Antimicrobial evaluation of herbal medicinal/plant extract based on green silver nanoparticle synthesis: A systematic review

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Abstract

Introduction: Medicinal plants have a broad range of active components that have been used by most of the world's population to cure a plethora of maladies. Many innovative approaches have been used in recent years to identify, proliferate, develop, and evaluate medicinal plants for use in modern and traditional medical formulations, as well as in drug discovery.

Methods: We looked for papers on green synthesis of AgNPs (silver nanoparticles)by various plant extracts on Google Scholar and Pub Med. "Ag Nanoparticles," "Plant Extract," and "Antimicrobial" were the search terms. Eligibility testing was done in a standardized, non-blinded way. First author, year of publication, subject related to green synthesis of silver nanoparticles from plants, Ag nanoparticles from leaf, peel and flower extract, antimicrobial properties of leaf, flower and peel extract were all retrieved from each paper.

Results: A PubMed search yielded 310 results. In all, 25 papers were considered in our review, which were published between 2011 and 2022. There were no human studies reported. Most of the studies considered (12/25; 63.15 percent) were carried out by Indian research groups. In seven studies, flower was used for the extraction of silver nanoparticlesand in 6 studies, leaf extract was used for the extraction of silver nanoparticles while in 12 studies, peel extract was used for the extraction. The size of synthesized silver nanoparticles ranged from 4nm to 90nm. The most used method for characterization included UV-Vis, TEM (fifteen studies), SEM (five studies), FTIR, XRD, Raman scattering (one study),Cell viability assay (one study). The antimicrobial properties were carried out by MIC assay.Almost all the studies showed positive MIC values against the studied microbes.

Conclusion: Green synthesized nanoparticles have been shown to be persistent, versatile, and are safe. Green synthesized silver nanoparticles can clearly compete with and sometimes outperform commercial antibiotics for the management of microbial diseases. As a result, these environmentally friendly silver NPs may be employed as an effective antibacterial agent against pathogenic microbes that are multidrug resistant.

Keywords: Antimicrobial activity, Biosynthesis, FTIR, green synthesis, nanoparticle, Plant extract, silver nanoparticles

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Introduction

Nanotechnology is a branch of science that deals with synthesis, modification and application of materials ranging within nanometers. With advancement of technologies and better scientific understanding, a route for study and development in medicinal and herbal plant biology toward intersection of the nanotechnology has now been discovered. One such interference is employing source of plants in nanoparticles green synthesis. Nanotechnology deals with the design, characterizations as well as performance of nanomaterials. Nanomaterials are the substances that have the particle size ranges from 1 - 100 nm [1,2]. Nanomaterials have garnered tremendous attentions owing to high surface area and various sophisticated chemical and physical capabilities. The characteristics of materials are distinct at nanoscale as opposed to larger particles owing to increased ratio of surface area to volume as well as quantum effect. The magnetic, electrical, and optical characteristics of materials are altered by quantum phenomena. The material at nanoscale is of 3 types, viz. 1, 2 and 3-dimensional. A thin film layer is involved with 1-D while nanotubes and nano wires are exposed to 2-D; nanoparticles are enduring 3-D structures [1]. The inorganic NPs such as metal oxide and metal NPs display numerous diverse chemical and physical characteristics other than their parent bulk molecule. They may be produced by addition of precipitating, reducing or oxidizing agents during their synthesis [3,4]. These nanoparticles exhibit cold welding qualities, distinct nonlinear optical characteristics, ceramics, super magneticbehavior, sensitivity, environmental remediation, catalytic properties, and antibacterial properties capacities [5, 6]. The commonly found inorganic metal oxide as well as metal oxide NPs are calcium oxide (CaO), gold (Au), platinum (Pt), palladium (Pd), cupric oxide (CuO), titanium dioxide (TiO2), zinc oxide (ZnO), manganese dioxide (MnO2), magnesium oxide (MgO), silver (Ag), zirconium dioxide (ZrO2), iron oxides and cerium oxide (CeO2) [7–12].

Silver nanoparticles stand out among all metallic nanoparticles, as these are most extensively studied by researchers throughout the world due to their ease of synthesis, diverse applications, flexibility, shape, and large surface areas. It has been discovered that silver nanoparticles have no effect on viable cells and are hence incapable of inducing microbial resistance [13]. It is hypothesized that silver NPs may bind to cell wall and interfere with the rate of cellular respiration as well as the permeability of cell wall [14]. The green synthesis of silver NPs by using microorganisms such as fungi, bacteria, as well as plants has received a great deal of attention in the studies to date. This is primarily due to the reducing and antioxidant properties of these microorganisms, which are typically responsible for reduction of the metal compounds in its respective NPs. Even though synthesis mediated by microbe is one of the different biological techniques of synthesis of silver nanoparticle, it is not particularly ideal for commercial applicability due to the demand for extremely aseptic settings and maintenance of these conditions. As a result, using plant extract for this purpose can be more beneficial than the employment of microorganisms because of the simplicity with which they may be improved, the lengthy maintaining process of cell cultures, and the lower risk of biohazard [15].

Metal NPs that are biocompatible have received a great deal of attention in recent years, and their prospective uses in biomedicine have sparked substantial interest in this area [16]. The bio-based or green synthetic techniques that use any materials that are plant-derived such as stem, root, flowers, leaves, peels, and bark are preferable to other traditional methods since they are more environmentally friendly. Picking plants for biosynthesis is

justified by the fact that they comprise essential reducing agents such as ascorbic acid, citric acid, reductases, flavonoids, and other enzymes as well as extracellular electron shuttlers and dehydrogenases, all of which have been shown to play a role in metal nanoparticles biosynthesis [17].

It has been shown that the employment of environmentally friendly synthetic technologies is cost-effective, rapid, and easy, efficient, and requires less energy. The plant-derived materials extract is often employed in the production of organic NPs, and they are also used in the manufacture of inorganic NPs. During synthesis of NPs, the secondary metabolites act as reducing, stabilizing, as well as capping agents. Compared to chemically synthesized NPs, green synthesized metal oxideand metal NPshave greater antibacterial activity owing to the incorporation of several medicinally essential natural chemicals into nanoparticles derived from plant extracts [18-26].

Several investigations on green synthesis of AgNPs and their antimicrobial capabilities were carried out in this systematic review, which incorporated the utilization of various medicinal plant extracts from different plant parts, such as plant flower and peel.

Materials And Methods

Source of data and eligibility

Author of the study devised a search method to find articles that would be included in systematic review. Searches for possibly suitable papers were conducted using electronic databases such as Scopus and PubMed, among others. In addition, online databases including Google as well as Google Scholar were employed to find any possibly eligible papers.

The review included (a) Studies focused on the antimicrobial evaluation of herbal plant extract based on green silver NPs; (b) peer-reviewed journal articles published between January 2011 to March 2022; and (c) peer-reviewed journal articles published between January 2011 and March 2022 that were written in English. Following that, articles were examined and rated independently, and data was extracted from them. Other exclusion criteria included publications that did not include original research (such as abstracts, reviews and perspectives, comments, and letters to the editor); and papers written in other than English language.

Screening strategy

Following a review of the titles as well as the abstracts of obtained studies from the relevant electronic databases, the words used in the initial search were categorized into four categories and merged with the Boolean operators "AND" and "OR" while the search process using electronic databases mentioned above(Table 1). The entire texts of each paper were downloaded and examined, and only the papers that passed the screening process were included in study. When complete texts of relevant papers were not available or were unavailable, the authors of the papers were requested to provide them. If it was not feasible to contact the writers, for example, because of a non-response or a negative response, the entire manuscripts were bought. In addition, the reference lists of the relevant papers were examined to increase the chances of finding publications that were suitable for inclusion.To represent the complete sequential process of screening approach, Preferred reporting items for Meta-Analyses (PRISMA) flowchart and systematic reviews was utilized [27].

Table 1. Searchedgroup of words to screen the relevant papers in various electronical database

NPs-extracted from plants	Plant Parts	Type and natureof synthesis of NPs	Outputs
'Plant extract' OR 'Herbal Plants' OR 'Flora'	'Flowers extract' OR 'Peels extract' OR 'Medicinal flower' OR 'Medicinal peel'OR'leaf extract'	'Biological synthesis' OR 'Green synthesis' OR 'Plant-mediated' OR 'Biosynthesis' OR 'Silver nanoparticles' OR 'herbal plant mediated'	'Antimicrobial activity' OR 'Antimicrobial potential' OR 'Effect' OR 'Properties'

Data verification for consistency

An Excel spreadsheet (MS Office 2019, USA) containing the relevant data was created toensure that the database's internal quality control. The information was also reviewed for integrity as part of the database's external quality control process. When mismatch in Excel sheets occur, the data were examined again.

Results

Study characteristics that were included in the review

A search of PubMed and Google Scholar found a total of 310 results. There was one duplication detected. 285 studies were discarded because they meet the exclusion criteria, which were as follows: reviews (111), conference proceedings (1), commentaries (12), topics other than silver nanoparticle (38), topics other than silver nanoparticles green synthesis (81), topics other than antimicrobial effects of leaf, flowers and peel extract (47). According to the selection procedure, a total of 19 studies were considered eligible. Figure 1 shows a summary of the studies that were included.

Between 2011 and 2022, a total of 25 studies were published. There were no human studies identified. In all this research, AgNPs derived from plants were successfully synthesized, described, and evaluated for their antibacterial properties. To produce NPs, all of them relied on plants as the biological source. Seven of the studies utilized flower extract, 6 of the studies used leaf extract and twelve of the studies used peel extract in the synthesis of AgNPs. Most of the studies considered (15/25; 60 percent) were carried out by Indian research groups.

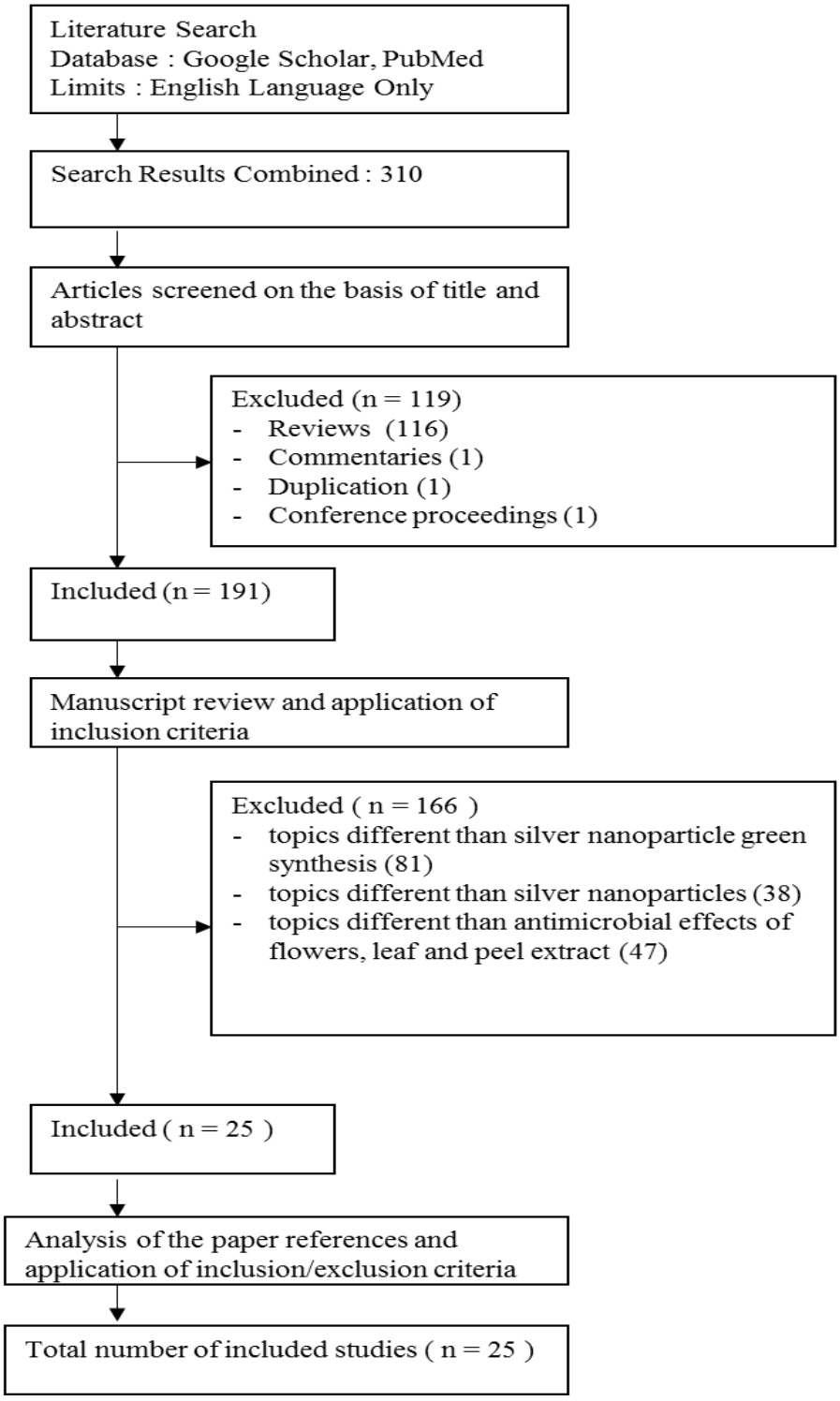

Figure 1.PRISMA flowchart depicting the methodology for selecting suitable papers for review.

Information on plants used for synthesis of silver nanoparticles

Across the globe, various plants were studied for their potential to elicit nano-sized compounds with antibacterial characteristics from the environment (Table 2). Plants were classified according to their morphological types. Some of these plants included *Syzygium aromaticum, Nyctanthes arbortristis, Musa paradisiaca,* and *citrus sinensis*, which are all known by their popular names of clove, night-flowering jasmine, banana, and sweet orange, among others.

Table 2. Various flower and peel extract of plants used for green synthesis of silver nanoparticles

Author	Plants used for synthesis of AgNPs	Plants Part	Test Microorganism	Common Name	Reference
Ajitha B et al.	*Syzygium aromaticum*	Flower	*Staphylococcus spp. E. coli, Pseudomonas spp., Bacillus spp., A. flavus, A. niger, Penicillium spp.*	Clove	[28]
Bindhu MR et al.	*Moringa oleifera*	Flower	*K. pneumonia, S. aureus*	Drumstick tree	[29]
Chandrasekhar N and Vinay SP	*Turnera ulmifolia*	Flower	*S. aureus, P. aeruginosa, E. coli, K. aerogenes*	West Indian holly	[30]
Ebrahiminezhad A et al.	*Alcea rosea*	Flower	*E. coli, S. aureus*	Hollyhock	[31]
Moteriya P and Chanda S	*Caesalpinia pulcherrima*	Flower	*Staphylococcus aureus, Candida glabrata, Bacillus cereus, Escherichia coli, Salmonella typhimurium , Candida albicans, Cryptococcus neoformansBacillus subtilis, Corallium rubrum, Pseudomonas aeruginosa, klebsiella pneumoniae*	Peacock Flower	[32]
Gogoi N et al.	*Nyctanthes arbortristis*	Flower	*E. coli*	Night Blooming Jasmine	[33]
Padalia H et al.	*Tagetes erecta*	Flower	*B. cereus, E. coli, S. aureus, P. aeruginosa, C. neoformans, C. glabrata, C. albicans*	African marigold	[34]
Dutta T et al.	*Citrus limetta*	Peel	*C. albicans, C. glabrata, C. parapsilosis, C*	Sweet lemon	[35]

			tropicalis, S. mutans, E. coli, S. aureus, S. epidermidis, M. luteus		
Das RK and Bhuyan D	*Solanum melongena*	Peel	*P. fluorescens, B. amyloliquefaciens*	Eggplant	[36]
Saratale RG et al.	*Citrus x clementina*	Peel	*S. aureus, B. cereus, E. coli*	Clementine	[37]
Annu M et al.	*Punica granatum*	Peel	*E. coli, S. aureus*	Pomegranate	[38]
Huo C et al.	*Citrus maxima*	Peel	*S. aureus, E. coli, V. dahlia, F. oxysporum,*	Pummelo	[39]
de Barros CH et al.	*Citrus sinensis*	Peel	*X. axonopodis pv. Citri (Xac)*	Sweet orange	[40]
Balavijayalakshmi J and Ramalakshmi V	*Carica papaya*	Peel	*E. coli, S. aureus*	Papaya	[41]
Ibrahim HM	*Banana (Musa paradisiaca)*	Peel	*S. aureus, B. subtilis, P. aeruginosa, P. aeruginosa, C. albicans, E. coli*	Banana	[42]
Kokila T et al.	*Cavendish banana*	Peel	*Bacillus. subtilis, Streptococcus. aureus, Escherichia coli, Klebsiella pneumoniae*	Banana	[43]
Alkhulaifi MM et al.	*Citrus limon*	Peel	*Acinetobacter baumannii, Salmonella typhimurium, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, and Proteus vulgaris.*	Lemon	[44]
Kaviya S et al.	*citrus sinensis*	Peel	*E. coli, P. aeruginosa, S. aureus*	Sweet orange	[45]
Rozykulyyeva L et al.	*Punica granatum*	Peel	*P. aeruginosa, A. actinomycetemcomitan , E. faecalis, S. aureus*	Pomegranate	[46]
J. Uthaya Chandirika and G. Annadurai	*Abutilum indicum*	Leaf	*E. coli and Streptococcus aurous*	Monkey bush	[47]
Awadhesh Kumar Mishra et.al.	*N. arbor-tristis*	Leaf	*Salmonella typhimurium, Salmonella typhi, Acinetobacter baumannii, Proteus mirabilis; Escherichia coli and Staphylococcus aureus)*	Night flowering jasmine	[48]
ChahandeR.K.	*Murraya*	Leaf	*Escherichiacoli, P.*	Curry tree	[49]

	koenigii		*aeruginosa, E.faecalis, C. albicans*		
NyabolaA.O.	*Aspilia pluriesta*	Leaf	*B. subtilis Escherichia. coli, P. aeruginosa, Candida albican,* S. *aureus*	Daisy	[50]
Biswas A.	*Mikania micrantha*	Leaf	*S. pneumonia, Pseudomonas aeruginosa, B.subtilis*	Climbing hemp vine	[51]
VijilvaniC.	*Solanum nigrum*	Leaf	*Escherichia. coli*	Black nightshade	[52]

Techniques used for the green synthesis of silver NPs within the included studies

In seven out of the 25 studies, flowers were employed as biological materials for silver nanoparticle synthesis and in six studies, leaf were employed as biological materials for silver nanoparticle, while 12 studies used plant peel as a biological material for silver nanoparticle synthesis. Aqueous extracts were produced primarily by decantation, which required to be combined with a metal precursor for nanoparticles synthesis, according to the scientists. Indeed, after thorough cleaning (with tap anddouble water) and chopping, the biological material was boiled. Water was primarily used for extraction solvent as well as the solution mixture was then eluted and screened with the help of Whatman N°1 filter papers. The screened extract was employed in the synthesis of AgNPs, which were then purified further.

Tosynthesize AgNPs, filtrate extract was added with 1 mM aqueous solution of AgNO3 (silver nitrate). In this case, reduction of the silver ions occurs. The reaction mixture was then incubated in the dark for an extended period to prevent the photoactivation of AgNO3 while the settings were static. As a result of the reduction of Ag+ into Ag0 NPs, the solution changes its color from yellow to the brownish-yellow and then to deep brown, which is indicative of the creation of silver nanoparticles, depending on the parameters investigated. The AgNP solution produced because of this procedure was purified by centrifugation several times.

Techniques used for studying nanoparticles

The synthesis of the NPs was proved by ultraviolet–visible spectroscopy (UV–Vis) by demonstrating the typical plasmon vibration. NPs were characterized using TEM and SEM, which were used to identify their form and size. SEM is used in conjunction with energy dispersive X-ray spectroscopy (EDS, EDX), that offers elemental mapping in term of atomic composition, whereas transmission electron microscopy is used in conjunction with SAED (Selected Area Electron Diffraction), which reveals the samplescrystallographic planes. FTIR technique wereutilized to investigate the interaction between NPs and secondary metabolites by measuring molecular vibrations. The technique of XRD (X-ray diffraction) had been used to determine the nature of the material, its crystallinity, and its size and shape. Dimensional information on size distributions in terms of hydrodynamic radius is provided by DLS (dynamic light scattering). A few studies investigated the stability of nanoparticles by evaluating their Zeta potential and silver content.

Characteristics of plant-synthesized nanoparticles

Silver nitrate was primarily utilized as a metal precursor for plant-derived NPssynthesis. The color shift indicating the formation of NPs occurred between 10 to 150 minutes after the combination of the plant extract and precursor metal was completed. It is caused by the free oscillation of the electrons on a metallic surface that characteristic plasmon vibration is produced.

Methods for Antimicrobial Assay

The antibacterial activity of MHA (Mueller Hinton Agar) was tested using the agar well and disc diffusion technique. In bacteriological incubator, the plates were incubated at temperature of 37 degree Celsiusfor 24 hrs, and ZOI (zone of inhibition) was calculated by subtracting the diameter of well from the overall inhibition zone diameter, similarly in disc diffusion method, inhibition zone was calculated. The size of the clear zone is used to determine bactericidal activity; the larger the ZOI, the stronger the bactericidal activity. Gram negativeand gram-positive microorganisms were tested for antibacterial activity.

MIC Assay of different studies

In all the studies, the MIC values of the produced AgNPs against microorganisms were assessed using the standard procedure [47]. Tables 3 and 4 show the results of studies that used flower, leaf and peel to extract AgNPs.

Table 3.MIC values of AgNPs from flower and leaf extract from various studies

S. No	Author	Extract	Microorganism Used	MIC Value
Flower extract				
1	Padalia H et al.	*Tagetes erecta*	*E. coli*	10 mm
			Staphylococcus aureus	36 mm
			Bacillus cereus	-
			C. glabrata	32 mm
			Pseudomonas aeruginosa	24.5 mm
			C. neoformans	25 mm
			Candida albicans	21 mm
2	Gogoi N et al.	*Nyctanthes arbortristis*	*E. coli*	14.7 mm
3	Moteriya P and Chanda S	*Caesalpinia pulcherrima*	*C. glabrata*	2.5 mg/ml
			S. aureus	2.5 mg/ml
			S. typhimurium	5 mg/ml
			B. cereus	5 mg/ml
			Escherichia coli	5 mg/ml
			C. neoformans	5 mg/ml
			C. albicans	5 mg/ml
			C. rubrum	10 mg/ml
			Bacillus. subtilis	10 mg/ml
			K. pneumoniae	-
			P. aeruginosa	-
4	Ebrahiminezhad A et al.	*Alcea rosea*	*E. coli*	37.5 µg/ml
			S. aureus	37.5 µg/ml
5	Chandrasekhar N and Vinay SP	*Turnera ulmifolia*	*S. aureus*	21 mm
			P. aeruginosa	21 mm
			E. coli	21 mm
			K. aerogenes	27 mm
6	Bindhu MR et al.	*Moringa oleifera*	*K. pneumonia*	17 mm
			S. aureus	29 mm
7	Ajitha B et al.	*Syzygium aromaticum*	*Escherichia coli*	6 ± 1 mm
			Penicillium spp	6 ± 1 mm
			Bacillus spp	7 ± 1 mm
			Pseudomonas spp	8 ± 1 mm

			Aspergillus flavus	5 ± 1 mm
			Aspergillus nige	5 ± 1 mm
			Staphylococcus spp	5 ± 1 mm
Leaf extract				
8	J. Uthaya Chandirika and G. Annadurai	*Abutilum indicum*	*E. coli*	21±33 mm
			Streptococcus aureus	160 ±180 mm
9	Awadhesh Kumar Mishra et.al.	*N. arbor-tristis*	*Staphylococcus aureus*	17±23 mm
			Proteus mirabilis	5±7 mm
			Salmonella typhi	16±20 mm
			Acinetobacter baumannii	12±15 mm
			Escherichia coli	10±15 mm
			Salmonella typhimurium	12±20 mm
10	R.K. Chahande et.al.	*Murraya koenigii*	*Escherichia coli*	26.17mm
			Pseudomonas aeruginosa	18±20 mm
			Candida albicans	18±20 mm
11	A.O. Nyabola et.al.	*Aspilia pluriesta*	*Bacillus subtilis*	26.17mm
			Streptococcus aureus,	-
			P. aeruginosa	-
			Escherichia coli	26.05 mm
			C. albicans	-
12	Biswas et.al.	*Mikania micrantha*	*Escherichia coli*	26.05 mm
			P. aeruginosa	-
			Bacillus subtilis	26.17mm
			S. pneumonia	-
13	C.Vijilvani et.al.	*Solanum nigrum*	*Escherichia coli*	22 mm

As per Padalia H et al., When comparing *P. aeruginosa*and *E. coli*to other harmful bacteria, the results demonstrated that *Escherichia. coli* and *P. aeruginosa* had higher bactericidal activity.The ZOI ranges from 21 mm to 36 mm against different microorganism.Greater ZOI against *S. aureus*was observed as compared to the others. *B. cereus* showedresistance against AgNPs [34].*Nyctanthes arbortristis* and *Syzygium aromaticum* extracted AgNPs showed lower ZOI as compared to the others [33, 28]. In another study, Moteriya P and Chanda S found that *Pseudomonas aeruginosa* and *K. pneumoniae* were resistance towards silver nanoparticles [32].*Syzygium aromaticum* extracted AgNPs showed lower ZOI as compared to other studies [28]. Ebrahiminezhad A et al. reported the MIC was found to be similar in both *E. coli* and *S. aureus*[31]. In another study, the MIC ranges from 2.5 mg/ml to 10 mg/ml [32].

Acc. to Awadhesh Kumar Mishra Except for Methicillin-resistant *Staphylococcus aureus*, leaf extract (25–100 g/disc) had no effect on bacterial growth. At all concentrations, the leaf extract effectively inhibited MRSA development, with a zone of inhibition (5–10 mm) that was less than the positive control (12 mm). The silver nanoparticles derived from leaf extract generate excellent inhibitory zones. A higher quantity of nanoparticles increased the width of the zone of inhibition. For all pathogenic bacteria except *P. mirabilis*, the zone of inhibition was larger than the positive control's zone. This was due to the fact that the silver nanoparticles caused a smaller zone of

inhibition on *P. mirabilis* (5–7 mm) (10 mm). To characterize chosen medicinal plant extracellular activity against drug-resistant Gram positive and negative bacteria synthesizing silver nanoparticles. The studies detailed here were done to study fungus. The *Abutilum indicum* extract has antibacterial action against *E. coli* and *Streptococcus aureus* 21-33 mm. Compared to plant extracts, silver nanoparticles had the strongest antibacterial action, with a larger inhibition zone. Silver nanoparticles with *E. coli* and *Streptococcus aureus* Zone of Inhibition (mm). Bacillus sp. (100 g/ml) was the most sensitive, followed by Streptococcus sp. (50 g/ml). Recently, gold nanoparticles functionalized with small molecules have showed excellent antibacterial action.According to R.K. Chahande et.al.*Aeruginosa* (ZOI of 18mm) and *Candida albicans* (ZOI of 18mm) are both Gram-negative bacteria that are susceptible to AgNPs (18 mm ZOI). Nyabola et al. found that leaf extracts of plants like *Aspilia pluriseta*, AgNPs, had good antibacterial action against a wide range of pathogens. To test AgNPs against B. subtilis and E. coli, Biswas et al. used *Mikania micrantha* leaf extract, which had a ZOI of 26.17 mm and 26.05. C.Vijilvani et.al Recently, *Solanum nigrum* plant leaf extract was used to make AgNPs with an average size of 3.46 nm For *E. coli*, the ZOI of AgNPs was 22 mm, whereas that of Au and Pd NPs was 20 mm.

Table 4.MIC values of AgNPs from peel extract from various studies

S. No	Author	Extract	Microorganism Used	MIC Value
1	Dutta T et al.	*Citrus limetta*	*M. luteus*	11.5 ± 0.55 mm
			C. parapsilosis	14 ± 0.70 mm
			C. albicans	15 ± 0.75 mm
			C. glabrata	14 ± 0.70 mm
			C tropicalis	14 ± 0.7 0 mm
			S. epidermidis	11.5 ± 0.55 mm
			S. mutans	12 ± 0.60 mm
			Escherichia coli	12.5 ± 0.60 mm
			S. aureus	11.5 ± 0.55 mm
2	Das RK and Bhuyan D	*Solanum melongena*	*P. fluorescens*	13 mm
			B. amyloliquefaciens	15 mm
3	Saratale RG et al.	*Citrus x clementina*	*E. coli*	40.0 ± 2.2 µg/mL
			B. cereus	40.0 ± 2.6 µg/mL
			S. aureus	50.0 ± 2.7 µg/mL
4	Annu M et al.	*Punica granatum*	*E. coli*	15.5 mm
			S. aureus	16.5 mm
5	Huo C et al.	*Citrus maxima*	*S. aureus*	Not mentioned
			E. coli	Not mentioned
			V. dahliae	Not mentioned
			F. oxysporum	Not mentioned
6	de Barros CH et al.	*Citrus sinensis*	*X. axonopodis pv Citri (Xac)*	22 ± 2 µg mL
7	Balavijayalakshmi J and Ramalakshmi V	*Carica papaya*	*E. coli*	75 mm
			S. aureus	65 mm

8	Ibrahim HM	*Banana (Musa paradisiaca)*	*S. aureus*	16 mm
			B. subtilis	12 mm
			P. aeruginosa	18 mm
			P. aeruginosa	20 mm
			Escherichia coli	17 mm
9	Kokila T	*Cavendish banana*	*Bacillus subtilis*	20 mm
			S. aureus	22 mm
			Escherichia coli	17 mm
			K. pneumonia	19 mm
10	Alkhulaifi MM et al.	*Citrus limon*	*Acinetobacter baumannii*	15 mm
			Salmonella typhimurium	33 mm
			E. coli	35 mm
			Pseudomonas aeruginosa	30 mm
			Staphylococcus aureus	35 mm
			Proteus vulgaris	12 mm
11	Kaviya S et al.	*citrus sinensis*	*E. coli*	12.5 mm at 25 ◦C, 16 mm at 60 ◦C
			Pseudomonas aeruginosa	11.7 mm at 11.7 ◦C, 13.4 mm at 60 ◦C
			Staphylococcus aureus	7.8 mm 25 ◦C, 9.2 mm at ◦C
12	Rozykulyyeva L et al.	*Punica granatum*	*P. aeruginosa*	1.7 mm
			A. actinomycetemcomitan	1.3 mm
			E. faecalis	1.2 mm
			S. aureus	1.5 mm

Citrus limetta peel extract showed greater MIC against *C. albicans* and the lowest was observed in *M. luteus, S. epidermidis* and *S. aureus*[43]. In another study, similar result was found in *P. fluorescens* and *B. amyloliquefaciens*[42]. As per the study conducted by Saratale RG et al., *S. aureus* showed greater MIC compared to others [45]. The highest MICwas observed in *Carica papaya* against *S. aureus* and *E. coli* [38]. The similar results were found in *Banana (Musa paradisiaca)*and*Cavendish banana* against the microorganisms [36,37].In another study, greaterMIC was observed in *E. coli* and the lower in*Proteus vulgaris* [35]. Kaviya S et al. demonstrated the MIC at various temperatures. It was found that at increasing temperature, the ZOI increases in *E. coli, Pseudomonas aeruginosa*and *Staphylococcus aureus*[45]. The lower ZOI was observed by Rozykulyyeva L et al. which ranges from 1.2mm to 1.7mm [46]. In another study, the silver nanoparticles had a good inhibitory impact on the bacterial strains, but the *C. maxiam* peel extract had no discernible inhibitory effect. [39].

Discussion

The antimicrobial activities of biologically synthesized AgNPs were the focus of this systematic review. Green synthesis, or the

synthesis of NPs using living organisms, is much more appealing since it addresses environmental and economic concerns. In comparison to their physical and chemical counterparts, this technique is environmentally safe, nontoxic, fastin most situations, cost-effective and easily scalable up for Nanoparticle synthesis on a huge scale [53, 54]. Furthermore, substances utilized in the chemical production of NPs, such as Tollen's reagent or sodium borohydride (NaBH4), are toxic to humans and non-biodegradable, which may cause cancer [55].

Plant extracts were primarily used in the green production of metal nanoparticles. Plants are more favorable because they lower the threat of biohazard and minimizes the expenses associated with microbe isolation, purification, and cell culture maintenance [56].

For the synthesis of NPs, silver was primarily employed as a metal precursor. This might be attributed to the atom's intriguing features, such as its chemical stability and broad antibacterial action [57]. In most cases, the synthesis yields silver chloride nano crystallites, pure silver, or a combination of the two. In ancient times, this atom was recognized to have biocidal properties against a wide spectrum of microbes. Silver ions are now employed to inhibit bacterial development in a variety of medical situations, such as water purification, catheter cleaning, dental procedures, and food hygiene [58-60].

The use of extracts of peel as reducing agents for NPs green synthesis with specific sizes has recently gotten a lot of interest. Numerous peel extracts have been employed in the biosynthesis of thus far. For silver NPsgreen synthesis, *Cavendish banana* peel extract [43], banana (*Musa paradisiaca*) [42], *Citrus sinensis* [45], and *Carica papaya* [41] were used. The bactericidal efficacy of the generated AgNPs was investigated by testing them against different bacterial strains. It was discovered that the silver nanoparticles derived from diverse peel extracts caused significant disruption of cells. The effect of several parameters on AgNO3 bio-reduction were explored, and it was discovered that dry banana peel (20.4 mg), AgNO3 (1.75 mM), of 4.5 pH, and 72 hours of incubation period were the most effective. The produced silver nanoparticles had synergistic effects with antibiotic levofloxacin, according to the authors [42]. For silver nanoparticles green synthesis with ranging sizes from 4 to 11 nm, peel extract of *Citrus maxima* had been utilized as both capping as well asreducing agent. The bactericidal efficacy of synthesized silver nanoparticles was evaluated against *Escherichia coli* and*Steptococcus. aureus*, and it was discovered that peel extract of *Citrus maxima* mediated silver nanoparticles inhibited both bacterial strains significantly. Furthermore, the bactericidal activity was tested towards plant pathogens including *V. dahlia* and *F. oxysporum*, and both pathogens exhibited good inhibitory effect [39]. Apart from *Citrus x clementine* [37], *Punica granatum* [46], as well as*Solanum melongena* L [36], extracts of peel were used to green synthesize silver nanoparticles, which were then evaluated for bactericidal efficacy against variety of bacterium strains. The findings demonstrated that both the Gram-positive as well as Gram-negative bacteria cell walls were severely damaged by the synthesized silver nanoparticles. In contrast to *E. coli* (15.5 mm), silver nanoparticles synthesized from peel extract of *Punica granatum* had a strong zone of inhibition against *S. aureus* (16.5 mm) [46]. To improve the rate of silver NPs bio reduction, a microwave irradiation approach was used to green synthesize silver nanoparticles from peel extract of *Solanum melongena* L. Furthermore, the nanoparticles synthesized by this technique are 92.4 nm in diameter and spherical in form [36]. Dutta et al [35] highlighted a green synthesis of silver nanoparticles utilizing peel extract of *Citrus limetta* as both capping as well as reducing agent in another study. The bactericidal activity of the synthesized silver nanoparticles against a variety of pathogens, including *Candida albicans, Candida tropicalis, Candida parapsilosis,Candida glabrata,E. coli, S. epidermidis, S. aureus, S. mutans,* and*M. luteus*,

demonstrated that the peel extract of *Citrus limetta* mediated silver nanoparticles have a potential of disruptingcells and can thus be utilized in the pharmaceutical industry. Moreover, a test of the produced silver nanoparticles antifungal effectiveness against Candida species demonstrated that the nanoparticle had the potential to distort the cell membranes. The impact of silver nanoparticles on *C. albicans* micromorphological alterations was clearly obvious, and it was discovered that silver NPs causes cell blebs as well as deposition of a thick exudate surrounding the cells, indicating intercellular materials leakage. Based on the findings, authors concluded that peel extract of *Citrus limetta* mediated silver nanoparticles had exceptional antimicrobial activities.

The production of AgNPs has been aided by the use of a wide range of leaf extracts.Uthaya Chandrika and G. Annadurai studied selected medicinal plant extracellular activities against drug-resistant Gramnegative and positive bacteria synthesizing silver nanoparticles. The tests detailed here were done to examine The *Abutilum indicum* extract produced silver nanoparticles with antibacterial activity against *Escherichia coli* and *Streptococcus aureus* 21-33 mm. Compared to plant extracts, silver nanoparticles had the most antibacterial action, and the inhibition zone diameter increased. Silver nanoparticles utilizing *Escherichia.coli* and *Streptococcus aureus* Zone of Inhibition (mm). This was followed by *Streptococcus sp.* (50 g/L) and *Bacillus sp.* Recent research suggests that gold nanoparticles functionalized with small molecules have antibacterial action [47].Interestingly, biogenic AgNPs produced by*Murraya koenigii* leaf extract showed very comparable effectiveness against Gram-negative bacteria *P. aeruginosa* (ZOI of 18 mm) and a fungus *C. albicans,* according to R.K. (18 mm ZOI) [49].In 2020 A.O. Nyabola et al., different leaf extracts of plants like *Aspilia pluriseta*, AgNPs are demonstrated to have strong antibacterial activity against several common pathogenic microorganisms [50]. Biswas et al. observed that *Mikania micrantha* leaf extract mediated AgNPs had high ZOI of 26.17 mm against *B. subtilis* and 26.05 mm against *E. coli*[51].

Vijilvani et.al. Solanum nigrum leaf extract was recently used to make 3.46 nm AgNPs. The ZOI of AgNPs was 22 mm in E. coli, whereas Au and Pd NPs were 20 and 19 mm [52]. This was determined by evaluating the extent of the zone of inhibition of plant extract and silver nanoparticles against human pathogenic Gram positive (MRSA) and Gram negative (*Acinetobacter baumannii, Proteus mirabilis; Escherichia coli, Salmonella typhi, and Salmonella typhimurium*) bacteria (ZOI). Except for MRSA, leaf extract (25–100 g/disc) had no effect on the growth of human pathogenic bacteria. A zone of inhibition (5–10 mm) shorter than the positive control was seen with leaf extract at all doses (12 mm). It has excellent inhibitory zones. Its diameter grew with nanoparticle concentration. Except for P. mirabilis, the inhibition zone was greater. Its inhibitory zone on *P. mirabilis* was narrower (5–7 mm) than the positive control's (10 mm). Pathogenic bacteria were susceptible to biosynthesized nanoparticles in the following order: silver nanoparticles have strong antibacterial activity [48].

For the synthesis of nanoparticles, flower extracts have been widely used. The bio-reduction of AgNO3 to silver NPs has been studied extensively in the literature. Padalia et al [34]. used *Tagetes erecta* flower extract to bio-reduce AgNO3 to produced silver nanoparticles and evaluate their bactericidal efficacy against Gram-negative and -positive bacteria such *B. cereus, S. aureus, P. aeruginosa, E. coli, C. albicans, C. neoformans,* and *C. glabrata*. When comparing *P. aeruginosa* and *E. coli* to other pathogenic bacteria's, the results demonstrated that *P. aeruginosa* and *E. coli* had higher bactericidal activity. Besides that, the authors claimed that silver nanoparticles antifungal activity in combination with antibiotics against a Gram-negative bacteria and fungal strain was much higher than antibiotics alone. Flower extracts from plants including *Caesalpinia pulcherrima* [32],

Nyctanthes arbortristis [33], *Argemone Mexicana* [30], and *Alcea rosea* [31] have also been reported from biogenic silver nanoparticles production. For biosynthesis of the spherical silver NPs with sizes ranging from 50 to 60 nm, flower extract of *Tecoma stans* was used. *Moringa oleifera* produced nanosized silver NPs with a high zone of inhibition of 29 mm against *S. aureus* [29]. Due of its small size, it is one of highest ZOIs ever seen utilising biogenic silver nanoparticles at this concentration. Another fascinating discovery in this study is that silver nanoparticles had better antibacterial action in a grampositive (i.e., *S. aureus*) then gramnegative bacteria (i.e., *K. pneumonia*), which is an uncommon event. Ajitha et al. revealed that polydisperse silver NPssynthesis utilizingextract of flower*Syzygium aromaticum* as both a capping as well as bio-reducing agent in another study. The antibacterial activities of synthesized nanoparticles were investigated against a variety of pathogens, and it was discovered that the nanoparticles cause bacterial cell disruption, which is greatest in *Pseudomonas* spp [28].

Green synthesized nanoparticles have been shown to be persistent, versatile, and are safe. Green synthesized silver nanoparticles can clearly compete with and sometimes outperform commercial antibiotics for the management of microbial diseases. As a result, these environmentally friendly silver NPs may be employed as an effective antibacterial agent against pathogenic microbes that are multidrug resistant. These AgNPs might also be employed to reduce microbial burden in wastewater treatment. Green synthesis promises to be a non-toxic, cost-effective, environmentally friendly alternative to traditional microbiological, chemical, and physical approaches, and might be used to construct a large-scale biological process.

Conclusion

This review highlights the benefits of employing living organisms including plants to synthesize metal NPs in terms of environmental friendliness and rapidity. It gives a broad review of these nanomaterials' antibacterial capabilities, emphasizing their potential as sources of novel antimicrobial medicines. According to the findings of the research included in this review, silver nanoparticles (AgNPs) have the ability to suppress the growth of microorganisms.All of the studies have shown positive outcomes. Finally, the study emphasizes the need of doing detailed investigations on safety profiles of currently available NPs before they are used on humans.

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