, *Shigella sonnei*; S7, *Staphylococcus aureus*; S8, *Staphylococcus coagulase*; S9, *Staphylococcus epidermidis*; S10, *Staphylococcus haemolyticus*; S11, *Streptococcus pneumonia*; S12, *Streptococcus pyogenes*; T1, *Trichophyton mentagrophytes*; T2, *Trichophyton rubrum*; V1, *Vibrio cholera*; V2, *Vibrio vulnificus*.

Peer review under responsibility of King Saud University.

* Corresponding author.

E-mail addresses: eabada@jazanu.edu.sa (E. Abada), amashraqi@jazanu.edu.sa (A. Mashraqi), ymodafer@jazanu.edu.sa (Y. Modafer), malabboud@jazanu.edu.sa (M.A. Al Abboud), ael-shabasy@jazanu.edu.sa (A. El-Shabasy).

https://doi.org/10.1016/j.sjbs.2023.103877
Received 18 October 2023; Received in revised form 3 November 2023; Accepted 24 November 2023
Available online 26 November 2023

synthesize nanoparticles since it is the most widely used form of green chemistry and is eco-friendly. This strategy attracted scientists and researchers' interest because of the ease of distribution and availability of plants. It is a source of different metabolites and is safe to use.

2. Green synthesis of nanoparticles

The three most important conditions for synthesizing nanoparticles are the right choice of a renewable and environmentally safe solvent, a harmless material, and a powerful reducing agent for stabilization. Chemical processes are generally too costly and include dangerous and harmful substances responsible for various environmental hazards (Nath and Banerjee, 2013). The biosynthesis method is a green, healthy, biologically compatible, and environmentally sustainable way to synthesize nanoparticles for biomedical applications using microorganisms and plants. According to the phytochemicals in their extract, certain plant parts as stems, roots buds, leaves, seeds and rhizomes have been utilized to synthesize different nanoparticles (Narayanan and Sakthivel, 2011; Abdelghany et al., 2018a; Al-Rajhi et al., 2022; Abdelghany et al., 2023). Various biological methods for technology of nanoparticle synthesis are shown in (Fig. 1).

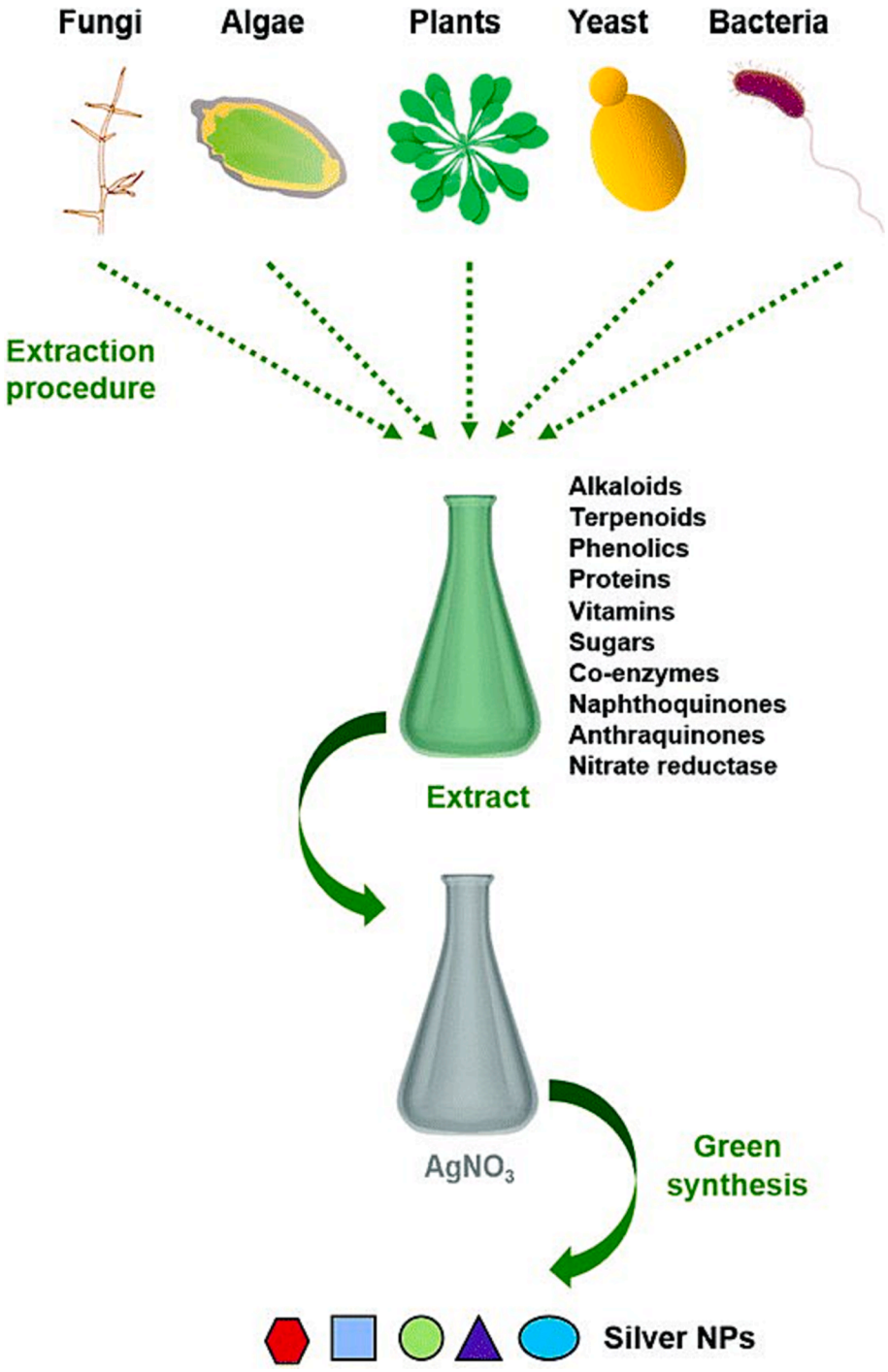

Fig. 1. Biological Synthesis of AgNPs.

2.1. Role of plants in green nanoparticles synthesis

AgNPs manufacture by plant components is considered one of the most important sciences of manufacturing processes (Makarov et al., 2014).

The different bioactive molecules in the plant extracts like alkaloids, phenols, citric acid, polyphenolic, terpenes, ascorbic acid, flavonoids, and other components play an crucial value for being reducing agents. Nanoparticle biosynthesis through phytobiomass is necessary for nanotechnology because the plant extracts regard as reducing with capping ability (Haldar et al., 2022).

Moreover, plant extracts are able to provide several phytochemicals like proteins, amino acids, carbohydrates, saponins, flavonoids, chromone, quinic acid, steroids, saturated besides unsaturated fatty acids, terpenoids and phytol that have great influence on physical and organic chemical fundementals. They occupy in the plant chemistry an essential role in improving reduction size, rate and stabilization by acting as the perfect surfactant, reducing, capping and structure-directing agent (Potbhare et al., 2019).

By using of plant extracts in the nanoparticle biosynthesis approaches many researchers encourage for discovering different applications which are executed actually and other are already underway) Fig. 2). Experiments have shown that the metal nanoparticle formation depends on chemical and physical factors as time, pH, besides type of mineral (Haldar et al., 2022).

2.2. Possible mechanisms involved in nanoparticles synthesis

It is vital to understand the process and metabolic pathways that contribute to the manufacture of metal nanoparticles to establish a good strategy for nanoparticle synthesis. Many other theories about making nanoparticles have existed in the last few years. However, the specific process underlying the biological metal nanoparticle synthesis is not yet cleared, and further research is required to determine this. The Secondary metabolites and proteins present in the water-soluble portions of *Geranium* leaves were investigated. It was hypothesized that reduction and oxidation of Ag ions and carbonyl groups are caused by terpenoids respectively. It was stated that polyols were able to reduce silver by *Cinnamomum camphora* leaves extract. The use of stimulant plant extracts like tea leaves and coffee seeds in the green production of AgNPs was focused studied. The capping and reduction of AgNPs by oxidized polyphenols and caffeine have done concurrently after complexation with Ag metal salts. The cyclic octa-peptide was predominately responsible for reduction of Ag^{+} to AgNPs. It was assumed that the curcain enzyme in the latex of *Jatropha curcus* helps stabilize AgNPs. In another study, the flavonoids or polyphenols of leaves were responsible for synthesizing Au and Ag nanoparticles. Also, the citric acids in citrus plant extracts were reported as the major reducing agents for synthesis of nanoparticle (Bar et al., 2009; Rao et al., 2021) (Fig. 3).

2.3. Characterization of nanoparticles

The most famous very common methods which are applied for the nanoparticle synthesis and characterization are Ultraviolet–Visible (UV) spectroscopy, (SEM), Photoluminescence (PL), (FTIR), Raman Spectroscopy, (XPM), (TEM), (XRD), (EDAX), (DLS) and (AFM). (AgNPs) on the nanosheet surfaces of Graphene Oxides (GOs) are considered as the multi-functional antimicrobial materials which were prepared by using pathogenic bacteria biomass extract that have been fabricated to nanocomposites. The manufactured materials were characterized by variety of high spectroscopic techniques, as Raman Spectroscopy, (XRD), (EDX), (FTIR), (TEM) and (SEM) (Potbhare et al., 2020).

2.4. Ag nanoparticles

Any reducing biological agents with the Ag ions solutions become essential factors for synthesizing AgNPs eco-friendly. The integrated biological reaction with phenols, vitamins, amino acids, or proteins prepared the reduction of AgNPs. Those are the most effortless, least costly processes for producing silver nanoparticles (Tolaymat et al., 2010). Biogenic synthesis of AgNPs is a simple one-step protocol that does not produce harsh or harmful chemicals; they are cost-effective, ecological, and environmentally friendly. Recently, plants have been extensively studied for the AgNPs biosynthesis from different sizes,

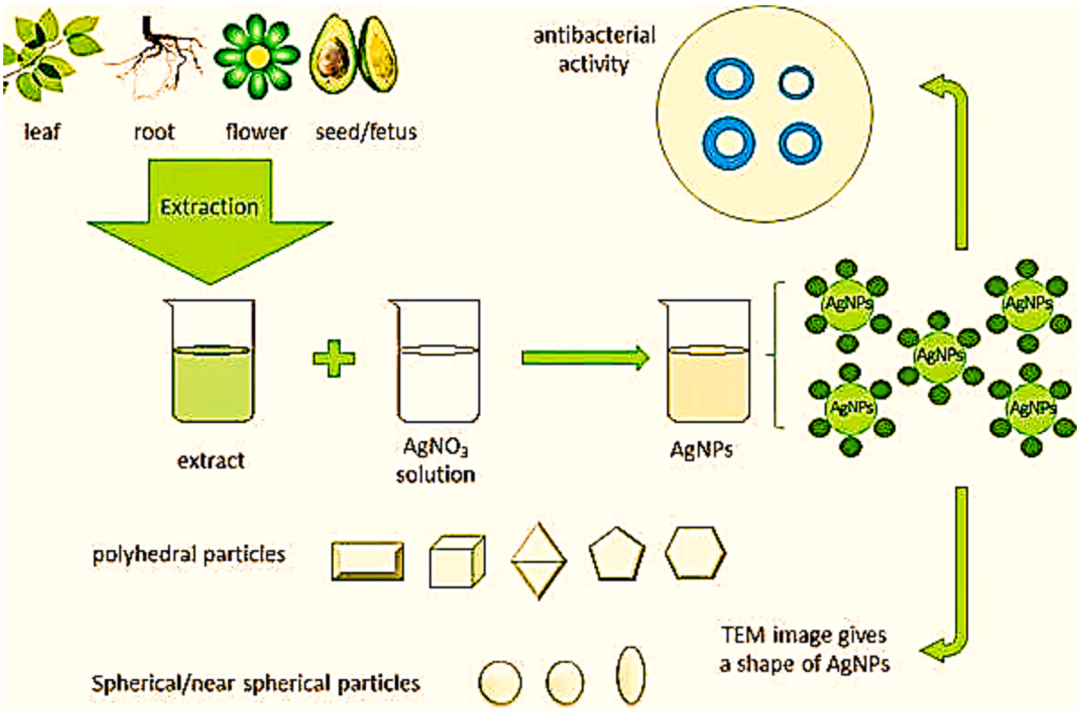

Fig. 2. Biological synthesis of AgNPs from different plant parts.

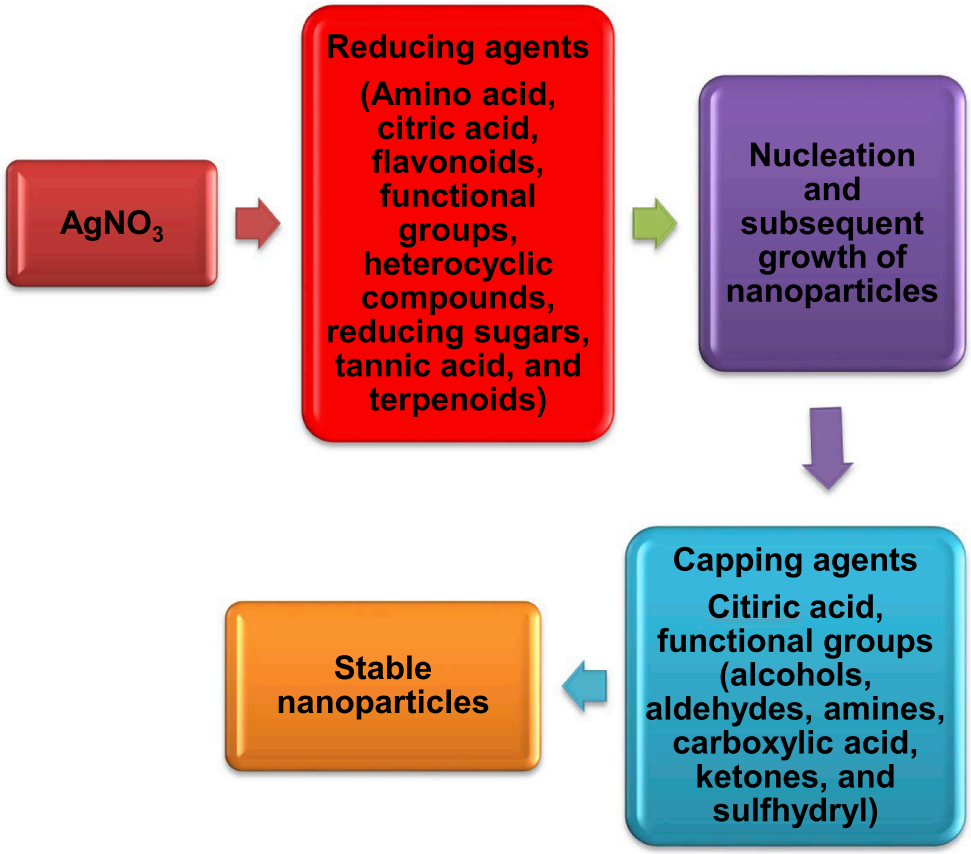

Fig. 3. Role of capping and reducing agents in AgNPs synthesis.

forms, antimicrobial efficacy, and stability. Different plant portions as fruits, leaves, stems and flowers have been synthesize AgNPs successfully due to presence of many phytochemicals of plant extract which is fully responsible for AgNPs synthesis (Ahmed et al., 2017).

2.4.1. Biosynthesis of the AgNPs from plant leaves

Many leaf extracts have been used for the AgNPs biosynthesis. It has been stated that the *Skimmia laureola* leaf extract was capable of forming spherical AgNPs in a diameter of 38.2 nm that were measured versus *S. aureus, P. aeruginosa, P. vulgaris, K. pneumonia* besides *E. coli* (Ahmed et al., 2017). At room temperature, *Prosopis farcta* leaf extract was able to establish AgNPs. The analysis of the antimicrobial activity of AgNPs by using wild leaves indicated that it exhibits antimicrobial activity against Gram-positive and Gram-negative with an average size of 11.2 nm (Miri et al., 2015).

Spherical biogenic AgNP was also synthesized using *Leptadenia reticulata*, *Aloe vera* and *Eclipta prostrata* from leaves extract was used for AgNPs synthesis, and the antibacterial activity results showed inhibition action is more effective aginst Gram-positive bacteria (Medda et al., 2014). AgNPs were collected as highly crystals from *Canna edulis*, which showed the greatest antimicrobial activity against *S. typhimurium* (Otari et al., 2017).

Petiveria alliacea mediated AgNPs evaluated full inhibition versus *E. coli, K. pneumonia* besides *S. aureus* (Lateef et al., 2018). *Thymbra spicata* extract decreased sizes of nanoparticles to increase the antibacterial activities (Erci et al., 2017). It has been reported that the *Solanum nigrum* and *Clitoria ternatea* leaf extract can synthesize tiny AgNPs, tested versus *P. aeruginosa, K. aerogenes, B. subtilis, E. coli, S. aureus* besides *S. pyogenes*. Due to their small scale, AgNPs from *Clitoria ternatea* had better efficacy against nosocomial pathogens than AgNPs from *Solanum nigrum* (Karthiga, 2018). It has been stated that the leaf extract of *Withania somnifera*, *Grewia flaviscences*, *Justicia adhatoda,* and *Prunus yedoensis* could synthesize AgNPs in a size of 8–100 nm mainly spherically (Sana et al., 2015;. Velmurugan et al., 2015). The AgNPs of *Prunus yedoensis* were used for care for *P. acnes* and *S. epidermidis* infection. Moreover, it was discovered that commercial AgNPs are less effective versus well-known skin bacteria like *S. epidermidis* and *P. acnes* than biosynthesized AgNPs (Bose and Chatterjee, 2015). *Ficus recurva, Pistacia atlantica,* and *Tectona grandis* have also been reported to synthesize AgNPs and studied against various microbes (Marslin et al., 2015). Furthermore, AgNPs have been synthesized using plant leaf extracts from *Cassia fistula*, *Artocarpus altilis*, *Terminalia arjuna*, *Psidium guajava*, and *Cardiospermum halicacabum*. When the AgNPs were tested against different bacteria, they demonstrated the largest inhibition zone against *P. aeruginosa* and *E. coli*. Also, it showed less activity against *Klebsiella pneumoniae* (Anandalakshmi et al., 2016). *Catharanthus roseus* was identified by changed color with Ultra Violet spectrum in XRD, FTIR, AFM techniques to ensure AgNPs biosynthesis (Sara et al., 2019). Using ultrasonication in the biosynthesis of AgNPs increases the reaction conditions by shortening the time and rate of reaction. It has been exhibited that the extract from leaves of *Lantana camara* were used to bio-synthesize spherical AgNPs by ultrasonic assistance. The AgNPs verified the antimicrobial activity against Gram-positive and Gram-negative bacteria (Manjamadha and Muthukumar, 2016). The spherical shapes which have diameters with the range of 11–47 nm of AgNPs by Transmission Electron Microscope (TEM) analysis, was obtained by *Lavandula intermedia* (Christophe et al., 2008). *Artemisia vulgaris* mediated AgNPs revealed significant inhibition activities against tested bacterial pathogens like *S. aureus* (Rasheed et al., 2017). *Camellia sinensis* was conducted by using AgNPs in antimicrobial fabric tests on the dyed cloths (Onitsuka et al., 2019).

TEM study of AgNP synthesized by *Jatropha curcas* leaf extract indicated variance in particle sizes (20–50 nm) and form. In contrast, SEM study revealed that the diameter of AgNP was in the between of

50–100 nm (Chauhan et al., 2016). The sensitivity test revealed that it's susceptible to *E. coli* but showed less activity against *S. aureus*. *Lawsonia inermis, Urtica dioica,* and *Ziziphus oenoplia* are mediated to produce AgNPs with the great antibacterial activities (Ali et al., 2016). *Sesbania grandiflora*, *Indigofera articulata,* and *Phlomis cancellat* extracts were useful for the reduction of $AgNO_3$ to AgNP biologically (Ajitha et al., 2016). Small-size AgNPs of *Caesalpinia pulcherrima* showed antimicrobial activity versus *K. pneumonia* and *E. coli*. (Kuppurangan et al., 2016). *Aspilia pluriseta, Melia azedarach, Mikania micrantha,* and *Scoparia dulcis* were proven to be excellent antimicrobial activity versus numerous common pathogenic microbes like *E. coli* and *B. subtilis* when mediated with AgNPs (Nyabola et al., 2020; Saratale et al., 2017).

Recently, *Solanum nigrum* plant leaf extract was used to form $AgNO_3$ with an average diameter of 3.46 nm (Vijilvani et al., 2020). The biogenic AgNPs are one of the smallest reported NPs, as small as 1.74 nm. *E. coli* (DH5a) was used to study the antimicrobial activity of the produced AgNPs. 5 μg/mL is a MIC value which significantly reduced the growth on an agar plate. *Azadirachta indica* was able to synthesize AgNPs and evaluated pH effects on the formation of nanoparticles. The produced *Pedalium murex* nanoparticles were tested against many pathogenic microorganisms and exhibited the largest ZOI of 10.5 mm (in 15 mL for 1 scale) versus *P. aeruginosa* and *E. coli* (Ghotekar et al., 2018). Mediated AgNPs of *Croton bonplandianum* were reported to be highly active particles against several pathogenic microorganisms (Mudasir et al., 2017). In addition, *Tamarix gallica* was used to synthesize AgNPs to evaluate the activity against *E. coli* (López-Miranda et al., 2016). *Taraxacum* sect. *Taraxacum* mediated AgNPs were the best synergistic antibacterial activity against several standard commercial antibiotics (Jyoti et al., 2016). *Salvia leriifolia, Tecoma stans, Leucaena leucocephala,* and *Galega officinalis* produced spherical AgNPs with size-dependent antibacterial activities (Baghayeri et al., 2018; Manosalva et al., 2019). Various antimicrobial AgNPs were synthesized by *Capparis pyrifolia, Kleinia grandiflora* and *Corymbia citriodora* (Kanagamani et al., 2019; Nilavukkarasi et al., 2020). *Ligustrum lucidum* expressed Synergistic antimicrobial activity after mediation with AgNPs against *S. turcica* (Huang et al., 2020). *Aesculus hippocastanum* (horse chestnut) was able to mediate the unique size of AgNPs (0.00019 μg/ml) to have the highest antibacterial activity acheived versus Gram (-) bacteria (Fatma et al., 2020). Green AgNPs synthesis promoted the antibacterial activity of *Melaleuca alternifolia* versus many resistent skin bacteria involving *S. epidermis* besides methicillin-resistant *Staphylococcus aureus* (Ramadan et al., 2020). Interestingly, biogenic AgNPs derived from *Bergera koenigii* extracts displayed the highest activity versus *P. aeruginosa* (Chahande et al., 2020). The Biosynthesis of AgNPs using *Curcuma longa* investigated AgNPs-coated cotton fabric with high antimicrobial activity (Maghimaa and Ali, 2020). Synthesis of spherical CuNPs, FeNPs and AgNPs with different sizes using leaf extract of *Syzygium cumini* leaf extract was confirmed to have antibacterial properties against vancomycin and methicillin resistance *S. aureus* (Asghar et al., 2020). *Cestrum nocturnum* and *Cleistanthus collinus* also have produced AgNPs (Keshari et al., 2020; Lourthuraj et al., 2020). *Mentha aquatica* extract produced an ultra sound-assisted AgNPs as a reducing agent with capping ability (Nouri et al., 2020). *Ceropegia thwaitesii* and *Salvia rosmarinus* extract-mediated AgNPs revealed constant higher activity versus Gram (-) bacteria (Muthukrishnan et al., 2015). Other plant species in this study were prepared as AgNPs with cubic, pentagonal, and hexagonal shapes of various sizes against several microbes (Chhangte et al., 2021) (Table 1 **&** Table 7**).**

2.4.2. Biosynthesis of the AgNPs from seeds

Durio zibethinus seed extract had the ability to synthesize spherical and polygonal AgNPs with 25–35 nm diameter. The extract's polysaccharides induced bio-reduction, and amino acids stabilized the AgNPs.The produced NPs showed great inhibitory ability exclusively against four bacteria: *A. punctat*, *V. alginolyticus*, *V. parahaemolyticus,* and *V. anguillarum* (Xu et al., 2014). AgNPs with strong antibacterial activity were generated by seed extracts of plants such as *Trigonella foenum-graecum*, *Persea americana*, *Trachyspermum ammi* and *Salvia hispanica*, (Giron-Vázquez et al., 2019; Hernandez et al., 2019; Rautela et al., 2019; Varghese et al., 2019). The size of AgNPs was dependent on the *Persea americana* seed extract concentration. Small AgNPs were observed at low concentrations of aqueous extract, while larger NPs were observed at high concentrations of aqueous extract. In the AgNPs produced by *Trifolium resupinatum* seeds extracts, the maximum inhibitory effect of 94.1 percent and 84 percent was obtained against *N. parvum* and *R. solani*, respectively (Khatami et al., 2016). Moreover, spherical AgNPs were synthesized by many plant seeds such as *Embelia ribes, Myristica fragrans,* and *Nigella arvensis* were used (Chahardoli et al., 2017; Dhayalan et al., 2016; Haseeb et al., 2017). In most cases, AgNP technique is more effective as antimicrobials than other metal-NPs; it is worth noting that *E. coli* is less susceptible to *Embelia ribes* derived AgNPs, with a less ZOI than for AuNPs (Dhayalan et al., 2016). Compared to *P. aeruginosa*, AgNPs mediated by *Alpinia katsumadai* seed extract had excellent antibacterial activity. Those produced from *Myristica fragrans* seed extract were reported to be particularly sensitive to *S. typhi* a multidrug-resistant (MDR) strain with the highest inhibition zone at concentration 100 mg mL^{-1} (He et al., 2017). *Leucaena leucocephala* exhibited the lowest toxicity versus *S. aureus* besides *E. coli* (Varghese et al., 2019). It has been shown that the AgNPs size was varied on *Persea Americana* extract concentration where low concentration resulting in small NPs and high concentration resulting in larger NPs were appeared. It studied synergistic antibiotic action on the bacterial strains *S. aureus*, *B. cereus* plus *E. coli* with AgNPs in seeds of *Hibiscus cannabinus*. At the same time, they were in vitro applied with antibiotics. *Carum copticum* mediated AgNPs suppressed the biofilm formation of *P. aeruginosa* through an additional percent in different *Carum copticum* mediated AgNPs concentration respectively (Qais et al., 2020). The effect of several parameters such as time, temperature, solvent besides solvent/plant ratio have been studied for AgNPs biosynthesis from *Pimpinella aromatica* seeds extracts (Zayed et al., 2020).

Similarly, roasted and dried coffee seeds (*Coffea arabica*) were used to reduce and stabilize the eco-friendly AgNPs. The researchers are able to raise the bactericidal effect versus *S. aureus* besides *E. coli*. The results displayed that the AgNPs had the high ZOIs at a concentration between 0.04 M and 0.1 M. (Dhand et al., 2016).Other plant seeds in this investigation used as reducing as well as stabilizing agents for AgNPs biosynthesis **(Md *et al.*, 2022)** (Table 2 **&** Table 8**).**

2.4.3. Biosynthesis of the AgNPs from flower

Flower extracts have recently been extensively used in NP biosynthesis by using *Tagetes erecta* leaf extracts to synthesize AgNPs. They evaluated the bactericidal activity versus Gram (-) besides Gram (+) bacteria *E. coli*, *C. neoformans*, *C. albicans*, *Staphylococcus aureus*, *P. glabrata*, and *B. cereus*. The results exhibited that *P. aeruginosa* and *E. coli* have higher bactericidal activity than other pathogenic microorganisms. The authors also observed the antifungal activity of antibiotics and AgNPs versus Gram-negative bacteria compared to antibiotics alone, demonstrating significant activity. Flower extracts from *Alcea rosea*, was also reported for the biogenic synthesis AgNP (Ebrahiminezhad et al., 2017; Chandrasekhar et al., 2017). It has been revealed that *Moringa oleifera* leaf extract produced ultra-small AgNPs with a 29 mm ZOI against *S. aureus*. Due to its small size, this has one of the greatest ZOIs yet seen utilizing biogenic AgNPs. According to (Ajitha et al., 2015), leaf extract of *Turnera ulmifolia* was able to be as a capping agent and bio-reducing produced polydisperse AgNPs. The antibacterial activity of the AgNPs was evaluated versus different pathogens and was found to be maximal in *Pseudomonas spp*. *Tecoma stans* flower extract synthesized spherical AgNPs of 50–60 nm. The antibacterial activity versus Gram (+) and Gram (-) bacterial species was tested. The result indicated that the ZOI is lower for Gram (-) than Gram (+) (Ngoan et al., 2022) (Tables 3 & 9**).**

Table 1
Examples of leaf extract used and families with MIC for the green synthesis of AgNPs.

No.	Plant Species	Family	MIC µg/ml	Ref.
1	*Aesculus hippocastanum* L.	Hippocastanaceae	0.00019	Fatma et al., 2020
2	*Aloe vera* (L.) Burm.f.	Asphodelaceae	6.25	Medda et al., 2014
3	*Aloysia citrodora* Paláu	Verbenaceae	0.02	Aditi et al., 2021
4	*Amaranthus tricolor* L.	Amarnthaceae	8.5	Aditi et al., 2021
5	*Andrographis echioides* (L.) Nees	Acanthaceae	1.5	Aditi et al., 2021
6	*Argemone mexicana* L.	Papaveraceae	0.01	Aditi et al., 2021
7	*Artemisia vulgaris* L.	Asteraceae	50	Mollick et al., 2019
8	*Artocarpus altilis* (Parkinson) Fosberg	Moraceae	100	Bose and Chatterje, 2015
9	*Aspilia pluriseta* Schweinf. ex Engl.	Asteraceae	6.26	Nyabola et al., 2020
10	*Atalantia monophylla* DC.	Rutaceae	2.0945	Aditi et al., 2021
11	*Azadirachta indica* A. Juss.	Meliaceae	5	Verma, and Mehata, 2016
12	*Bergera koenigii* L.	Rutaceae	133.33	Chahande et al., 2020
13	*Brassica oleracea* L.	Brassicaceae	10	Aditi et al., 2021
14	*Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	100	Kuppurangan et al., 2016
15	*Camellia sinensis* (L.) Kuntze	Theaceae	12.5	Onitsuka et al., 2019
16	*Canna indica* L.	Cannaceae	150	Otari et al., 2017
17	*Capparis pyrifolia* Lam.	Capparaceae	0.025	Nilavukkarasi et al., 2020
18	*Cardiospermum halicacabum* L.	Sapindaceae	20	Aditi et al., 2021
19	*Carya illinoinensis* (Wangenh.) K.Koch	Juglandaceae	0.005	Aditi et al., 2021
20	*Cassia fistula* L.	Fabaceae	20	Bose and Chatterje, 2015
21	*Catharanthus roseus* (L.) G.Don	Apocynaceae	0.01112	Sara et al., 2019
22	*Ceropegia thwaitesii* Hook.	Apocynaceae	200	Muthukrishnan et al., 2015
23	*Cestrum nocturnum* L.	Solanaceae	80	Keshari et al., 2020
24	*Cleistanthus collinus* (Roxb.) Benth. ex Hook.f.	Phyllanthaceae	100	Lourthuraj et al., 2020
25	*Clematis zeylanica* (L.) Poir.	Ranunculaceae	200	Aditi et al., 2021
26	*Clitoria ternatea* L.	Fabaceae	10	Lateef et al., 2018
27	*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	Myrtaceae	100	Qais et al., 2020
28	*Croton bonplandianus* Baill.	Euphorbiaceae	100	Alfuraydi et al., 2019
29	*Curcuma longa* L.	Zingiberaceae	39.06	Maghimaa and Ali, 2020
30	*Dracocephalum moldavica* L.	Lamiaceae	300	Aditi et al., 2021
31	*Eclipta prostrata* (L.) L.	Asteraceae	4.5	Aditi et al., 2021
32	*Erythrina abyssinica* Lam.	Fabaceae	100	Aditi et al., 2021
33	*Ficus recurva* var. *recurva*	Moraceae	40	Marslin et al., 2015
34	*Galega officinalis* L.	Fabaceae	50	Manosalva et al., 2019
35	*Grewia flavescens* Juss.	Malvaceae	50	Sana et al., 2015
36	*Indigofera articulata* Gouan	Fabaceae	0.039	Andra et al., 2019
37	*Jatropha curcas* L.	Euphorbiaceae	0.005	Anandalakshmi et al., 2016
38	*Justicia adhatoda* L.	Acanthaceae	40	Velmurugan et al., 2015
39	*Kleinia grandiflora* (Wall. ex DC.) N.Rani	Asteraceae	100	Kanagamani et al., 2019
40	*Lantana camara* L.	verbenaceae	100	Manjamadha and Muthukumar, 2016
41	*Lavandula* × *intermedia* Emeric ex Loisel.	Lamiaceae	0.5	Masum et al., 2019
42	*Lawsonia inermis* L.	Lythraceae	50	Aditi et al., 2021
43	*Leptadenia reticulata* (Retz.) Wight & Arn.	Apocynaceae	25	Ajitha et al., 2016
44	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	0.2407	Mahendran et al., 2016
45	*Ligustrum lucidum* W.T.Aiton	Oleaceae	0.001	Huang et al., 2020
46	*Melaleuca alternifolia* (Maiden & Betche) Cheel	Myrtaceae	0.02	Ramadan et al., 2020
47	*Melia azedarach* L.	Meliaceae	100	Jebril et al., 2020
48	*Melissa officinalis* L.	Lamiaceae	100	Aditi et al., 2021
49	*Mentha aquatica* L.	Lamiaceae	0.0625	Nouri et al., 2020
50	*Mikania micrantha* Kunth	Asteraceae	300	Biswas et al., 2019
51	*Nyctanthes arbor*-tristis L.	Oleaceae	25	Aditi et al., 2021
52	*Ocimum tenuiflorum* L.	Lamiaceae	3.90	Rupali et al., 2012
53	*Oryza sativa* L.	Poaceae	100	Aditi et al., 2021
54	*Paederia foetida* L.	Rubiaceae	50	Aditi et al., 2021
55	*Pedalium murex* L.	Pedaliaceae	0.005	Ghotekar et al., 2018
56	*Petiveria alliacea* L.	Phytolaccaceae	10	Lateef et al., 2018
57	*Phlomis cancellata* Bunge	Lamiaceae	160	Aditi et al., 2021
58	*Phyllanthus amarus* Schumach. & Thonn.	Phyllanthaceae	5	Aditi et al., 2021
59	*Pistacia atlantica* Desf.	Anacardiaceae	20	Marslin et al., 2015
60	*Prosopis farcta* (Banks & Sol.) J.F.Macbr.	Fabaceae	620	Miri et al., 2015
61	*Prunus* × *yedoensis* Matsum.	Rosaceae	250	Velmurugan et al., 2015
62	*Psidium guajava* L.	Myrtaceae	83.33	Aditi et al., 2021
63	*Raphanus raphanistrum* subsp. *sativus* (L.) Domin	Brassicaceae	50	Aditi et al., 2021
64	*Ricinus communis* L.	Euphorbiaceae	0.01	Aditi et al., 2021
65	*Salvia leriifolia* Benth.	Lamiaceae	40	Baghayeri et al., 2018
66	*Salvia rosmarinus* Spenn.	Lamiaceae	50	Hernandez-Morales et al., 2019
67	*Scoparia dulcis* L.	Plantaginaceae	100	Saratale et al., 2017
68	*Sesbania grandiflora* (L.) Poir.	Fabaceae	100	Ajitha et al., 2016
69	*Skimmia laureola* (DC.) Decne.	Rutaceae	32	Ahmed et al., 2017
70	*Solanum nigrum* L.	Solanaceae	25	Karthiga, 2018
71	*Syzygium cumini* (L.) Skeels	Myrtaceae	25	Asghar et al., 2020
72	*Talinum fruticosum* (L.) Juss.	Talinaceae	0.05	Aditi et al., 2021

No.	Plant Species	Family	MIC µg/ml	Ref.
73	*Tamarix gallica* L.	Tamaricaceae	20	Łopez-Miranda et al., 2016
74	*Taraxacum* sect. *Taraxacum* F.H.Wigg.	Asteraceae	4	Jyoti et al., 2016
75	*Tecoma stans* (L.) Juss. ex Kunth	Bignoniaceae	200	Biswas et al., 2018
76	*Tectona grandis* L.f.	Lamiaceae	60	Marslin et al., 2015
77	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	12,000	Aditi et al., 2021
78	*Terminalia chebula* Retz	Combretaceae	0.25	Aditi et al., 2021
79	*Thymbra spicata* L.	Lamiaceae	0.0125	Erci et al., 2017
80	*Urtica dioica* L.	Urticaceae	0.01	Mane et al., 2015
81	*Withania somnifera* (L.) Dunal	Solanaceae	40	Erci et al., 2017
82	*Ziziphus mauritiana* Lam.	Rhamnaceae	0.007812	Soman et al., 2016

Table 2
Examples of seed extract and families with MIC for the green synthesis of AgNPs.

No.	Plant Species	Family	MIC µg/ml	Ref.
1	*Alpinia hainanensis* K. Schum.	Zingiberaceae	83.33	He et al., 2017
2	*Coffea arabica* L.	Rubiaceae	0.8	Md et al., 2022
3	*Descurainia sophia* (L.) Webb ex Prantl	Brassicaceae	100	Ngoan et al., 2022
4	*Durio zibethinus* L.	Malvaceae	2000	Xu et al., 2014
5	*Embelia ribes* Burm.f.	Primulaceae	2000	Chahardoli et al., 2017
6	*Hibiscus cannabinus* L.	Malvaceae	100	Qais et al., 2020
7	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	6.25	Varghese et al., 2019
8	*Linum usitatissimum* L.	Linaceae	82	Ngoan et al., 2022
9	*Myristica fragrans* Houtt.	Myristicaceae	100	Dhayalan et al., 2016
10	*Nigella arvensis* L.	Ranunculaceae	8	Haseeb et al., 2017
11	*Persea americana* Mill.	Loranthaceae	100	Hernandez-Morales et al., 2019
12	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	344	Ngoan et al., 2022
13	*Pimpinella aromatica* M. Bieb.	Apiaceae	12.5	Zayed et al., 2020
14	*Rhamphospermum arvense* (L.) Andrz. ex Besser	Brassicaceae	100	Ngoan et al., 2022
15	*Salvia hispanica* L.	lamiaceae	40	Rautela et al., 2019
16	*Sesamum indicum* L.	Pedaliaceae	50	Ngoan et al., 2022
17	*Trachyspermum ammi* (L.) Sprague	Apiaceae	250	Varghese et al., 2019
18	*Trifolium resupinatum* L.	Fabaceae	0.0025	Khatami et al., 2016
19	*Trigonella foenum-graecum* L.	Fabaceae	0.00125	Giron-Vazquez et al., 2019

2.4.4. Biosynthesis of the AgNPs from root

Nowadays, the root plant extracts were used for AgNPs biosynthesis, and their application as antimicrobials has received much concern. The root extract of *Alpinia calcarata* was used as a stabilizing and bioreducing in the biosynthesis of spherical shape AgNPs. Antimicrobial activity was determined versus *P. mirabilis, B. cereus, S. aureus* besides *E. coli*. The results indicated that AgNPs have a high evaluation for cell lysis of the bacteria and have a shelf life of up to six months. Root-derived AgNPs from *Annona muricata*, *Asparagus racemosus*, *Pelargonium endlicherianum Fenzl.* were also highly sensitive to tested microorganisms (Kantipudi et al., 2018; Wang et al., 2016). The AgNPs from *Rheum palmatum* had a high ZOI but were less active than the antibiotic chloramphenicol (Srashti et al., 2022). *Phoenix dactylifera*, *Angelica pubescens*, *Lespidium draba,* root extracts were also shown to have antibacterial activity by AgNPs (Markus et al., 2017; Ovais et al., 2018). Although AuNPs and root extract have no antibacterial effect versus the studied Gram (-) besides Gram (+) bacterial strains, the AgNPs synthesis of *Angelica pubescens* demonstrated excellent antimicrobial properties (Markus et al., 2017). *Lysiloma acapulcensis* root extract was used to greenly synthesize AgNPs 3.2–6.0 nm. In other words, the researchers found that AgNPs induced by *Lysiloma acapulcensis* root extract had increased antibacterial activity. Many different types of bacteria were used to assess antimicrobial activity. The inhibitory potency was determined to be high in *C. albicans*, medium in *S. aureus* and low in *E. coli*. A research article denoted that there was a binding effect of reducing agents of *Raphanus sativus* on the size and shape of final nanoparticles (Garibo et al., 2020) (Tables 4 & 10).

2.4.5. Biosynthesis of the AgNPs from fruits

The fruit extracts are extensively studied in green nanoparticle synthesis (Alfuraydi et al., 2019). It has been stated that *Helicteres isora, Emblica officinalis*, *Solanum trilobatum, guava,* and *carambola* fruit extracts were used for spherical shape AgNPs synthesis (Mapara et al., 2015). The antibacterial activity of the fruit extract was explored against *B. subtilis, E. coli*, *K. pneumonia*, *S. aureus*, *B. cereus*, *S. typhi* besides *S. mutans*. The studies showed that while the fruit extract concentrations increase, the AgNP sizes decrease, sequentially increasing antibacterial activity (Mane et al., 2015).

Similarly, spherical shapes of AgNPs were synthesized from fruit extracts, including *Carissa macrocarpa* and *Rosa canina* extract, and the antimicrobial activity was performed (Soman et al., 2016; Kumar et al., 2017; Rashid et al., 2017). Several reports have shown that the fruit extracts of *Carissa macrocarpa* and *Rosa canina,* were successfully used in the antibacterial activity and the biosynthesis of AgNP studied (Andra et al., 2019; Du et al., 2019; Masum et al., 2019). The results displayed that the AgNPs of fruit extracts had significant antibacterial efficacy versus Gram (-) besides Gram (+) bacteria. The microwave was used for the biosynthesis of AgNPs by using cherry extracts. It was revealed to be less cost-effective processes and time. The synthesized NPs' size was tiny, which caused the cell of the human pathogen to lysis. Additionally, the antimicrobial activity of other fruit extracts like *Areca catechu* and *Capsicum frutescens*, mediated AgNPs was evaluated. The result revealed that AgNPs exhibited significant cell lysis of bacterial strains (Mollick et al., 2019; Odeniyi et al., 2020).

Besides, fruit extract of *Citrus limon* was treated for the AgNPs synthesis (Rahisuddin et al., 2015; Biswas et al., 2018). The lemon extract was combined with the shape directive CTAB to control the AgNP's shape. The results indicated that if the extract was directly applied to the various bacterial strains, it demonstrated the most potent activity against them [80In another study, the citrus extracts were used as a reducing material for the biosynthesis of AgNPs to study the antimicrobial activities versus *P. aeruginosa*, *E. coli,* and *S. aureus*. Fruit extracts from *Fragaria vesca* were (Mahendran et al., 2016). It was stated that the synthesized AgNPs size depends on multiple factors, including the $AgNO_3$ concentration, $AgNO_3$ ratio, the plant extract, time, the temperature of incubation and the pH (Dobrucka et al., 2018). The standard conditions for AgNPs synthesis showed the best incubation were at pH 10, 37C, 1:1 $AgNO_3$/Kokum fruit extract, 1.5 mM $AgNO_3$, for 24 h (Andra et al., 2019) (Tables 5 & 11).

2.4.6. Biosynthesis of the AgNPs from stem

The stem extract of plants has been widely used in the biosynthesis of AgNPs. Green synthesis of AgNPs was investigated through using *C. pulcherrima* stem extracts and evaluated its antimicrobial activities against various pathogenic microorganisms (Ahluwalia et al., 2018). Additionally, AgNPs biosynthesis was exhibited using different stem extracts such as *Fumariae herba,* and *Garcinia mangostana* (Moteriya and Chanda, 2020; Karthiga, 2018). The biosynthesized AgNPs were tested versus multiple Gram (+) besides Gram (-) bacterial strains. The results revealed that it's very effective in disrupting Gram-negative bacteria cell walls. The antimicrobial activities of AgNPs against various pathogenic bacterial strains was done by using synthesized AgNPs from aqueous extracts of *Swertia paniculate* besides *Cynodon dactylon*. The study indicated that the *Cynodon dactylon* extract mediates the synthesis of AgNPs, which was smaller than those mediated by Swertia paniculate. This implies that AgNPs of waste grass extract exhibit more significant antimicrobial activity owing to their ability to disrupt the bacterial cell wall structure easily. Another study used *Anthemis atropatana* extract to biosynthesize AgNPs. It evaluated the antimicrobial activities of the produced AgNPs versus many pathogenic bacteria, including *S. aureus*, *P. aeruginosa*, *E. coli* and *S. pyogenes.*. The results displayed that *P. aeruginosa* besides *S. aureus* have the lowest and highest MIC values, respectively (Table 6) (Khandel et al., 2018) (Tables 6 & 12).

2.5. Applications of silver nanoparticles

Many works of literature have been focusing on the useful application of AgNPs. It has been exhibited that the applications of silver nanoparticles are in the field of bio-medicine which includes cancer treatment, dental technology, bio-imaging, and other applications. Recently, cancer treatments have been attracted by the research of AgNPs owing to their high unique chemical and physical characters (Amarasinghe et al., 2020). Previous studies indicated that AgNPS have an obvious effect on cancer cells such as colon, uterine, and lung cancer. Also, AgNPs are considered one of the best great attractive and cheap particles, which have a wide range in environmental applications like repurification of wastewater treatment, agriculture and aqua mining. Silver nanoparticles can purify water and waste water by activating photolysis and adsorption (Castillo-Henríquez et al., 2020).

In agriculture, AgNPs are used to manufacture bio-fertilizers to control the absorption of plants, which helps preserve soil fertility through reducing nutrient loss in the soil (Martínez-Fernández et al., 2018). Silver nanoparticles are used now instead of inorganic and organic acids, because they are resistant to high temperatures, making them suitable in the food packaging industry. This increases its shelf life in preservation and makes it free from microbes (Jebril et al., 2020).

2.6. Antimicrobial mechanisms of silver nanoparticles

The real mechanisms of antibacterial, antifungal and toxic activities which carried out through AgNPs are nearly well-debated topic. Ag^{+} ions are suggested to have the great essential role in antimicrobial activities. Silver ions can form different complexes with nucleic acids such as DNA and RNA and preferentially interact with the phosphate group rather than nucleosides of nucleic acid. Some literatures show the electrostatic attractions among negatively charged bacterial cells besides positively charged nanoparticles which leads to be the most favorable suggested bactericidal agent (Biswas et al., 2019). Then, they have been exhibited to be accumulated inside the membrane in addition to diffuse inside the cells causing denature to the membranes or bacterial wall. It is proposed that Ag atom binds to thiol groups (-SH) of enzyme to form a stable S-Ag bond with thiol-containing structures. It may cause the inhibition of enzyme activity of the cell membrane that involves in transferring energy besides ions. It was also thought that Ag-I ion can enter the cell membrane and intercalate among the pyrimidine and purine base pairs distorting the hydrogen bonds between each two anti-parallel strand for denaturation of DNA molecules immediately. Nanoparticles are able to modify the phosphor-tyrosine profiles of bacterial peptides which influence on signal transduction lead to inhibit microorganism increment and growth. The antimicrobial effect is such a dose dependent with an independent of bacteria's acquisition of resistance versus antibiotics. Treatment of *E. coli* cells with AgNPs accumulating in its bacterial membranes causes increasing permeability and death of the cell (Parvataneni, 2020; Ganash et al., 2018; Abdelghany et al., 2018b).

3. Data analysis

In the present study, 62 % of the mentioned plant species are considered introduced cultivated hybrids. They are more represented in dicot plant families (91 %) (Fig. 4). many reasons enhance the concluded facts. First, monocot cells are unlike dicot ones in losing the ability to differentiate at an early level of development (Ajay et al., 2009). Different cell wall compositions among monocots and dicots govern the success of the AgNPs in vivo treatments. The cell wall of dicots is composed of β-linked glucose residues with chains of β-D-xyloglucans, glucuronoarabinoxylans and linear chains of β-*D*-xylose that characterize and polarize the interlocking toxicity of the Ag compounds. The AgNPs were prepared using either cysteamine hydrochloride (CHSB-AgNPs), tannic acid (TA-AgNPs) or trisodium citrate (TCSB-AgNPs). They showed comparable shape, size, distribution and nearly sizes equal to 15 ± 3 nm, which was reported by utilization of (TEM). The electrokinetic characteristics exhibited that TA-AgNPs and TCSB-AgNPs have negative charges, while CHSB-AgNPs have positive ones (Ewelina et al., 2022). Therefore, the types of secondary metabolite phytochemicals derived can be affected; moreover, charged ions can alter the active functional groups. In this investigation, alkaloids and phthalides are regarded as the most effective phytochemicals which show potential interactions in bacterial degradation and inhibition growth (Lucie et al., 2016) (Fig. 5). Second, the meristematic response of monocot cells to be hybrid and transgenic are less than dicot ones. This confirms why most silver nanoparticle research involves dicot plant species. Fabaceae and Lamiaceae are the most studied families in this field because Fabaceae plant members are the most adaptable plants in the world. In contrast, most medicinal plants are integrated in Lamiaceae (Fig. 6). On the other hand, Arecaceae, Poaceae, and Zingiberaceae are the most monocot families presented in this study (Fig. 7). Palm trees are the most evaluated monocot plants and grasses are the most abundant plants having highly sufficient dispersal mechanisms. The world map exhibits the studied plant families' distribution in all world countries. Africa, the Middle East, South Asia, southeastern Asia, the Far East, Eastern Europe, the USA, and the Southern American continent are concerned with invasive wild plant species. At the same time, western and northern Europe, Russia, Canada, Australia, New Zealand, and the Caribbean region trap most of the introduced cultivated hybrids (Map 1). This may refer to the nature of geographical areas and the use of the most advanced methods of genetic engineering and tissue culture approaches. The most commonly studied bacteria species was *E. coli*. (Fig. 8). MIC leaf values ranged (0.001–12,000 μg/ml) while other plant parts, seed (0.00125–20,000 μg/ml), flower (10–30,000 μg/ml), root (0.06–100,000 μg/ml), fruit (6.25–780 μg/ml), stem (3–500 μg/ml). The analysis of variance for all MICs is achieved. ANOVA test observed highly significant differences to leaves against other plant parts (F test = 134.24) (P value < 0.0001). Correlation analysis showed a very slightly negative value (-0.0197), which reflected that MIC values for all studied plant parts are more or less compatible. These values were represented graphically by regression. Regression describes the co-variation between MIC values of leaves and other plant parts (Al faifi et al., 2023). A simple Linear Regression (SLR) curve indicates the significant relationship between them, which forms a single horizontal line to show that the studied data was neutral and directed toward other plant parts (Fig. 9).

4. Conclusions

The increase in demand for green nanotechnology and chemistry has pushed toward adopting a green synthesis direction to synthesize nanomaterials via plants, microorganisms, and others over the last several decades. Considerable studies have been behaved on AgNPs synthesis through various plant extracts and their potency applications in other different fields like bioengineering sciences, biotechnology, catalysis, dye degradation medicine, electronics, imaging, sensors, textile engineering, water treatment, and optics. Additionally, plants contain various unique compounds that aid synthesis and speed up the synthesis rate. Sequentially, the process which is used to establish the nanoparticles does not necessitate using any nontoxic or toxic compounds that is why it is regarded as one of the significant defects of physical and chemical methods. Nano-technology is contniung in expanding and evolving in different fields. The findings of any nano-research project may improve other future studies and understand the technology in details moreover, educe the physical plus chemical properties of different compounds in plant extracts.

Nonetheless, novel and unique NPs will protect the environment while meeting the high needs for biomedical and clinical researches and drug developments. Bulk mass production of green material synthesis could improve people's general health in high densely populations distributed throughout under-developed countries. On account of the abundance of plant extracts, it may significantly reduce drug development costs and provide employment opportunities in remote source regions. Finally, the natural nanoparticles can improve world health by increasing the human's immunity with less drug toxicity and high biocompatibility enhancing establishment of a pure green environments for all living organisms on our planet.

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.

Acknowledgment

The author provide their continued grateful appreciation and thanks to the Deputyship for Research and Innovation, Ministry of Education in Saudi Arabia for funding this research article by a project number ISP23-62.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2023.103877.

References

Abdelghany, T.M., Al-Rajhi, A.M.H., Al Abboud, M.A., et al., 2018a. Recent advances in green synthesis of silver nanoparticles and their applications: About future directions. A review. *Bio Nano Sci.* 8, 5–16. https://doi.org/10.1007/s12668-017-0413-3.

Abdelghany, T.M., Al-Rajhi, A.M.H., Almuhayawi, M.S., et al., 2023. Green fabrication of nanocomposite doped with selenium nanoparticle-based starch and glycogen with its therapeutic activity: antimicrobial, antioxidant, and anti-inflammatory in vitro. Biomass Conv. Bioref. 13, 431–443. https://doi.org/10.1007/s13399-022-03257-8.

Abdelghany, T.M., Ganash M., Bakri M.M. *et al.* (2018b). Molecular characterization of *Trichoderma asperellum* and lignocellulolytic activity on barley straw treated with silver nanoparticles BioResources., 13: 1729-1744. https://doi.org/10.1016/j.arabjc.2022.103927.

Aditi, C., Joushan, A., Md, S.I., 2021. Green synthesis of phytochemical nanoparticles and their antimicrobial activity, A review study. Biomed. J. Sci. & Tech. Res. 34 (4), 26929–26935.

Ahluwalia V., Elumalai S., Kumar V., Kumar S., Sangwan R., S. (2018). Nano silver particle synthesis using *Swertia paniculate* herbal extract and its antimicrobial activity. *Microb. Pathog.* 114:402–8.

Ahmed, M.J., Murtaza, G., Mehmood, A., Bhatti, T.M., 2017. Green Synthesis of silver nanoparticles using leaves extract of *Skimmia laureola* characterization and antibacterial activity. Mater. Lett. 153, 10–13.

Ajay Pal S., Sandhua Gursharn S., Randhawab Kanwarpal S., Dhuggaa (2009). Plant Cell Wall Matrix Polysaccharide. *Biosyn. Mol. Pl.* pp. 1–11.

Ajitha, B., Reddy, Y.A.K., Reddy, P.S., 2015. Biosynthesis of silver nanoparticles using *Momordica charantia* leaf broth: Evaluation of their innate antimicrobial and catalytic activities. J. Photochem. Photobiol. B 146, 1–9.

Ajitha, B., Kumar, A., Reddy, Y., Rajesh, K.M., Sreedhara, R.P., 2016. Synthesis of copper nanoparticles and role of pH on particle size control. Mater. Today: Proc. 3, 1977–1984.

Al faifi, T., Abdurrahman S. Masrahi, A. El-Shabasy (2023). Mechanical structures of sidewalk plants: Anatomical evaluation. *Saudi J. Biological Sci.* (30) 103647.

Alfuraydi, A.A., Devanesan, S., Al-Ansari, M., AlSalhi, M.S., 2019. Eco-friendly green synthesis of silver nanoparticles from the sesame oil cake ants potential anticancer and antimicrobial activities. J. Photochem. Photobiol. 192, 83–89.

Ali Z. A., Yahya R., Sekaran S. D., Puteh R. (2016). Green synthesis of silver nanoparticles by using carambola fruit extract and their antibacterial activity. *Adv. Mater. Sci. Eng.* 4102196.

Al-Rajhi, A.M.H., Yahya, R., Bakri, M.M., et al., 2022. In situ green synthesis of Cu-doped ZnO based polymers nanocomposite with studying antimicrobial, antioxidant and anti-inflammatory activities. Appl. Biol. Chem. 65, 35. https://doi.org/10.1186/s13765-022-00702-0.

Amarasinghe, L.D., Wickramarachchi, P.A., Aberathna, A.A., Sithara, W.S., De Silva, C. R., 2020. Comparative study on larvicidal activity of green synthesized silver nanoparticles and *Annona glabra* (Annonaceae) aqueous extract to control *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae). Heli. 6, e04322.

Anandalakshmi, K., Venugobal, J., Ramasamy, V., 2016. Characterization of silver nanoparticles by green synthesis method using *Pedalium murex* leaf extract and their antibacterial activity. Appl. Nanosci. 6, 399.

Andra, S., Balu, S., Ramoorthy, R., Muthalagu, M., Manisha, V.S., 2019. *Terminalia bellerica* fruit extract mediated synthesis of silver nanoparticles and their antimicrobial activity. Mater. Today Proc. 9, 639–644.

Asghar, M.A., Zahir, E., Asghar, M.A., Iqbal, J., Rehman, A.A., 2020. Facile, one-pot biosynthesis and characterization of iron, copper and silver nanoparticles using *Syzygium cumini* leaf extract: As an effective antimicrobial and aflatoxin B1 adsorption agents. PLoS One 15, e0234964.

Baghayeri, M., Mahdavi, B., Hosseinpor-Mohsen, Z., Abadi, F.S., 2018. Green synthesis of silver nanoparticles using water extract of *Salvia leriifolia*: Antibacterial studies and applications as catalysts in the electrochemical detection of nitrite. Appl. Organomet. Chem. 32, e4057.

Bar, H., Bhui, D.K., Sahoo, G.P., Sarkar, P., Pyne, S., Misra, A., 2009. Green synthesis of silver nanoparticles using seed extract of *Jatropha curcas*. Colloids Surf. A Physicochem. Eng. Asp. 348, 212–216.

Biswas A., Vanlalveni C., Adhikari P. P., Lalfakzuala R, L., Rokhum L. (2019). Biosynthesis, characterisation and antibacterial activity of *Mikania micrantha* leaf extract-mediated AgNPs. *Micro. Nano. Lett.* 14, 799–803.

Biswas, A., Rokhum, L., 2018. Bio derived synthesis of silver nanoparticles from *Tecoma stans* leaf extract and its photocatalytic and antimicrobial activity. Int. Conf. Syst. Process. Phys. Chem. Biol. 1–7.

Bose, D., Chatterjee, S., 2015. Antibacterial activity of green synthesized silver nanoparticles using Vasaka (*Justicia adhatoda* L.) leaf extract. Indian J. Microbiol. 55, 163–217.

Castillo-Henríquez, L., Alfaro-Aguilar, K., Ugalde-Álvarez, J., 2020. Green synthesis of gold and silver nanoparticles from plant extracts and their possible applications as antimicrobial agents in the agricultural area. J. Nanomater. 10, 1763.

Chahande, R.K., Mehere, B.A., Pantawane, P.K., Chouke, P.B., Murai, S.R., 2020. Bio-inspired synthesis of silver nanoparticles assisted *Murraya koneigii* leaf extract and its antimicrobial activity. Mater. Today: Proc. 29, 923–928.

Chahardoli, A., Karimi, N., Fattahi, A., 2017. Biosynthesis, characterization, antimicrobial and cytotoxic effects of silver nanoparticles using *Nigella arvensis* seed extract. Iran J. Pharm. Res. 1167–1175.

Chandrasekhar, N., Vinay, S.P., 2017. Yellow colored blooms *Argemone mexicana* and *Turnera ulmifolia* mediated synthesis of silver nanoparticles and study of their antibacterial and antioxidant activity. Appl. Nanosci. 7, 851–861.

Chauhan, N., Tyagi, A.K., Kumar, P., Malik, A., 2016. Antibacterial potential of *Jatropha curcas* synthesized silver nanoparticles against food borne pathogen. Front. Microbiol. 7, 1748.

Chhangte V., Samuel L., Ayushi B., Manickam S., Bishwajit C., Samuel L. Rokhum (2021). Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: a review of recent literature, *RSC Adv.* 11, 2804.

Christophe, T., Emile, M., Jean-Marie, G., Agnel, B.R., 2008. Distilled lavandin (*Lavandula intermedia Emeric* ex *Loisel*) Wastes: A Rich Source of Coumarin and Herniarin. J. Essent. Oil Res. 20, 412–413.

Dhand, V., Soumya, L., Bharadwaj, S., Chakra, S., Bhatt, D., Sreedhar, B., 2016. Green synthesis of silver nanoparticles using *Coffea arabica* seed extract and its antibacterial activity. Mater. Sci. Eng. C 58, 36–43.

Dhayalan, M., Denison, M.I., Anitha, J.L., Krishnan, K., 2016. In vitro antioxidant, antimicrobial, cytotoxic potential of gold and silver nanoparticles prepared using *Embelia ribes*. Nat. Prod. Res. 31, 465–548.

Dobrucka, R., Kaczmarek, M., Dlugaszewska, J., 2018. Characterization and antibacterial activity of silver nanoparticles biosynthesized using (*Indigofera oblongifolia*) leaves extract. Adv. Nat. Sci. Nanosci. Nanotechnol. 9, 025015.

Du, J., Hu, Z., Yu, Z., Li, H., Pan, J., Zhao, D., Bai, Y., 2019. Antibacterial activity of a novel *Forsythia suspensa* fruit mediated green silver nanoparticles against food-borne pathogen and mechanisms. Mater. Sci. Eng. 102, 247–253.

Du, L., Xian, L., Feng, J.X., 2011. Rapid extra-/intracellular biosynthesis of gold nanoparticles by the fungus *Penicillium sp*. J. Nanopart. Res. 13, 921–930.
Ebrahiminezhad, A., Barzegar, Y., Ghasemi, Y., Berenjian, A., 2017. Green synthesis and characterization of silver nanoparticles using *Alcea rosea* flower extract as a new generation of antimicrobials. Chem. Ind. Chem. Eng. Q 2017 (232), 31–37.
Erci, F., Cakir-Koc, R., Isildak, I., 2017. Green synthesis of silver nanoparticles using *Thymbra spicata* L. var. *spicata* (zahter) aqueous leaf extract and evaluation of their morphology-dependent antibacterial and cytotoxic activity. Artif. Cells, Nanomed., Biotechnol. 1–9, 1415917.
Ewelina M., Anna G., Ewa P., Sebastian W., Przemieniecki M. Oćwieja (2022). Phytotoxicity of Silver Nanoparticles with Different Surface Properties on Monocots and Dicots Model. *Plants. J. Soil Sci. Plant Nut.* 22, 1647-1664.
Fatma, Ö.K., Seval, Ç., Fatih, D., 2020. Biosynthesis of silver nanoparticles using leaf extract of *Aesculus hippocastanum* (horse chestnut): Evaluation of their antibacterial, antioxidant and drug release system activities. Mater. Sci. Eng. 107, 110207.
Ganash M, Abdel Ghany T. M., Omar A. M. (2018). Morphological and biomolecules dynamics of phytopathogenic fungi under stress of silver nanoparticles. *BioNanoScience* 8:566-573 10.1007/s12668-018-0510-y.
Garibo D., Borbon-Nunez H. A., De Léon J. N., Garćia Mendoza E. (2020). Green synthesis of silver nanoparticles using *Lysiloma acapulcensis* exhibit high-antimicrobial activity. *Sci.* 10:12805.
Ghotekar, S., Savale, A., Pansambal, S., 2018. Phytofabrication of fluorescent silver nanoparticles from *Leucaena leucocephala* L. leaves and their biological activities. J. Water Environ. Nanotechnol. 3, 95–105.
Giron-Ávazquez N. G., Ǵomez-Gutiérrez C. M., SotoRobles C. A., Nava O. (2019). Study of the effect of *Persea americana* seed in the green synthesis of silver nanoparticles and their antimicrobial properties. *Results Phys.* 13:102142.
Haldar, A.G.M., Mahapatra, D.K., Dadure, K.M., Chaudhary, R.G., 2022. Natural extracts-mediated biosynthesis of zinc oxide nanoparticles and their multiple pharmacotherapeutic perspective. Jord. J. Physics. 15 (1), 67–79.
Haseeb, M.T., Hussain, M.A., Abbas, K.S., Youssif, B.G.M., Bashir, S., 2017. Linseed hydrogel-mediated green synthesis of silver nanoparticles for antimicrobial and wound-dressing applications. Int. J. Nanomed. 12, 2845–2855.
He, Y., Wei, F., Ma, Z., Zhang, H., Yang, Q., Yao, B., Huang, Z., 2017. Green synthesis of silver nanoparticles using seed extract of Alpinia katsumadia, and their antioxidant, cytotoxicity, and antibacterial activities. RSC Adv. 7, 39842–39851.
Hernandez-Morales L., Espinoza-Ǵomez H., FloresĹopez L. Z. (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. *Appl. Surf. Sci.* 489:952–61.
Huang, W., Yan, M., Duan, H., Bi, Y., Cheng, X., Yu, H., 2020. Synergistic antifungal activity of green synthesized silver nanoparticles and epoxiconazole against *Setosphaeria turcica*. J. Nanomater. 1–7, 9535432.
Jebril S. R., Khan R., Ben Jenana Dridi C. (2020). Green synthesis of silver nanoparticles using *Melia azedarach* leaf extract and their antifungal activities: In vitro and in vivo. *Mater. Chem. Phys.* 248, 122898.
Jyoti, K., Baunthiyal, M., Singh, A., 2016. Characterization of silver nanoparticles synthesized using *Urtica dioica* Linn. leaves and their synergistic effects with antibiotics. J. Radiat. Res. Appl. Sci. 9, 217–227.
Kanagamani, K., Muthukrishnan, P., Shankar, K., Kathiresan, A., Barabadi, H., Saravanan, M., 2019. Antimicrobial, cytotoxicity and photocatalytic degradation of norfloxacin using Kleinia grandiflora mediated silver nanoparticles. J. Cluster Sci. 30, 1415–1424.
Kantipudi, S., Pethakamsetty, L., Kollana, S.M., Sunkara, J.R., Kollu, P., 2018. *Diospyros assimilis* root extract assisted biosynthesized silver nanoparticles and their evaluation of antimicrobial activity. IET Nanobiotechnol. 12, 133–137.
Karthiga, P., 2018. Preparation of silver nanoparticles by *Garcinia mangostana* stem extract and investigation of the antimicrobial properties. Biotechnol. Res. Innov. 2, 30–36.
Keshari, A.K., Srivastava, R., Singh, P., Yadav, V.B., Nath, G., 2020. Antioxidant and antibacterial activity of silver nanoparticles synthesized by *Cestrum nocturnum*. J. Ayurveda Integr. Med. 11, 37–44.
Khandel, P., Yadaw, R.K., Soni, D.K., Kanwar, L., Shahi, S.K., 2018. Biogenesis of metal nanoparticles and their pharmacological applications: present status and application prospects. J. Nanostruct. Chem. 8 (3), 217–254.
Khatami, M., Nejad, M.S., Salari, S., Almani, P.G.N., 2016. Plant-mediated green synthesis of silver nanoparticles using *Trifolium resupinatum* seed exudate and their antifungal activity. IET Nanobiotechnol. 10, 237–243.
Kumar, C.M.K., Yugandhar, P., Savithramma, N., 2017. Isolation, characterization and in silico docking studies of synergistic estrogen receptor an anticancer polyphenols from *Syzygium alternifolium* (Wt.) Walp. J. Intercult. Ethnopharmacol. 6, 296–1210.
Kuppurangan, G., Karuppasamy, B., Nagarajan, K., Krishnasamy, S.R., Viswaprakash, N., Ramasamy, T., 2016. Biogenic synthesis and spectroscopic characterization of silver nanoparticles using leaf extract of *Indoneesiella echioides*: in vitro assessment on antioxidant, antimicrobial and cytotoxicity potential. Appl. Nanosci. 2016 (6), 973–982.
Ĺopez-Miranda J. L., Ávazquez M., Fletes N., Esparza R. Rosas G. (2016). Biosynthesis of silver nanoparticles using a *Tamarix gallica* leaf extract and their antibacterial activity. *Mater. Lett.* 176, 285–289.
Lateef, A., Ojo, S.A., Elegbede, J.A., 2016. The emerging roles of arthropods and their metabolites in the green synthesis of metallic nanoparticles. Nanotechnol. Rev. 5 (6), 601–622.
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. 1–7, 1479864.
Lourthuraj, A.A., Selvam, M.M., Hussain, M.S., Abdel-Warith, A.W.A., Younis, E.M., Al-Asgah, I.N.A., 2020. Dye degradation, antimicrobial and larvicidal activity of silver nanoparticles biosynthesized from *Cleistanthus collinus*. Saudi J. Biol. Sci. 2020 (27), 1753–1759.
Lucie, M., Jakub, R., Marketa, P., Tomas, M., Ondrej, U., 2016. Effects of secondary plant metabolites on microbial populations: Changes in community structure and metabolic activity in contaminated environments. Int. J. Mol. Sci. 17 (8), 1205.
Maghimaa, M., Ali, S., 2020. Green synthesis of silver nanoparticles from *Curcuma longa* L. and coating on the cotton fabrics for antimicrobial applications and wound healing activity. J. Photochem. Photobiol. b. 204, 111806.
Mahendran, G., Ranjitha, B., Kumari, D., 2016. Biological activities of silver nanoparticles from *Nothapodytes nimmoniana* (Graham) Mabb. Fruit Extract. Food Sci. Hum. Well. 5, 207–218.
Makarov, V.V., Love, A.J., Sinitsyna, O.V., Makarova, S.S., 2014. Green nanotechnologies: Synthesis of metal nanoparticles using plants. Acta Nat. 6, 35–44.
Mane Gavade S. J., Nikam G. H., Dhabbe R. S., Sabale S. R., Tamhankar B. V., Mulik G. N. (2015). Green synthesis of silver nanoparticles by using carambola fruit extract and their antibacterial activity. *Adv. Nat. Sci. Nanosci. Nanotechnol.* 6: 045015.
Manjamadha, V.P., Muthukumar, K., 2016. Ultrasound assisted green synthesis of silver nanoparticles using weed plant. Bioprocess. Biosyst. Eng. 39, 401–411.
Manosalva, N., Tortella, G., Diez, M.C., Schalchli, H., Seabra, A.B., Durán, N., Rubilar, O., 2019. Green synthesis of silver nanoparticles: Effect of synthesis reaction parameters on antimicrobial activity. World J. Microbiol. Biotechnol. 35, 88.
Mansoori, G.A., 2005. Principles of nanotechnology: molecular-based study of condensed matter in small systems. World Sci. 11.
Mapara, N., Sharma, M., Shriram, V., Bharadwaj, R., Mohite, K.C., 2015. Antimicrobial potential of *Helicteres isora* silver nanoparticles against extensively drug-resistant (XRD) clinical isolates of *Pseudomonas aeruginosa*. Appl. Microbiol. Biotechnol. 99, 10655–10667.
Markus, J., Wang, D., Kim, Y.J., Ahn, S., Mathiyalagan, R., Wang, C., 2017. Biosynthesis, characterization, and bioactivities evaluation of silver and gold nanoparticles mediated by roots of chines herbal *Angelica pubescens*. Nanoscale Res. Lett. 12, 46–54.
Marslin, G., Selvakesavan, R.K., Franklin, G., Sarmento, B., Dias, A.C.P., 2015. Antimicrobial activity of cream incorporated with silver nanoparticles biosynthesized from *Withania somnifera*. Int. J. Nanomed. 10, 5955–5963.
Martínez-Fernández, D., Barroso, D., Komárek, M., 2018. Root water transport of *Helianthus annuus* L. under iron oxide nanoparticle exposure. Environ. Sci. Pollut. Res. 23, 1732–1741.
Masum, M.I., Siddiqa, M.M., Ali, K.A., Zhang, Y., Abdallah, Y., 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.
Medda, S., Hajra, A., Dey, U., Bose, P., Mondal, N.K., 2014. Biosynthesis of silver nanoparticles from *Aloe vera* leaf extract and antifungal activity against *Rhizopus sp.* and *Aspergillus sp*. Appl. Nanosci. 5, 875–880.
Miri, A., Sarani, M., Rezazade, B.M., Darroudi, M., 2015. Plant-mediated biosynthesis of silver nanoparticles using *Prosopis farcta* extract and its antibacterial properties. Spectrochim. Acta, Part A 141, 287–291.
Mollick, M.M., Rana, D., Dash, S.K., Chattopadhyay, S., Bhowmick, B., 2019. Studies on green synthesized silver nanoparticles using *Abelmoschus esculentus* (L.) pulp extract having anticancer (in vitro) and antimicrobial applications. Arabian J. Chem. 12, 2572–2584.
Moteriya, P., Chanda, S., 2020. Green synthesis of silver nanoparticles from *Caesalpinia pulcherrima* leaf extract and evaluation of their antimicrobial, cytotoxic and genotoxic potential (3-in-1 System). *J. Inorg. Organomet. Polym. Mater.* 30, 3920–3932.
Mudasir, A., Kaiser, M., Sandeep, S., 2017. Chitosan centered bionanocomposites for medical specialty and curative applications: A review. Int. J. Pharma. 529 (1–2), 200–217.
Muthukrishnan S., Bhakya S., Senthil Kumar T., Rao M. V. (2015). Biosynthesis, characterization and antibacterial effect of plant-mediated silver nanoparticles using *Ceropegia thwaitesii*–An endemic species. *Rao, Ind. Crops Prod.*, 2015, 63, 119–124.
Narayanan, K.B., Sakthivel, N., 2011. Green synthesis of biogenic metal nanoparticles by terrestrial and aquatic phototrophic and heterotrophic eukaryotes and biocompatible agents. Adv. Colloid Interface Sci. 169 (2), 59–79.
Nath, D., Banerjee, P., 2013. Green nanotechnology–a new hope for medical biology. Environ. Toxicol. Pharmacol. 36 (3), 997–1014.
Ngoan T. T., Nguyen Luan M., Nguyen Thuy T. T., Nguyen Thuong, T., Nguyen Duyen T. C., Nguyen T., Tran V. (2022). Formation, antimicrobial activity, and biomedical performance of plant-based nanoparticles: a review. *Enviro. Chem. Lett.* 20:2531–2571.
Nilavukkarasi, M., Vijayakumar, S., Prathip, K.S., 2020. Biological synthesis and characterization of silver nanoparticles with *Capparis zeylanica* L. leaf extract for potent antimicrobial and anti proliferation efficiency. Mater. Sci. Energy Technol. 3, 371–376.
Nouri, A., Tavakkoli, Y.M., Lajevardi, A., Rezaei, Z., Ghorbanpour, M., Tanzi, M., 2020. Ultrasonic-assisted green synthesis of silver nanoparticles using *Mentha aquatica* leaf extract for enhanced antibacterial properties and catalytic activity. Colloids Interface Sci. 35, 100252 https://doi.org/10.1016/j.colcom.2020.100252.
Nyabola A. O., Kareru P. G., Madivoli E. S., Wanakai S., I., Maina E. G. (2020). Formation of Silver Nanoparticles via *Aspilia pluriseta* Extracts their Antimicrobial and Catalytic Activity. *J. Inorg. Organomet. Polym. Mater.* 30, 3493–3501.
Odeniyi, M.A., Okumah, V.C., Adebayo-Tayo, B.C., Odeniyi, O.A., 2020. Green synthesis and cream formulations of silver nanoparticles of *Nauclea latifolia* (African peach)

fruit extracts and evaluation of antimicrobial and antioxidant activities. Sustainable Chem. Pharm. 15, 100197.
Onitsuka, S., Hamada, T., Okamura, H., 2019. Preparation of antimicrobial gold and silver nanoparticles from tea leaf extracts. Colloids Surf. B 173, 242–248.
Otari S. V., Pawar S. H., Patel S., K. S., Singh R. K., Kim S. Y., Lee J. H., Zhang L., Lee J. K. (2017). *Canna edulis* leaf extract-mediated preparation of stabilized silver nanoparticles: characterization, antimicrobial activity, and toxicity studies. *J. Microbiol. Biotechnol.*, 2017, 27, 731–738.
Ovais, M., Khalil, A.T., Islam, N.U., 2018. Role of plant phytochemicals and microbial enzymes in biosynthesis of metallic nanoparticles. Appl. Microbiol. Biotechnol. 102, 6799–16714.
Parvataneni, R., 2020. Biogenic synthesis and characterization of silver nanoparticles using aqueous leaf extract of *Scoparia dulcis* L. and assessment of their antimicrobial property. Drug Chem. Toxicol. 43, 307–321.
Potbhare, A.K., Chaudhary, R.G., Chouke, P.B., Yerpude, S., Mondal, A., Sonkusare, V.N., et al., 2019. Phytosynthesis of nearly monodisperse CuO nanospheres using *Phyllanthus reticulatus/Conyza bonariensis* and its antioxidant/antibacterial assays. Mater. Sci. Eng. c. 99, 783–793.
Potbhare, A.K., Chouke, P.B., Mondal, A., Thakare, R.U., Mondal, S., Chaudhary, R.G., Rai, A.R., 2020. *Rhizoctonia solani* assisted biosynthesis of silver nanoparticles for antibacterial assay. Mater. Today Proc. 29, 939–945.
Qais, F.A., Shafiq, A., Ahmad, I., Husain, F.M., Khan, R.A., Hassan, I., 2020. Green synthesis of silver nanoparticles using *Carum copticum*: Assessment of its quorum sensing and biofilm inhibitory potential against gram negative bacterial pathogen. Microb. Pathog. 144, 104172.
Rahisuddin, S.A.A., Khan, Z., Manzoor, N., 2015. Green synthesis of biogenic silver nanoparticles using *Raphanus sativus* extract, effects of stabilizers on the morphology, and their antimicrobial activities. Bioprocess Biosyst. Eng. 38, 1773–1781.
Ramadan, M.A., Shawkey, A.E., Rabeh, M.A., Abdellatif, A.O., 2020. Promising antimicrobial activities of oil and silver nanoparticles obtained from *Melaleuca alternifolia* leaves against selected skin-infecting pathogens. J. Herb. Med. 20, 100289.
Rao, K.J., Korumilli, T., Jakkala, S., Singh, K., 2021. Optimization of the one-step green synthesis of silver and gold nanoparticles using aqueous *Athyrium filix femina* extract using the taguchi method. Bionanosci. 11 (4), 915–922.
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 158, 408–415.
Rashid, M.M., Akhter, K.N., Chowdhury, J.A., Hossen, F., Hussain, M.S., Hossain, M.T., 2017. Characterization of phytoconstituents and evaluation of antimicrobial activity of silver-extract nanoparticles synthesized from *Momordica charantia* fruit extract. BMC Complement. Altern. Med. 17, 336.
Rautela, A., Rani, J., Debnath, M., 2019. Green synthesis of silver nanoparticles from *Tectona grandis* seeds extract: characterization and mechanisms of antimicrobial action on different microorganisms. J. Anal. Sci. Technol. 10, 1–10.
Ray, P.C., 2010. Size and shape dependent second order nonlinear optical properties of nanomaterials and their application in biological and chemical sensing. Chem. Rev. 110 (9), 5332–5365.
Rupali, S., Patil, M.R., Kokate, S., Kolekar, S., 2012. Bioinspired synthesis of highly stabilized silver nanoparticles using *Ocimum tenuiflorum* leaf extract and their antibacterial activity. Spectrochim. Acta Part A: Mol. Biomol. Spect. 91, 234–238.
Sana S. S., Badineni V. R., Arla S. K., Naidu Boya V. K. (2015). Eco-friendly synthesis of silver nanoparticles using leaf extract of *Grewia flaviscences* and study of their antimicrobial activity. *Mater. Lett.* 145:347–50.
Sara, E., Gomaa, M., Yahayu, M., Nurjayadi, D., Joe, D., El Enshasy, H., 2019. Antimicrobial Compounds from *Catharanthus roseus* review. Int. J. Sci. Tech. Res. 8 (10), 113–121.
Saratale, R.G., Benelli, G., Kumar, G., Kim, D.S., Saratale, G.D., 2017. Exploiting fruit byproducts for eco-friendly nanosynthesis: *Citrus* × *clementi*na peel extract mediated fabrication of silver nanoparticles with high efficacy against microbial pathogens and rat glial tumor C6 cells. Environ. Sci. Pollut. Res. 25, 10392–10406.
Soman, S., Ray, J.G., Photochem, J., 2016. Silver nanoparticles synthesized using aqueous leaf extract of *Ziziphus oenoplia* (L.) Mill: Characterization and assessment of antibacterial activity. Photobiol. B 163, 391–402.
Srashti, C., Aditi, D., Panwar, N.S., 2022. A review on *Skimmia laureola*. Rev. - *Mod. Phytomorph.* 16 (1), 12–13.
Tolaymat, T.M., El Badawy, A.M., Genaidy, A., 2010. An evidencebased environmental perspective of manufactured silver nanoparticle in syntheses and applications: a systematic review and critical appraisal of peer-reviewed scientifc papers. Sci. Total Environ. 408, 999–1006.
Varghese, R., Almalki, M.A., Ilavenil, S., Rebecca, J., Choi, K.C., 2019. Silver nanopaticles synthesized using the seed extract of *Trigonella foenum-graecum* L. and their antimicrobial mechanism and anticancer properties. Saudi J. Biol. Sci. 26, 148–154.
Velmurugan, P., Cho, M., Lim, S.S., Seo, S.K., Myung, H., Bang, K.S., 2015. Phytosynthesis of silver nanoparticles by *Prunus yedoensis* leaf extract and their antimicrobial activity. Mater. Lett. 138, 272–325.
Verma, A., Mehata, M.S., 2016. Controllable synthesis of silver nanoparticles using *Neem* leaves and their antimicrobial activity. J. Radiat. Res. Appl. Sci. 9, 109–115.
Vijilvani, C., Bindhu, M.R., Frincy, F.C., AlSalhi, M., Sabitha, S., 2020. Antimicrobial and catalytic activities of biosynthesized gold, silver and palladium nanoparticles from *Solanum nigurum* leaves. J. Photochem. Photobiol. b. 202, 111713.
Wang, D., Markus, J., Wang, C., Kim, Y.J., Mathiyalagan, R., Aceituno, V.C., 2016. Green synthesis of gold and silver nanoparticles using aqueous extract of *Cibotium barometz* root. *Artif. Cells Nanomed. Biotechnol.* 45, 1548–1555.
Xu, H., Wang, L., Su, H., Gu, L., Han, T., Meng, F., Liu, C., 2014. Making good use of food wastes: green synthesis of highly stabilized silver nanoparticles from grape seed extract and their antimicrobial activity. Food Biophys. 10, 12–18.
Zayed, M.F., Mahfoze, R.A., El-kousy, S.M., AlAshkar, E.A., 2020. In-vitro antioxidant and antimicrobial activities of metal nanoparticles biosynthesized using optimized *Pimpinella anisum* extract. Colloids Surf. 585, 124167.

Further reading

Anjali Sumit K., Tulasi K., Rajneesh T. R., Arutselvan Abhijeet S. K., Yasser N., Victor C., Tatiana M., Chetan K. (2023). Role of plant secondary metabolites in defence and transcriptional regulation in response to biotic stress. *Plant Str.* 8, 100154.
Asem, M.D., Khomdram, K.D., Pukhrambam, P.D., Moirangthem, L.D., Sudripta, D., 2023. Metabolic engineering of plant secondary metabolites: prospects and its technological challenges. Front. Plant Sci. 14, 1–3.
Gattu S., Yih-Yuan C., Neelamegam R., Muthukalingan K., Kayalvizhi N., Douglas J. H. Shyu (2022). Biologically Synthesized Silver Nanoparticles and Their Diverse Applications. *Nanomater.* 12, 3126.
Suresh, M., 2019. Efficacy and mechanism of traditional medicinal plants and bioactive compounds against clinically important pathogens. Antibio. 8 (4), 257.
Xue, Z., Meng, Z., Fujiao, H., Gang, O., Zhangyong, S., Fangyan, L., 2023. The potential role of plant secondary metabolites on antifungal and immunomodulatory effect. Appl. Micro. Biotech. 107, 4471–4492.
Zubair, A.R., Waqar, A., Alexander, S.L., Saad, B.J., 2023. From Nature to Lab: A Review of Secondary Metabolite Biosynthetic Pathways, Environmental Influences, and In Vitro Approaches. Metaboli. 13 (8), 895.