Journal of Microbiological Methods 167 (2019) 105766

Contents lists available at ScienceDirect

Journal of Microbiological Methods

journal homepage: www.elsevier.com/locate/jmicmeth

Review

New avenues of controlling microbial infections through anti-microbial and anti-biofilm potentials of green mono-and multi-metallic nanoparticles: A review

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ARTICLE INFO

Keywords:
Metallic nanoparticles
Green technology
Antimicrobial
Anti-biofilm

ABSTRACT

Nanoparticles synthesized through the green route deserve special mention because this green technology is not only energy-efficient and cost-effective but also amenable to the environment. Various biological resources have been used for the generation of these 'green nanoparticles'. Biological wastes have also been focused in this direction thereby promoting the value of waste. Reports indicate that green nanoparticles exhibit remarkable antimicrobial activitiesboth singly as well as in combination with standard antibiotics. The current phenomenon of multi-drug resistance has resulted due to indiscriminate administration of high-doses of antibiotics followed by significant toxicity. In the face of this emergence of drug-resistant microbesthe efficacy of green nanoparticles might prove greatly beneficial. Microbial biofilm is another hurdle in the effective treatment of diseases as the microorganismsbeing embedded in the meshwork of the biofilmevade the antimicrobial agents. Nanoparticles may act as a ray of hope on the face of this challenge tooas they not only destroy the biofilms but also lessen the doses of antibiotics requiredwhen administered in combination with the nanoparticles. It should be further noted that the resistance mechanisms exhibited by the microorganisms seem not that relevant for nanoparticles. The current review, to the best of our knowledgefocuses on the structures of these green nanoparticles along with their biomedical potentials. It is interesting to note how a variety of structures are generated by using resources like microbes or plants or plant products and how the structure affects their activities. This study might pave the way for further development in this arena and future work may be taken up in identifying the detailed mechanism by which 'green' synthesis empowers nanoparticles to kill pathogenic microbes.

1. Introduction

The word 'Nanotechnology' was coined in 1974 by Norio Taniguchi of Tokyo University of Science. The term 'nano' is derived from the Greek word 'nanos' meaning "dwarf" which refers to things of one billionth in size. However, long before 1974, the foundation stone of the domain of Nanotechnology was laid down in 1959 by Richard Feynman, the "Father of nanotechnology"who explained about methods which can transform individual atoms from one form to a smaller form. These nanoparticles, as described by Zhang et al. (2008) are of very small size, have large surface area : mass ratio and high reactivity, thereby making them greatly different from the bulk materials of the same composition. Nanoparticle usage may help in overcoming of the shortcoming of the whole metals as certain metals like silver is antimicrobially active but ions or salts of this metal have limited usefulness because of interfering effects of salts and also there is continuous release of enough concentration of silver ions from the metal form (Tiwari et al., 2008). This is because of the fact that all materials have some critical range below which their properties change drastically. Particles below 100 nm in diameter show properties that are different from those of conventional solids.

Synthesis and subsequent applications of metallic nanoparticles are of prime importance in academia and research (Thakkar et al., 2010). The physical and chemical methods of synthesizing metal nanoparticles are not cost-effective as material conversions have difficult, low yield purifications that are time and energy consuming because of the involvement of high temperature and vacuum conditions (Sathishkumar et al., 2009b; Ai et al., 2011). Ill effects are not only exerted upon the environment due to usage of hazardous chemicals and generation of toxic by-products (Pugazhendhi et al., 2019; Thakkar et al., 2010)but cytotoxicity and even carcinogenicity are also exerted (Shah et al., 2015). Therefore, the biological process of nanoparticle synthesis has

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https://doi.org/10.1016/j.mimet.2019.105766
Received 26 May 2019; Received in revised form 31 October 2019; Accepted 31 October 2019
Available online 07 November 2019
0167-7012/ © 2019 Published by Elsevier B.V.

Table 1
Biomedical potentials of monometallic nanoparticles.

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
Copper nanoparticles (Cu- NP)[a]	Phytochemicals from *Crotalaria candicans* (Isoquercetin and Cassinopin)	Exerted antibacterial activity against *Bacillus subtilis, Enterococcus faecalis, Staphylococcus aureus, Salmonella typhi, Escherichia coli, Pseudomonas aeruginosa, Enterobacter cloacae* and *Klebsiellla pneumoniae* (MICs ranged from 1–4 μg ml^{-1} and MBCs ranged rom 4–16 μg ml^{-1}) and anti-biofilm activity (ranged from 1–8 μg ml^{-1} for the strains tested and it was 2 μg ml^{-1} against MRSA i.e. methicillin resistant *S. aureus*)	Spherical crystalline particles with an average size of 30 nm	Lotha et al., 2019.
	Clove (*Syzygium aromaticum*) bud extract	Antimicrobial activity against *Bacillus* sp. and *Penicillium* sp.	Spherical highly crystalline particles	Rajesh et al., 2018.
	Morganella psychrotolerans	Antibacterial activity (growth inhibiting effect on *B. subtilis* at 126 ppm but no inhibitory effect at same concentration of the commercially available NPs)	Particles were irregular in size and shape with a diameter of from 4–60 nm	Pantidos et al., 2018.
	Shewanella loihica	Inhibit *E. coli* (antibacterial efficacy of 100 μg ml^{-1} NPs on 10^5 CFU ml^{-1} fresh *E. coli* suspension was ~86.3 ± 0.2% within 12 h)	Spherical polycrystalline monodisperse particles with size in the range of 10–16 nm	Qing et al., 2018.
	Artemisia haussknechtii leaf aqueous extract	Active against MDR-*S. aureus, S. epidermidis, Serratia marcescens* and *E. coli* (MIC and MBC were 10 and 60 μg ml^{-1} respectively for both *E. coli* and *S. aureus*; 10 and 40 μg ml^{-1} for *S. marcescens*; 4 and 20 μg ml^{-1} for *S. epidermidis*)	Spherical crystalline particles with average diameter sizes of 100 particles around 35.36 ± 44.4 nm	Alavi and Karimi, 2018.
	Fruit extracts of *Ziziphus spina-christi*	Activity of NPs against *S. aureus* and *E. coli* (at concentrations of 25–100%, zones of inhibition ranged from 1.1–1.8 cm)	Spherical crystalline, homogeneous, well-dispersed particles in the size range of 5–20 nm	Khani et al., 2018.
Copper oxide nanoparticles (CuO-NP)[b]	Aqueous floral extract of *Cordia sebestena*	Antibacterial activity	Agglomerated spherical shaped particles with size between 20–35 nm	Prakash et al., 2018.
	Bauhinia tomentosa leaf extract	Active against *E. coli* and *P. aeruginosa* (zone of inhibition was 22 mm against *E. coli* and 17 mm against *P. aeruginosa*)[a]	Spherical crystalline particles	Govindasamy et al., 2018.
	Actinobacteria	Active against human and fish pathogens like *S. aureus, B. cereus, P. mirabilis, A. caviae, Edwardsiella tarda A. hydrophila* and *V. anguillarum* (zones of inhibition ranged from 11–24 mm at concentrations 5–100 μg ml^{-1})	Average size of the spherical crystalline particles was 61.7 mm	Nabila and Kannabiran, 2018.
	Tabernaemontana divaricate leaves	Active against urinary tract pathogen *E. coli* (maximum zone of inhibition was found at 50 μg ml^{-1})	Spherical crystalline particles of ~48 nm	Sivaraj et al., 2014.
Gold nanoparticles (Au-NP)[c]	*Salix alba* leaves extract	Active against *S. aureus, A. flavus, A. niger* and *Alternaria solani* (while the zone of inhibition against the bacterium was 10 mm that for the fungi ranged from 10–50 mm)	Crystalline spherical particles with an average size of 60 nm	Islam et al., 2015.
	Essential oil from *Coleus aromaticus*leaves	Efficacious against *E. coli* and *S. aureus*	Spherical crystalline particles	Vilas et al., 2016b.
	Seed aqueous extract of *Abelmoschus esculentus*	Active against *Puccinia graminis, A. flavus, A. niger* and *C. albicans* (maximum activity towards *P. graminis* and *C. albicans*)	Spherical crystalline particles in the range of 45–75 mm	Jayaseelan et al., 2013.
	Cynara cardunculus leaf extract	Active against *E. coli* and *S. aureus*(inhibitory effect at 20 mM and in lower concentrations the effect is minimal)	Semi-spherical morphology particle size less than 45 nm	de Jesús Ruíz-Baltazar et al., 2018.
	Blue green algae *Spirulina platensis*	Active against *B. subtilis* and *S. aureus*	Stable well defined spherical particles with size ranging from 2–8 nm	Suganya et al., 2015b.
	Nigella arvensis leaf extract	Activity against clinical isolates of *S. epidermidis, S. aureus, B. subtilis S. marcescens, P. aeruginosa* and *E. coli* (MICs against these test organisms ranged from 62.5–250 μg ml^{-1})	Crystalline spherical particles with size ranging from 3–37 nm	Chahardoli et al., 2018b.
	Extract of the marine red algae, *Galaxaura elongata*	Effective against *E. coli, K. pneumoniae, S. aureus*, MRSA (methicillin resistant *S. aureus*) and *P. aeruginosa* (zone of inhibitions against these microorganisms ranged from 7.5 to 17 mm)	Crystalline spherical particles with an average diameter in the range of 3.85– 77.13	Abdel-Raouf et al., 2017
	Aqueous leaf extract of *Euphrasia officinalis*	No antimicrobial activity but only inhibited human cervical cancer cells	Quasi-spherical crystalline particles with an average size of 49.72 ± 1.2 nm	A. Singh et al., 2018; H. Singh et al., 2018
	Anacardium occidentale leaves extract	Effective against *E. coli* and *B. subtilis* (zones of inhibiton ranged from 8–24 mm against these microorganisms for different concentrations of the NPs)	Spherical crystalline particles with size between 10–30 nm	Sunderam et al., 2018.
	Aqueous extract of floral bud of *Brassica oleracea*	Active against human pathogenic *S. aureus, K. pneumoniae, A. flavus, A. niger* and *C. albicans* (concentrations of NPs used were 10–50 μg ml^{-1}and	Spherical crystalline particles with size between 13–20 nm	Piruthiviraj et al., 2016.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		zones of inhibition ranged for 10–22 mm in bacteria and 5–12 mm in fungi)		
Gold nanoparticles (Au-NP)[c]	Aqueous extract of *Salicornia brachiata*	Active against *E. coli, P. areuoginosa, S. typhi* and *S. aureus* (synergistic activity with the antibiotic ofloxacin)	Crystalline spherical with size between 22–35 nm	Ahmed et al., 2014.
	Vegetable wastes	Active against *Klebsiella* sp. and *Staphylococcus* sp.	Crystalline spherical with size between 10–70 nm	Mythili et al., 2018.
	Phytochemicals present in *Areca catechu* nut	Significant activity against a broad spectrum of bacterial pathogens	Crystalline spherical with size of ~14 mm	Rajan et al., 2015.
	Dried fruit extract of *Tribulus terrestris*	Activity against MDR- *Helicobacter pylori* strains (while MICs ranged from 16–21 $\mu g\ ml^{-1}$, MBCs ranged from 18 – 24 $\mu g\ ml^{-1}$)	Crystalline spherical with size of ~7 mm	Gopinath et al., 2019.
	Juice of Longan fruit (*Dimocarpus longan*)	Antibacterial activity (MIC against *E. coli*was 75 $\mu g\ ml^{-1}$ and that against both *S. aureus* and *B. subtilis* was 50 $\mu g\ ml^{-1}$)	Spherical crystalline particles	Khan et al., 2016b.
		Antioxidant action and cytotoxic activity against human breast cancer cell line MCF-7	Spherical crystalline particles with average size of 25 nm	Khan et al., 2016d.
	Micrococcus yunnanensis	Active against both Gram positive and Gram negative bacteria	Spherical crystalline particles with average size of 53 nm	Jafari et al., 2018.
	Camellia japonica leaf extract	Active against *B. subtilis, S. aureus, S. faecalis, P. aeruginosa, K. pneumoniae, E. coli* and *C. albicans* (zones of inhibition ranged from 10 – 15 mm)	Spherical crystalline particles with average size of 20 nm	Sharma et al., 2019.
	Aqueous leaf extract of *Crescentia cujete*	Active against *E. coli, B. subtilis, P. aeruginosa, V. cholerae, S. typhi* and *S. flexneri* (mechanism of action may be through change of membrane potential and inhibition of the subunit of the ribosomal protein S10 with tRNA-binding function)	Crystalline spherical particles with a mean size of 33 nm	Seetharaman et al., 2017.
	Punica granatum fruit extract	Active against *C. albicansA. flavus S. aureus, S. typhi* and *V. cholerae*	Crystalline triangular and spherical shaped particles with a size between 5–20 mm	Lokina et al., 2014.
	Sporosarcina koreensis	Active against *V. parahaemolyticus, E. coli, S. enterica, B. anthracis, B. cereus* and *S. aureus* (MICs ranged from 3.9–6 $\mu g\ ml^{-1}$ and while ~3 μg NPs enhanced the activity of antibiotics like vancomycin, rifampicin, oleandomycin, penicillin G, novobiocin, and lincomycin 6 μg NPs inhibited the biofilm formation by *S. aureus, E. coli* and *P. aeruginosa*)	Crystalline spherical particles	Singh et al., 2016.
	Aqueous leaf extract of *Justicia glauca*	Potent activity against oral pathogens like *M. luteus, B. subtilis S. aureus, S. mutans, E. coli, Lactobacillus acidophilus, P. aeruginosa, S. cerevisiae* and *C. albicans* (MICs were 6.2–25 $\mu g\ ml^{-1}$ for bacterial and 12.5 $\mu g\ ml^{-1}$ for fungal pathogens respectively), synergistic activity of the NPs and antibiotics, namely, azithromycin and clarithromycin, was also observed against the tested oral pathogens	Crystalline spherical particles	Emmanuel et al., 2017.
	Aqueous extract of *Rhazya stricta decne*	Active against *Leishmania tropica, E. coli, S. aureus* and *B. subtilis*(IC_{50} against *Leishmania* amastigotes was 43 $\mu g\ ml^{-1}$, MICs against *E. coli* and *B. subtlis* were 25 and 50^{-1})	Spherical crystalline particles with an average size of 40 nm	Ahmad et al., 2017.
	Endosymbiont *P. fluorescens* inhabiting *Coffea arabica*	Activity against *P. aeruginosa, E. coli, S. aureus, B. subtilis* and *K. pneumoniae* (zones of inhibition ranged from 11–22 mm)	Spherical to hexagonal to triangular-shaped crystalline particles of size between 5–50 nm	Baker et al., 2016b.
	Dracocephalum kotschyi leaf extract	No antimicrobial activity	Spherical crystalline particles with a mean size of 11 nm	Dorosti and Jamshidi, 2016.
	Cladosporium cladosporioides, an endophytic fungus of the seaweed, *Sargassum wightii*	Antimicrobial activity against a panel of pathogenic microbes	Spherical crystalline particles with a size of around 100 nm	Hulikere et al., 2017.
	Aqueous extract of *Lyptolyngbya* sp.	Active against *E. coli* and *S. aureus* (zones of inhibition ranged from 14–18 mm)	Spherical crystalline particles of size between 100–200 nm	Zada et al., 2018.
	Non-pathogenic fungus *Trichoderma viride*	Significant activity against *E. coli* with vancomycin	Crystalline spherical particles	Fayaz et al., 2011.
	Leaf extract of *A lternanthera bettzickiana*	Activity against *B. subtilis, S. aureus, S. typhi, P. aeruginosa, M. luteus* and *E. aerogenes* (volumes of NPs used to note the growth inhibition were 10 μl, 20 μl, 30 μl and 40 μl; zones of inhibition for different microorganisms and different volumes ranged from 5–31 mm)	Crystalline spherical particles with size ranging between 80–120 nm	Nagalingam et al., 2018.
	Aqueous extract of roots of the medicinally important plant *Plumbago zeylanica*	Activity against *E. coli, A. baumannii, S. aureus*, and a mixed culture of *A. baumannii* and *S. aureus* (MIC was 8 μg/disk against all test organisms) Anti-biofilm activity against the same test	Particles were differently shaped like spheres, triangles, and hexagons	Salunke et al., 2014.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		organisms (96%–99% and 93%–98%, with AgNPs and AgAuNPs respectively)		
Gold nanoparticles (Au-NP)[c]	Aqueous extract of *Elettaria cardamomum* seeds	Active against *S. aureus, E. coli* and *P. aeruginosa* (zones of inhibition ranged from 11–16 mm)	Crystalline spherical particles with an average size of 15 mm	Rajan et al., 2017.
	Cucurbita pepo	Active against *B. cereus, S. aureus, E. coli, S. typhi* and *S. enterica* (MICs ranged from 400–800 μg ml^{-1})	Spherical crystalline particles of size between 1–100 nm	Chandran et al., 2014.
	Malva crispa	Active against *B. cereus S. aureus, E. coli, S. typhi, L. monocytogenes* and *S. enterica* (MICs ranged from 400–800^{-1})		
	Aqueous root extract of the medicinal plant, *Glycyrrhiza uralensis*	No antimcirobal activity	Crystalline spherical particles with 10–15 nm in diameter	Huo et al., 2018
	Aqueous leaf extract of *Indigofera tinctoria*	Active against *E. coli, S. aureus, B. pumilis, Pseudomonas* sp. *A. niger* and *A. fumigatus* (zones of inhibition for different microorganisms ranged from ~12–20 mm)	Crystalline particles of size between 6 – 29 nm and shapes were triangular / spherical / hexagonal	Vijayan et al., 2018.
	Aqueous extract of dried fruits of *Amomum villosum*	No antimicrobial activity	Crystalline spherical particles with size of 5–10 nm	Soshnikova et al., 2018.
	Leaf extracts of *Camellia sinensis*	Antibacterial activity upon being immobilized on cotton cloths	Crystalline spherical particles with size of 10 nm	Onitsuka et al., 2019
	Natural honey	Active against different strains of *E. coli, B. ceerus, S. typhi, S. aureus, P. aeruginosa, Streptococcus mutans* and *C. albicans* (MICs ranged from 31–250 μg ml^{-1})	Crystalline spherical particles with size of 10 nm	Sreelakshmi et al., 2011.
	Root extract of *Coleous forskohlii*	Active against pathogenic isolates of *P. vulgaris* and *M. luteus* (zone of inhibition ranged from 1–15 mm)	Crystalline spherical particles with size of 10–30 nm	Dhayalan et al., 2018.
	Brassica oleracea	Active against bacterial and fungal pathogens (at 50 μg ml^{-1}, zone of inhibition against *S. typhi, E. coli, S.aureus* and *B. subtilis* ranged from 6–9 mm and for *Aspergillus* sp. and *Pneumocystis* sp., it ranged from 5–6 mm)	Crystalline particles with different type of morphologies like spherical rod-shaped and triangular-shaped with average size of 24–38 nm	Kuppusamy et al., 2015.
	Solanum lycopersicum	No antimicrobial activity	Crystalline spherical particles with an average size of 14 nm	Bindhu and Umadevi, 2014.
	Mentha piperita extract	Active against clinically isolated human pathogens, *S. aureus* and *E. coli*	Crystalline spherical particles with a size of 90 mm	Ali et al., 2011.
Iron nanoparticles (Fe-NP)[d]	Leaf and seed extracts of *Moringa oleifera*	Activity of the NPs against *E. coli* was more prominent than standard antibiotics like ampicillin, gentamycin, erytomycin and vancomycin	Spherical amorphous particles with size between 2.6–6.2 nm	Katata-Seru et al., 2018.
	Trigonella foenum-graecum seed extract	Activity towards E. *coli* and *S. aureus* (MIC for *E. coli* and *S. aureus* was 32 μg ml^{-1} and 64 μg ml^{-1} respectively)	Spherical crystalline particles of ~11nm	Radini et al., 2018.
	Eichhornia crassipes	Active against *S. aureus* and *P. fluorescens* (at 100 μg ml^{-1} concentration)	Crystalline rod-shaped particles	Jagathesan and Rajiv, 2018.
Iron oxide-NP[e]	*Lantana camara* leaf extract	Antibacterial activity (highest zone of inhibition was observed in *Pseudomonas* sp. at 100 μg ml^{-1} of NPs)	Crystalline nanorods with average size of 10 –20 nm	Rajiv et al., 2017.
	Leaf extracts of *Agrewia optiva*	Efficacious against *S. aureus, S. mutans, S. pyrogenes, E. coli, C. diphtheriae, Corynebacterium xerosis, K. pneuomoniae* and *P. aeruginosa* (zone of inhibition for various microorganisms ranged from 6 –12 mm)	Irregular clusters with rough surfaces, agglomerated, quasi-spherical and size ranging from 15–60 nm	Mirza et al., 2018.
	Leaf extracts of *Prunus persica*		Spherical granular with size in the range of 13–70 nm	
	Extract of grey mangrove *Avicennia marina*	Anti-biofilm activity against *E. coli, P. aeruginosa* and *S. aureus* (by inhibiting the initial attachment and subsequent biofilm development; these NPs also inhibit the production of exopolysaccharide in *E. coli, P. aeruginosa* and *S. aureus* from 90% to 69%, 92% to 65% and 86% to 60% respectively)	Spherical crystalline particles with size ranging from 10–25 nm	Vaikundamoorthy et al., 2019.
	Skimmia laureola leaf extract	Efficacious against bacterial wilt pathogen *Ralstonia solanacearum* both *in vitro* and *in planta*	Polydisperse nanoparticles in the size range of 56–350 nm	Alam et al., 2019
Iron oxide-NP[f]	Aqueous extract of the edible fruits of *Couroupita guianensis*	Active against human bacterial pathogens like *E. coli, S. aureus, K. pneumoniae* and *S. typhi* (mechanism of action may be through either of cell membrane damage or DNA damage and ROS generation)	Crystalline particles with a mean diameter of 17 ± 10 nm.	Sathishkumar et al., 2018.
	Aqueous extracts of food processing wastes, like silky hairs of corn	Positive synergistic activity in combination with kanamycin and rifampicin (against pathogenic foodborne bacteria with inhibition zones between 9.36–24.42 mm) and amphotericin-B (activity against five different pathogenic *Candida* sp. with inhibition zones between 9.81–17.68 mm)	Crystalline particles with size of 84.81 nm	Patra and Baek, 2017.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Aqueous extracts of food processing wastes, like outer leaves of Chinese cabbage	Synergistic activity in combination with kanamycin, rifampicin and amphotericin-B	Crystalline particles with size of 48.91 nm	
Lead oxide nanoparticles (PbO-NP)[g]	Aqueous leaf extracts of *Sageretia thea*	Inhibited *P. aeruginosa*	Average size of the quasispherical particles was ∼27 nm	Khalil et al., 2017.
Magnesium oxide nanoparticles (MgO-NP)[h]	*Bauhinia purpurea* leaf extract	Activity against *S. aureus* (MIC was 250 μg ml^{-1} as opposed to prior reports of chemically synthesized MgO-NP exhibiting MIC of 625 μg ml^{-1} against *S. aureus*; mechanism of bacterial growth inhibition and death may be significant alteration in the surface morphology ofthe bacterial cells)	Thin flake-like structure of polycrystalline nature	B. Das et al., 2018; M. P. Das et al., 2018; S. Das et al., 2018.
	Melanin from the fungus, *Penicillium chrysogenum*	Active against MDR-*E. faecalis, C. albicans* and *K. pneumoniae* (zone of inhibition being 22, 20 and 20 mm respectively and MICs of 7.8 μg ml^{-1}, 15.62 μg ml^{-1} and 15.62 μg ml^{-1} respectively)	Spherical particles with a mean diameter of 10.28 nm	El-Sayyad et al., 2018.
	Extract of marine brown algae, *Sargassum wighitii*	Potent antibacterial and antifungal activities against human pathgens (while MIC for both MRSA and *P. aeruginosa* was 256 μg ml^{-1}MBC was 256 and 1024 μg ml^{-1} for MRSA and *P. aeruginosa* respectively)	Flower-shaped crystalline particles with a face-centered cubic structure	Pugazhendhi et al., 2019.
Manganese nanoparticles (Mn-NP)[i]	*Cinnamomum verum* bark extracts	Active against *S. aureus* and *E. coli* (activity was comparable with the standard antibiotic streptomycin)	Spherical crystalline particles with variable size and tendency to aggregatesize was in the range of 50–100 nm	Kamran et al., 2019.
Nickel nanoparticles (Ni-NP)[j]	Extracts of *Calotropis gigantea*leaves	Broad spectrum activity against *E. coli* and *B. subtilis*	Average size of particles was < 60 nm	Din et al., 2018.
Nickel oxide nanoparticles (NiO-NP)[k]	Extracts of *Calotropis gigantea* leaves	Broad spectrum activity against *E. coli* and *B. subtilis*	Average size of the particles 20–40 nm	Din et al., 2018
	Medicinal plant *Monsonia burkenea*	Selective bactericidal activity against Gram-negative strains like *E. coli* and *P. aeruginosa* (activity against *E. coli* at 5 mg ml^{-1} but that against *P. aeruginosa* was at 50 mg ml^{-1})	Spherical crystalline particles with average size of 25 nm.	Kganyago et al., 2018
	Neem (*Azadirachta indica*) leaf	Active against *S. aureus* and *E. coli*	Hexagonal crystalline particles with average size of 10 ± 2 nm	Helan et al., 2016.
	Leaves of *A. marmelos*	Effective towards Gram positive bacteria like *S. aureus* and *Streptococcus pneumoniae* (mechanism of action may be cell penetration thereby disturbing electron transport and affecting DNAprotein and mitochondriafinally leading to cell death)	Spherical and cubic particles with slight agglomeration and an average size of 8–10 nm.	Ezhilarasi et al., 2018.
Palladium nanoparticles (Pd-NP)[l]	*Filicium decipiens* leaf extract	Active against *E. coli, P. aeruginosa, S. aureus* and *B. subtilis*	Particles were spherical with size range of 2–22 nm	Govindasamy et al., 2017.
	Fruit extract of *Couroupita guianensis* Aubl.	Antibacterial activity	well-dispersed, spherical NPs with size between 5 and 15 nm	Gnanasekar et al., 2018.
Platinum nanoparticles (Pt-NP)[m]	Leaf extract of *Xanthium strumarium*	Active against *E. coli, P. aeruginosa, S. aureus, B. subtilis, K. pneumoniae, Candida* sp. and *Aspergillus* sp. (IC_{50} of 50 μg ml^{-1})	Cubic to rectangular shape particles with smooth surface and average size of 22 nm.	Kumar et al., 2019.
	Plant extract of highly active medicinal plant*Taraxacum laevigatum*	Strong antibacterial activity against *P. aeruginosa* and *B. subtilis* both of which have strong defensive systems against several antibiotics	Uniformly dispersedsmall sized (2–7 nm) and spherical in shape	Tahir et al., 2017.
Selenium nanoparticles (Se-NP)[n]	Aqueous berry extract of *Murraya koenigii*	Active against *E. faecalis* and *S. mutans* (MIC being 40 μg ml^{-1} for both); *Shigella sonnei* and *P. aeruginosa* (MIC being 50 μg ml^{-1} for both)	Spherical particles with a size between 50–150 nm	Yazhiniprabha and Vaseeharan2019.
	Cell-free supernatant of *B. licheniformis* isolated from food wastes	Control growth and biofilm formation by *B. cereus, E. faecalis, S. aureus, E. coli, S. typhimurium* and *S. enteritidis* (MIC against all tested microorganisms was 25 μg ml^{-1}whereas the antibiofilm concentration was 20 μg ml^{-1} against all bacteriaexcept *B. cereus*)	Spherical crystalline particles with diameter range of 10–50 nm	Khiralla and El-Deeb2015.
	Actinobacterium, *Streptomyces minutiscleroticus*	Anti-biofilm potentials along with good antiviral activity against Dengue virus	Spherical particles with size in the range of 10–250 nm	Ramya et al., 2015.
Selenium nanoparticles (Se-NP)[n]	*Zinziber officinale*	Active against *E. coli, Klebsiella* sp.*Pseudomonas* sp.*S. aureus* and *Proteus* sp. (MIC against *Proteus* sp. was 250 μg ml^{-1})	Spherical crystalline particles with size around 100–150 nm	Menon et al., 2019.
	Bacillus sp.	Active against *Leishmania major* promastigote and amastigote forms (IC_{50} were 1.62 ± 0.6 and 4.4 ± 0.6 μg ml^{-1} against the promastigote and amastigote forms respectively, after a 72 h incubation period)	No information available	Beheshti et al., 2013.
	Bacillus licheniformis	Anti-biofilm activity against *S. aureus* (NPsat a concentration of 0.5 μg ml^{-1}reduced bacterial adherence to more than 60% on glass and catheter surface)	No information available	Sonkusre and Cameotra2015.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Bacillus sp.	Inhibits biofilm produced by *S. aureusP. aeruginosa* and *P. mirabilis* (by 42%34.3%and 53.4% respectively, compared to that of the non-treated samples)	Spherical nano-structure in the size range of 80–220 nm	Shakibaie et al., 2015.
Silver nanoparticles (Ag-NP)[o]	Aqueous leaf extract of *Indigofera tinctoria*	Active against *E. coli, S. aureus, B. pumilisPseudomonas* sp.*A. niger* and *A. fumigatus* (zones of inhibition for different microorganisms ranged from 20–30 mm)	Crystalline spherical particles of size between 9 – 26 nm	Vijayan et al., 2018.
	Aqueous extract of dried fruits of *Amomum villosum*	Inhibition of pathogenic *E. coli* and *S. aureus* (zones of inhibition were 1.3 – 1.5 mm wider than that promoted by commercial antibioticneomycin)	Crystalline spherical particles with size of 5–15 nm	Soshnikova et al., 2018.
	Leaf extracts of *Camellia sinensis*	Antibacterial activity upon being immobilized on cotton cloths	Crystalline spherical particles with size of 30 nm	Onitsuka et al., 2019.
	Natural honey	Active against different strains of *E. coli, B. cereus, S. typhi, S. aureus, P. aeruginosa, Streptococcus mutans* and *C. albicans* (MICs ranged from 2.8–11.2 µg ml^{-1})	Crystalline spherical particles with size of ~12 nm	Sreelakshmi et al., 2011.
	Root extract of *Coleous forskohlii*	Active against pathogenic isolates of *P. vulgaris* and *M. luteus* (zone of inhibition ranged from 11–19 mm)	Crystalline elliptical-shaped particles with size of 5–35 nm	Dhayalan et al., 2018.
	Brassica oleracea	Active against bacterial and fungal pathogens (at 50 µg ml^{-1} zone of inhibition against *S. typhi, E. coli, S. aureus* and *B. subtilis* ranged from 7–11 mm and for *Aspergillus*sp. and *Pneumocystis* sp.it ranged from 6–7 mm)	Crystalline spherical particles with average size of 30–45 nm	Kuppusamy et al., 2015.
	Aqueous extract of roots of the medicinally important plant *Plumbago zeylanica*	Antimicrobial activity against *E. coliA. baumannii S. aureus* and a mixed culture of *A. baumannii* and *S. aureus* (MIC against *E. coli* was least i.e. 2 µg /diskin comparison with *A. baumannii* and *S. aureus* i.e. 8 µg /disc); anti-biofilm activity against the same test organisms (96–99% biofilm inhibition)	Spherically shaped	Salunke et al., 2014
	Solanum lycopersicum	Antibacterial activity against *P. aeruginosa* and *S. aureus*	Crystalline spherical particles with an average size of 12 nm	Bindhu and Umadevi, 2014.
	Fusarium oxysporum	Active against *E. coli* and *S. aureus* (at 470 mg l^{-1}maximum zone of inhibition was 2 mm in *E. coli* and 1.6 mm in *S. aureus*)	Spherical well-dispersed NP of size between 5 – 13nm	Husseiny et al., 2015.
	Rosmarinus officinalis leaf extract	Antibacterial and antifungal activities	Spherical morphology with a size range of 10–33 nm	Ghaedi et al., 2015.
	Thyme (*Thymus vulgaris*) extract	Significant antimicrobial and anti-biofilm properties against methicillin-resistant *S. aureus* (MRSA cell membrane impaired at MIC of 1 mg ml^{-1})	Spherical	Manukumar et al., 2017.
	Yellow pepper (*Capsicum annuum)*	Robust anti-bacterial and anti-biofilm activity against ESβL (+) *E. coli, P. aeruginosa* and MRSA (methicillin resistant *Staphylococcus aureus*)	Monodispersedpleomorphic particles with a size range of 1–40 nm	Ahmed et al., 2018.
	Silver tolerant bacterium characterized as *Bacillus cereus*	Anti-microbial and anti-biofilm potency against multidrug resistant (MDR)-ESKAPE pathogens	Well-defined shape and size with an average particle size of about 17.51 nm	Khan et al., 2019a.
	Aqueous leaf extracts of *Psidium guajava*	Broad-spectrum anti-microbial and anti-biofilm activity against potentially pathogenic *S. aureus, E. coli* and *Candida albicans*	Spherical with a mean diameter size of ~60 nm	Gupta et al., 2014.
	Extracts of *Dimocarpus longan*	Active against *P. aeruginosaE. coli* and *S. aureus* (antibacterial activity could be from both AgNP and Ag_2Owhich might be formed along with Ag-NP)	Crystalline spherical particles with an average size of 38.6 ± 7.0 nm	Phongtongpasuk et al., 2017.
	Fruit body extract of *Tribulus terrestris*	Active against clinically isolated MDR- *S. pyogenes, P. aeruginosa, E. coli, B. subtilis* and *S. aureus*	Spherical shaped particles with a size range of 16–28 nm	Gopinath et al., 2012.
	Artemisia nilagirica	Antibacterial activity	Average diameter of the spherical particles between 70–90 nm	Vijayakumar et al., 2013.
	Leaf extract of *Acalypha indica*	Active against water borne pathogens like *E. coli* and *Vibrio cholerae* (MIC against *E. coli* and *V. cholerae*– 10 µg ml^{-1}; mechanism of action might be alteration in membrane permeability and respiration of the Ag-NP treated cells)	Crystalline spherical particles of size between 20–30 nm	Krishnaraj et al., 2010.
	Extract of *Alternanthera sessilis*	Antimicrobial activity	Particles of various shapes and sizes	Niraimathi et al., 2012.
Silver nanoparticles (Ag-NP)[o]	Leaf extract of *Withania somnifera*	Active against human pathogensnamely*S. aureusP. aeruginosaP. vulgarisE. coli,* and *C. albicans* and plant pathogen like *Agrobacterium tumefaciens* (NP act by disrupting the cell membrane)	Spherical crystalline particles with size ranging between 70–110 nm	Marslin et al., 2015.
	Papaya fruit (*Carica papaya*) extract	Killing of MDR-human pathogenic bacteria (50 ppm of NP inhibited *E. coli* and *P. aeruginosa* whereas the same concentration of standard antibiotics was ineffective)	Cubic and hexagonal shaped particlesaverage size is 15 nm with a size range of 10-50 nm	Jain et al., 2009.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Gum extract of *Boswellia serrata*	Significant antibacterial effect on both Gram positive and negative bacteria	Monodispersed spherical particles of size 7.5 ± 3.8 nm	Kora et al., 2012.
	Bark extract and powder of novel *Cinnamomum zeylanicum*	Bactericidal activity (EC_{50} value against *E. coli* BL-21 strain was ~11 mg l^{-1})	Nano-crystalline particles	Sathishkumar et al., 2009a.
	Citrus sinensis peel	Active against *E. coli, P. aeruginosa* and *S. aureus*	Spherical-shaped particles of 35 and 10 nm sizesynthesized at 25 °C and 60°C respectively	Kaviya et al., 2011.
	Extracts of *Citrus maxima*	Active against many clinical as well as MDR-bacteria (MICs against various microbes ranged from 20 to 150 μg ml^{-1} where that for chemically synthesized AgNPs was > 200 μg ml^{-1})	Crystalline spherical particles with a size between 2 and 50 nm	Jha et al., 2017.
	Terpene-rich extract of *Lantana camara* leaf	Active against *E. coli, P. aeruginosa* and *S. aureus* (activity against *S. aureus* was also comparable with that of the standard antibiotic ciprofloxacin)	Spherical crystalline particles with a mean size of 410–450 nm without agglomeration	Shriniwas and Kumbhar, 2017.
	Cinnamon extract (*Cinnamomum* sp.)	Activity against both Gram positive and negative bacteria (action of the cinnamon loaded AgNPs can be seen best on Gram negative bacteria like *E. coli, P. aeruginosa* and feebly on Gram positive bacteria like *B. cereus* and *S. aureus*)	Mono dispersedspherical crystalline particles in the range of 50–70 nm	Premkumar et al., 2018.
	Bark extracts of *Ficus benghalensis* Bark extracts of *Azadirachta indica*	Active against both Gram positive bacteria like *B. subtilis* and Gram negative bacteria like *E. coli, P. aeruginosa* and *V. cholerae*	Crystalline spherical particles	Nayak et al., 2016.
	Lantana camara leaf extract	Active against *E. coli, Pseudomonas*sp.*Bacillus* sp. and *Staphylococcus* sp. (as Ag-NP volume changed from 2–10 μl zone of inhibiton of different bacteria varied from 3–7 mm).	Crystalline spherical particles with fair agglomerationsize of particles varied with precursor $AgNO_3$ concentrations (as $AgNO_3$ concentration decreased from 0.01–0.001 Maverage particle size decreased from 37–29 nm)	Ajitha et al., 2015.
	Dioscorea bulbifera tuber extract	Potent activity both singly and in combination with broad spectrum antibiotics against *P. aeruginosaE. coli* and multidrug-resistant *Acinetobacter baumannii* (0.1 to 11 fold increase in activity of different classes of antibiotics in combination with the Ag-NP)	Spherical in the size range of 8–20 nm	Ghosh et al., 2012.
	Selaginella bryopteris plant extract	Active against human pathogens *S. aureus, E. coli* and *A. niger* respectively (while MIC of Ag-NPs was 0.25 mg in both *E.coli* and *S. aureus*MIC was 1 mg against *A. niger*)	Spherical crystalline particles with an average size of 5–10 nm	Dakshayani et al., 2019.
	Ocimum basilicum extract	Activity against both Gram positive and Gram negative bacteria	Crystalline spherical particles with average size of ~23 nm	Pirtarighat et al., 2019.
	Plant extract of *Salvia spinosa* (grown under *in vitro* condition)	Active against both Gram positive and Gram negative bacteria (mechanism of bactericidal activity is most likely due to the attachment of the NPs to the cell wall and generation of free radicals)	Crystalline particles of which majority were spherical and few ovalapproximate size was 19–125 nm	Pirtarighat et al., 2019b.
	Juniperus chinensis leaf extract	Active against nosocomial bacterial pathogens like *B. subtilisE. coli, S. aureus* and *P. aeruginosa* (MICs ranging between 14–18 μg ml^{-1} and MBCs from 18–21 μg ml^{-1})	Spherical crystalline particles with average sizes in the range of 18–25 nm	Al-Dhafri and Ching2019.
	Blue-green algae*Spirulina platensis*	Active against bacteria isolated from HIV patients	Well defined and monodispersed (spherical) with an average size of 6 nm	Suganya et al., 2015.
	Apple snail (*Pomacea bridgesii*) eggs	Potent antibacterial activity against both *S. aureus* and *E. coli* (while MICs against *E. coli* and *S. aureus* were 0.8 mg ml^{-1}MBCs against *E. coli* and *S. aureus* were 1.6 and 3.2 mg ml^{-1} respectively)	Spherical crystalline particles with sizes ranging from 1–30 nm	Janthima et al., 2018.
	Coffea arabica seed extract	Reduced growth of *E. coli* and *S. aureus* (MICs against the test organisms was ≤0.2675 mg l^{-1}both 0.05 M and 0.1 M NPs were as strong as the standard drugampicillin)	Particles with typical spherical and ellipsoidal morphologyapproximate particle diameter was in the range of 10–40 nm10–50 nm and 20–150 nm for 0.1 M0.05 M and 0.02 M samples respectively	Dhand et al., 2016.
	Aqueous extract of *Panax ginseng* root	Active against influenza virus (inhibitory rates of 5.31%4.18%5.97%.7.10% and 15.12% respectively were detected at Ag-NP concentrations of 0.0050.010.150.02 and 0.25 M; howevernone of the tested Ag-NP concentrations had any cytotoxic effects on uninfected normal MDCK cells)	Quasi-spherical crystalline particles with sizes ranging from ~ 5–15 nm	Sreekanth et al., 2018.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
Silver nanoparticles (Ag-NP)[o]	*Nigella arvensis* leaf extract	Active against clinical bacterial isolates like *E. coli, P. aeruginosa, S. marcescens, S. aureus, B. subtilis* and *S. epidermidis* (MICs for these isolates were 7.82. 15.63, 62.5, 7.82, 31.25 and 7.82 μg ml^{-1} respectively)	Highly dispersed, mostly spherical crystalline particles with sizes in the range of 5–100 nm	Chahardoli et al., 2018.
	Aqueous extract of roots of *Rheum palmatum*	Active against *S. aureus* and *P. aeruginosa* (IC_{90} and IC_{50} values were noted to be 15 μg ml^{-1} and 7.5 μg ml^{-1} for both strains)	Spherical and hexagonal shaped particles with an average size of 121.5 nm	Arokiyaraj et al., 2017.
	Endophytic fungus*Penicillium polonicum* (isolated from the marine green algae *Chetomorpha antennna*)	Efficacious against MDR-biofilm-forming *Acinetobacter baumanii*(MIC was 15.62 μg ml^{-1} and the MBC was 31.24 μg ml^{-1})	Crystalline spherical particles with an average size of 10–15 nm	Neethu et al., 2018.
	Crude extract of the aerial parts of *Anthemis atropatana*	Active against *S. aureus, E. coli, S. pyogenes* and *P. aeruginosa* (MICs were 12.5, 25, 50 and 100 μg ml^{-1} respectively)	Crystalline structure with spherical shape and an average size of 38.89 nm	Dehghanizade et al., 2018.
	Aqueous extract of leaves of traditional medicinal plant*E. scaber*	Active against *Bacillus* sp.*Pseudomonas* sp. and *Aspergillus* sp.(antibacterial activity was more prominent than antifungal activity)	Spherical crystalline particles with a size of 37.86 nm	Francis et al., 2018.
	Waste grass	Active against *P. aeruginosa* and *A. baumannii* (while MICs against *A. baumannii* and *P. aeruginosa* were 1.56 and 0.78 ppm respectively, MBCs against them were 3.12 and 1.56 ppm respectively); NPs also showed activity against *Fusarium solani* and *Rhizoctonia solani* (highest growth-inhibitory effect against *R. solani* and *F. solani* were ~55% and ~ 90%both at a concentration of 20 μg ml^{-1})	Spherical crystalline particles with a size ranging from 4–34 nm	Khatami et al., 2018a.
	Aqueous leaf extract of *Euphrasia officinalis*	Active against pathogenic bacteria like *E. coli, P. aeruginosa S. aureus* and *V. parahaemolyticus* (at 500 ppm of NPsantibacterial activity ranged from ~10 –15 mm and biofilms of *S. aureus* and *P. aeruginosa* were completely inhibited at 10 μg ml^{-1})	Quasi-spherical crystalline particles with an average size of 40.37 ± 1.8 nm	A. Singh et al., 2018; H. Singh et al., 2018.
	*Brassica oleracea*var. *botrytis* and *Raphanus sativus*	Activity against *E. coli, Myroides* sp.*P. aeruginosa, Kocuria*sp.and *Promicromonospora* sp. (while 5 ppm of NPs formed from *Brassica* sp. showed maximum inhibition of *Myroides* sp.5 ppm of NPs formed from *Raphanus* sp. showed maximum inhibition of *Pseudomonas* sp.)	Spherical crystalline particles in the range of 4–18 nm	A. Singh et al., 2018; H. Singh et al., 2018
	Aqueous extract of *Persea americana* seeds	Activity against *E. coli* (at Ag-NP concentrations of 6.01, 334.11 and 823.34 μg ml^{-1}growth inhibition was 1 mm1.5 mm and 1 mm respectively; small size of the particles might have contributed in the interaction of NPs with the cell walls and the plasma membrane and allowed their entry into the cytoplasmwhich could then generate cell death)	Crystalline spherical to large oblongated particles with the size and unevenness of the NPs growing as more extract was usedsize in the range of 20–40 nm	Girón-Vázquez et al., 2019.
	Aqueous extract of leaves of *Annona reticulata*	Active against *B. cereus, S. aureus, P. aeruginosa, E. coli* and *C. albicans* (complete inhibition was found at 125 mg ml^{-1} for *B. cereus*31.2 mg ml^{-1} for *S. aureus*62.5 mg ml^{-1} for *P. aeruginosa*62.5 mg ml^{-1} for *E. coli* and 62.5 mg ml^{-1} for *C. albicans*)	Crystalline spherical particles with size of 7–8 nm	Parthiban et al., 2019.
	Leaves and fruits of *Aegle marmelos*	Inhibited *B. cereus, P. aeruginosa, S. dysenteriae, E. coli* and *S. aureus* (highest zone of inhibition was against *B. cereus* i.e. ~ 19mm at 40 μl followed by inhibition zones of ~15–16 mm against *P. aeruginosa, S. dysenteriae, E. coli* and *S. aureus*; MIC of biosynthesized NPs was in the range of 0.009875–0.0395 mg/100 μl which was quite lower than the MIC of crude extract i.e. 0.0781–0.3125 mg/100 μl)	Crystalline spherical particles with a smooth surfacewithout any pinholes	Devi et al., 2019.
	Extracts of the leaves of *Dodonaea viscosa*	Activity against *Streptococcus pyogenes* (significant zones of inhibition i.e. 20, 16, 13 and 18 mmfor Ag-NPs synthesized by methanolacetoneacetonitrile and water extracts respectively)	Different nano sized particles (15, 18, 12 and 20 nm) with different surface morphology (worm-likeirregular flowerspherical and dendritic structures) prepared using different solvent extracts (methanolacetoneacetonitrile and water)	Anandan et al., 2019.
	Leaf extract of *Platycodon grandiflorum*	Activity against *E. coli* and *B. subtilis*	Uniform crystalline spherical particles with average sizes of 19 and 21 nm for Ag-NPs produced at 37 °C and 50 °C respectively, with slightly larger NPs formed at 50 °C owing to agglomeration	Anbu et al., 2019.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Aqueous extract of *Givotia moluccana*	Active against both Gram positive *S. aureus* and Gram negative bacteria*E. coli, P. vulgaris* and *K. pneumonia e* (mechanism of action may be due to alteration in membrane permeabilityloss of ATP synthesis and DNA replication ability)	Crystalline spherical particles with average size of 55 nm	Sana and Dogiparthi, 2018.
	Fritillaria sp. flower plant extract	Active against some human pathogens (MICs and MBCs were also appreciable)	Spherical crystalline particles with a particle size of 10 nm	Hemmati et al., 2019.
Silver nanoparticles (Ag-NP)[o]	*Thymbra spicata* L. var. *spicata* leaf extract	Antibacterial activity was observed in Gram-positive bacterial pathogens like *B. cereus* and *S. aureus* and in Gram-negative ones like *E. coli* and *S. typhimurium* (zone of inhibition ranged from 10–16 mm against the different test strainsMICs and MBCs ranged from 12.5–200 μg ml^{-1} and 25–200 μg ml^{-1} against the different test strains)	Crystallinemostly spherical shaped particles with size in the order of 20–50 nm	Erci et al., 2018.
	Stemsroots and leaves of the mangrove plant *Rhizophora mucronata*	Activity was more intense in Gram-positive bacterial pathogens like *B. cereus* and *S. aureus* than Gram-negative ones like *P. aeruginosa* and *V. harveyi* (zone of inhibiton against different bacteria ranged from 7–19 mm)	Crystalline spherical particles with size ranging between 1–80 nmmean size being 32.44 nm	Abdi et al., 2019.
	Extract of the medicinal herb *Swertia paniculata*	Active against *P. aeruginosaK. pneumoniae* (synthesized Ag-NP had better antimicrobial activity than the extract under standard incubation conditions)	Crystalline spherical particles with size ranging between 31–44 nm	Ahluwalia et al., 2018.
	Leaf extract of *Dolichos lablab*	Active against *E. coli* and *B. subtilis*(MICs of NPs against *B. subtilis* and *E. coli* were 32 and 8 μg ml^{-1} respectively)	Crystalline spherical particles with a size range of 4–16 nm	Kahsay et al., 2018.
	Extract of the marine red algae*Gracilaria birdiae*	Active against *E. coli* and *S. aureus* (MICs at different pH ranged from 34 – 80 μM against *E. coli* and 80–160 μM against *S. aureus*)	Spherical crystalline particles with diameter between 20.3 and 94.9 nm	Aragão et al., 2016.
	Aqueous extract of rhizome of *Acorus calamus*	Antibacterial activity against three different pathogenic bacteriagrowth kinetic study with *E. coli* indicated the arrest of growth in the log phase.	Spherical particles with average size 31.86 nm	Nakkala et al., 2014.
	Supernatant of endophytic fungus *Alternaria* sp. isolated from the healthy leaves of *Raphanus sativus*	Active against Gram positive methicillin resistant *B. subtilisS. aureus* and Gram negative bacteria *E. coli* and *S. marcescens* (inhibition zones had different concentrations of NPs ranging from 6–23 μg ml^{-1} for Gram positive bacteria and 24–36 μg ml^{-1} for Gram negative bacteria)	Spherical crystalline particles with an average size of 4–30 nm	Singh et al., 2017.
	Seed extract of *Trigonella foenum-graecum* L.	Suppressed the growth of Gram positive and Gram negative bacteria (MICs against *S. aureus* and *E. coli* were 62.5 μg ml^{-1} and 125 μg ml^{-1} respectively, whereas for both *P. aeruginosa* and *S. typhi* the MIC was 500 μg ml^{-1} and for fungi like Trichoderma viridiae, Trichophyton rubrum and A. flavus, the MIC was 250 μg ml^{-1})	Face centered cubic structurecrystalline in nature	Varghese et al., 2019.
	Ocimum gratissimum leaf extract	Antibacterial activity against MDR-*E. coli* and *S. aureus* (while MICs for MDR-*E. coli* and MDR-*S. aureus* were 4 and 8 μg ml^{-1}MBCs were 8 and 16 μg ml^{-1} respectively) as well as anti-biofilm activity (while inhibition of *E. coli* biofilm was ~65% at 4 μg ml^{-1}it was > 80% for *S. aureus* at 8 μg ml^{-1})	Crystalline,well-separated particlespredominantly triangular in shape with mean size of 18 ± 3 nm	Das et al., 2017.
	Edible fruit juices	Activity against *P. aeruginosa* (inhibition of swarming motility and also growthprobably through membrane destabiliation)	Crystalline particles of size between 19–45 nm	Samrot et al., 2018.
	Ganoderma applanatum	*In vitro* activity against *S. aureus* and *E. coli* (at 50 μg ml^{-1}zone of inhibition of *S. aureus* was 16.33 mm and in the case of *E. coli* was 13.33 mm); *in vivo* activity against phtytopathogens (at 50 μg ml^{-1}inhibition of *Botrytis cinerea* and *Colletotrichum gloeosporioides* were noted)	Crystalline spherical particles in the size range of 20–25 nm	Jogaiah et al., 2017.
	*Fusarium oxysporum*fungal culture filtrate	Activity against *Candida albicans, C. parapsilosis* and *Xanthomonas axonopodis* (MICs ranged from ~ 6–104 μg ml^{-1}); NP-impregnated cotton fibers inhibited microbial growth (growth was inhibited even after repeated mechanical washing cycles of up to 10 which might find potential applications in hospital patients)	Spherical homogeneous particles with a size of 28.0 ± 13.1 nm	Ballottin et al., 2017.
	Leaf extract of *Justicia glauca*	Active against *S. mutans, S. aureus, L. acidophilus, M. luteus, B. subtilis, E. coli, P. aeruginosa* and *C. albicans* (both AgNPs and drug blended AgNPs showed significant antibacterial and antifungal activity with MIC in the range of 25–75 μg ml^{-1})	Spherical crystalline particles of size between 10–20 nm	Emmanuel et al., 2015.
		Active against *E. coli, P. aeruginosaSalmonella*sp. *S. aureus, S. pyogenes* and *C. albicans* (AgNPs alone	Spherical crystalline particles with size < 100 nm.	Ghiuță et al., 2018.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Culture supernatants of *B. subtillis* and*B. amyloliquefaciens*	were more active than the standard antibiotic against *C. albicans* and activity of antibiotics tested was enhanced in synergism with NPs)		
	Coriandrum sativum leaf extract	Active against acne-causing agent *P. acnes* (MIC being 3.1 μg ml^{-1}) and dandruff causative agent *M. furfur* (MIC of 25 μg ml^{-1})	Spherical crystalline particles with size ~37 nm	Sathishkumar et al., 2016.
	Solanum torvum extract	Active against bacterial and fungal pathogensnamely *P. aeruginosa S. aureusA. flavus* and *A. niger* (zones of inhibition ranged from 4–17 mm)	Spherical crystalline particles with size ~14 nm	Govindaraju et al., 2010.
	Seaweed *Enteromorpha flexuosa* (wulfen) J. Agardh extract	Active against Gram-positive and negative bacteria	Spherical crystalline particles with size ~30 nm	Yousefzadi et al., 2014.
	Anaerobically digested *Parthenium hysterophorous* slurry	Active against *E. coli* and *Pseudomonas* sp.	Spherical crystalline particles with size ~19 nm	Adur et al., 2018.
Silver nanoparticles (Ag-NP)[o]	Extract of inflorescence of *Cocos nucifera*	Active against human bacterial pathogens like *K. pneumoniae, B. subtilis, P. aeruginosa* and *S. paratyphi*	Spherical crystalline particles with a size of 22 nm	Mariselvam et al., 2014.
	Allium cepa extract	Antibacterial activity against *Bacillus* sp.*Staphylococcus* sp.*Streptococcus* sp.*K. pneumoniae, E. coli, S. typhimurium, P. vulgarius, S. marcescens* and *C. albicans* (while MIC for different bacteria ranged from 1.25–5 mg $ml^{-1}$for *C. albicans* it was 10 mg ml^{-1})	Spherical crystalline particles with a size ranging from 10–23 nm	Gomaa, 2017.
	Callus and leaf of *Sesuvium portulacastrum*	Active against clinical isolates of both bacteria and fungi (antibacterial activity was more prominent than antifungal activity)	Spherical particles with variable size ranging from 5–20 nm	Nabikhan et al., 2010.
	Green tea (*Camellia sinensis*)	Active against pathogenic isolates of *S. aureus, P. aeruginosa, K. pneumoniae, E. coli* and *S. enterica*	Spherical particles with sizes ranging from 2–4 nm	Rolim et al., 2019.
	Aqueous flower extract of *Tagetes erecta*	Synergistic antimicrobial potential with various commercial antibiotics against *S. aureus, B. cereusE. coli, P. aeruginosaCandida glabrataC. albicans* and*Cryptococcae neoformans*(0.1–0.6 times increase in activity of antibiotics was observed against the test organisms)	Spherical hexagonal and irregular shaped particles with size ranging from 10–90 nm	Padalia et al., 2015.
	Culture supernatants of *Klebsiella pneumoniae*	Active against *S. aureus* and *E. coli* (enhanced activities of penicillin Gamoxicillinerythromycinclindamycin and vancomycin)	Spherical crystalline particles	Shahverdi et al., 2007.
	Solanum triobatum, Ocimum tenuiflorum, Syzygium cumini, Centella asiatica and *Citrus sinensis* extracts	Active against *S. aureus, P. aeruginosa, K. pneumoniae* and *E. coli* (zones of inhibition ranged from 7–30 mm for Ag-NPs generated from different plant extracts)	Spherical crystalline particles with size ranging from 22–65 nm	Logeswari et al., 2015.
	Leaf extract of *Allophylus cobbe*	Active against *P. aeruginosaShigella flexneri S. aureus* and *S. pneumoniae* (MICs against the test isolates ranged from 0.59–0.76 μg $ml^{-1}$and biofilm formation was inhibited from 20 to ~100% with NP-concentrations ranging from 0.1–0.7 μg ml^{-1})	Spherical crystalline particles with size of ~5 nm	Gurunathan et al., 2014.
	Culture supernatant of an agriculturally important bacterium*Serratia* sp. BHU-S4	Antifungal activity against *Bipolaris sorokiniana*spot blotch pathogen in wheat plants (2, 4 and 10 μg ml^{-1} NPs promoted total inhibition of conidial germination)	Spherical crystalline particles with size in the range of 8–22 nm	Mishra et al., 2014.
	Leaf extract of *Argemone mexicana*	Efficacious against *Peste des petits ruminants virus* (inhibited viral replication at the level of virus entry)	Spherical crystalline particles with a size of 5–30 nm	Khandelwal et al., 2014.
	Leaf extract of *Argemone mexicana*	Antibacterial activity against *E. coli* and *P. synrigae* and antifungal activity against *A. flavus* at a concentration of 50 ppm	Cubic & hexagonal shape with average size of 20 nm	Singh et al., 2010.
	Acacia rigidula	*In vitro* and *in vivo* activity against *E. coli, P. aeruginosa* and a clinical isolate of MDR-*P. aeruginosa* (MICs ranged from 0.5– 62.5 ppm)	Spherical crystalline particles with a mean diameter of ~22 nm	Escárcega-González et al., 2018.
	Phyllanthus amarus	Active against MDR burn isolates of *P. aeruginosa* (MICs ranged from 6.25–12.5 μg ml^{-1})	Spherical crystalline particles with a size of 24 ± 8 nm	Singh et al., 2014.
	Ginger rhizome (*Zingiber officinale*) extract	Substantial antibacterial activity against both Gram positive*S. aureus* and *B. subtilis* and Gram negative bacteria*E. coli* and *P. aeruginosa* (at concentrations beyond 40 μg ml^{-1}no growth of the test isolates occcured)	Almost spherical particles with average diameter of ~5 nm	Dinda et al., 2019.
	Rhizome extract of medicinally important plant *Nardostachys jatamansi*	Significant anti-biofilm activity	Spherical crystalline particles in the diameter range of 10–15 nm	Muthuraman et al., 2019.
	Bacillus pumilus	Active against *E. coli, S. sonneiP. aeruginosaK. pneumoniae S. bovis* and *S. aureus* (MICs ranged	Mono-dispersedtriangularhexagonal and spherical shaped	Elbeshehy et al., 2015.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		from ~6–50 μg ml^{-1} and MBCs ranged from ~12–~100^{-1})	particles with average size of ~70 mm	
	B. persicus	Active against *E. coli, S. sonneiP. aeruginosaK. pneumoniae S. bovis* and *S. aureus* (both MIC and MBCs ranged from 12–100 μg ml^{-1}) *Bacillus licheniformis* Active against *E. coli, S. sonneiP. aeruginosaK. pneumoniae S. bovis* and *S. aureus* (MICs ranged from ~3–25 μg ml^{-1}and MBCs ranged from ~3–50 μg ml^{-1}); antiviral activity against bean yellow mosaic virus (post-infection treatment with NPs caused a decrease in virus concentrationpercentage of infection and disease severity)		
	Culture supernatants of *S. aureus*	Active against methicillin-resistant strains of *S. aureus* and *S. epidermidis*; S. *pyogenes S. typhiK. pneumoniae* and *V. cholerae* (zones of inhibition ranged from 11–18 mm for S. *pyogenes S. typhi,* MRSA and MRSE but only very faint activity towards *K. pneumoniae* was notedwhile against *V. cholerae* no action was observed)	Spherical crystalline particles with size ranging from 160–180 nm	Nanda and Saravanan2009
	Penicillium italicum	Active against MDR isolates of *S. aureus, E. coli, Shewanella putrefaciens, V. parahaemolyticus* and *C. albicans*	Spherical crystalline particles with a size of ~33 nm	Nayak et al., 2018.
Berberis vulgaris leaf and root aqueous extracts	Effective against *E. coli* and *S. aureus* (at 3 and 5 ppm NP-concentrations)	Spherical crystalline particle in the size range of 30–70 nm	Behravan et al., 2019.	
Silver nanoparticles (Ag-NP)[o]	*Fusarium oxysporium*	Active against *L. amazonensis* amastigote and promastigote forms at concentrations of 0.25 and 0.5 μg ml^{-1} (mechanism of action may be through damage to mitochondria and plasma membrane as well as increased ROS production)	Spherical particles with size around 57 nm	Fanti et al., 2018.
	Lippia nodiflora extract	Active against human pathogenic bacteria like *S. aureus, S. mutans S. pneumoniaeE. coli* and *K. pneumoniae* (zones of inhibition ranged from 18–24 mm)	Spherical crystalline particle in the size range of 30–60 nm	Arumugam et al., 2017.
	Latex serum extract of *Calotropis procera*	Higher antimicrobial efficacy than crude latex against *E. coli, P. aeruginosa, Serratia* sp.*Trichophyton rubrum, C. albicans* and *A. terreus* (MICs against the bacterial strains ranged from 5–10 μl while that for fungi ranged from 10–25μl)	Spherical crystalline particle with an average size of 12 nm	Mohamed et al., 2014.
	Leaf aqueous extract of *Andrographis echioides*	Active against *E. coli* and *S. aureus* (zones of inhibition in both were > 20 mm)	Spherical crystalline particle	Elangovan et al., 2015.
	Pod extract of *Cola nitida*	Complete inhibition of MDR-*K. granulomatis, P. aeruginosa, E. coli, S. aureus* (zones of inhibition ranged from 7–28 mm at concentrations ranging from 50–150 μg ml^{-1}); activity against *A. niger, A. flavus* and *A. fumigatus* (complete inhibition of fungi with NPs-treated paint compared to the abundant growth observed in the control)	Spherical crystalline particle in the size range of 12–80 nm	Lateef et al., 2016.
	Cell-free extract of *Bacillus safensis*	Inhibited a clinical isolate of *C. albicans* (zone of inhibition was ~ 11–15 mm with MIC of 40^{-1})	Spherical crystalline particles with size of 5–95 nm	Lateef et al., 2016.
	Leaf extracts of the medicinal plant *Tropaeolum majus*	Activity against *P. aeruginosa* (MIC of 6.25 μg ml^{-1}) and *Penicilium notatum* (MIC of 31.2 μg ml^{-1})	Spherical crystalline particles	Valsalam et al., 2018.
	Aqueous extract of *Sesbania grandiflora* leaves	Antimicrobial activity	Spherical crystalline particles	Ajitha et al., 2016.
	Sesbania grandiflora leaf extract	Antibacterial activity against MDR *S. enterica* and *S. aureus*	Spherical crystalline particleswith size in the range of 10–25 nm.	Das et al., 2013.
	Carnivorous plants like *Dionaea muscipula*	Antimicrobial activity (MIC was between 5.3 μg ml^{-} for *D. dadantii* and *P. aeruginosa* and 170 μg ml^{-1} or more for *S. aureus* and *C. albicans*).	Spherical crystalline particleswith size in the range of 5–10 nm.	Banasiuk et al., 2017.
	Extract of *Eucalyptus chapmaniana*	Antimicrobial activity against *S. aureus, S. pneumoniaeP. aeruginosaK. penumoniaeE. coli, P. vulgaris* and *C. albicans* (zone of inhibition ranged from 19–27 mm at concentrations 0.01–0.02mmol l^{-1})	Spherical crystalline particles with size in the range of 60 nm	Sulaiman et al., 2013.
	Streptomyces sp. isolated from fertile soil sample	Activity against extended spectrum β-lactamase i.e. ESBLproducing pathogens and ESBL clinical isolates like *K. penumoniae, E. coli* and *Citrobacter*sp.(MICs ranged from 1.4 – 4 μg ml^{-1})	Spherical with the size range of 20–70 nm	Subashini et al., 2013.
	Crude methanolic root extracts of *Diospyros paniculata*	Active against test pathogenic fungal strains as well as Gram positive and negative bacterial strains	Spherical crystalline particles with average size of 17 mm	Rao et al., 2016.
	Crude methanolic root extracts of *Diospyros sylvatica*			Pethakamsetty et al., 2017.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		Activity against test pathogenic Gram positive and Gram negative bacterial as well as fungal strains (*B. pumilis* was completely killed at 25 μg ml-1)	Spherical crystalline particles with average crystallite size of 10 mm	
	Rhizomes of medicinally important plant*Bergenia ciliata*	Enhanced biological activities against the pathogenic fungal and bacterial strains as compared to *B. ciliata* extract (while zones of inhibition against bacteria like *S. aureusM. luteusE. aerogenes* and *B. bronchiseptica* ranged from 8–11 mmand against fungi like *Aspergillus* sp. and *F. solani* ranged from 7–8 mm)	Spherical crystalline particles with average crystallite size of 35 mm	Phull et al., 2016.
	Extracts of medicinal plant*Juniperus procera*	Antimicrobial activity (zones of inhibition against test organisms like *B.* subtilis*P. mirabilisM. luteusK. pneumoniae* and *C. albicans* ranged from 18–24 mm)	Spherical and cubic shaped particles with an average size of 30–90 nm	Ibrahim et al., 2018Khan et al., 2016
	Caruluma edulis	action against *B. subtilis* and *S. aureus* (MIC values of 125 μg/ml) and against *E. coli* (MIC value of 250 μg/ml)	spherical crystalline particles of size in the range between 2-10 nm	Khan et al., 2016
	Sugarcane (*Saccharum officinarum*) bagasse extract	Active against *E. coli, P. aeruginosa* and *S. aureus*	Spherical shaped particles	Aguilar et al., 2018.
	Fruit extract of *Garcinia indica*	Antibacterial activityboth alone as well as in combination with tetracyclin	Spherical-shaped crystalline particles	Sangaonkar and Pawar, 2018.
	Garcinia mangostana leaf extract	Killing of MDR-human pathogenic *E. coli* and *P. aeruginosa* (zones of inhibition were almost similar with standard antibiotics but at lower concentrations)	Spherical-shaped particles with size ranging 6 to 57 nm	Veerasamy et al., 2011.
	Culture supernatant of *Pseudomonas putida*	Significant antibacterial activity against *E. coli, P. aeruginosa, H. pylori, S. aureus* and *B. cereus*(MICs ranged from 6–25 μg ml-1 and MBCs ranged from 8–25 μg ml-1)	Spherical crystalline particles with size between 6 to 16 nm	Gopinath et al., 2017.
	Arisaema flavum	Antimicrobially active (at 20 mg ml-1 concentrationzones of inhibition against *E. coli, S. aureus* and *P. putida* ranged from 11–20 mm and against an MDR-*E. coli* with a zone of > 30 mm)	Spherical crystalline particles with size between 5 to 8 nm	Rahman et al., 2019.
	Aqueous extract of lychee (*Litchi sinensis*) fruit peel	Marked activity against *E. coli, S. aureus* and *B. subtilis* (MIC values were 125 μg against *E. coli* and 62.5 μg against both the other two microbes)	Spherical crystalline particles	Khan et al., 2016c.
	Bacillus flexus	Effective against clinically isolated MDR microbes	Spherical and triangular shaped particles with size in the range of 12– 65 nm	Priyadarshini et al., 2013.
Silver nanoparticles (Ag-NP)[o]	Cell-free supernatants of cultures of *F. chlamydosporum*	Inhibited mycotoxin production (MIC for complete inhibition of aflatoxin and ochratoxin production by *A. flavus* and *A. ochraceus* respectively were 5.9 and 6.3 μg ml-1)	Spherical crystalline particles with size between 6 to 26 nm	Khalil et al., 2019.
	Cell-free supernatants of cultures of *Penicillium chrysogenum*	Inhibited mycotoxin production (MIC for complete inhibition of aflatoxin and ochratoxin production by *A. flavus* and *A. ochraceus* respectively were 5.6 and 6.1 μg ml-1)	Spherical crystalline particles with size between 9 to 18 nm	
	Cell-free supernatants of cultures of *Trametes ljubarskyi* Cell-free supernatants of cultures of *Ganoderma enigmaticum*	Significant antimicrobial activity against *E. coliB. subtilisM. luteusP. putidaK. aerogenesK. pneumonia e* and *S. aureus* (zones of inhibition ranged from 24–28 mm for all these microbes)	Spherical crystalline particles with size between 15 to 25 nm	Gudikandula et al., 2017.
	Juice of Longan fruit (*Dimocarpus longan*)	Active against *S. aureus, B. subtilis* and *E. coli* (MICs were ∼31 μg ml-1 against both of *S. aureus* and *B. subtilus* but it was ∼62 μg ml-1 against *E. coli*)	Spherical crystalline particles with size between 4 to 10 nm	Khan et al., 2016a.
	Leaf extract of *Alternanthera bettzickiana*	Active against *S. aureus, S. mutans, E. coli, S. typhi* and *P. aeruginosa* (zones of inhibition ranged from 11–17 mm for NP concentrations between 5–100 μg)	Spherical crystalline particles with size between 5 to 15 nm	Ramalingam et al., 2017.
	Limonia acidissima leaf	Active against *S. aureus, S. typhi* and *P. aeruginosa* better than erythromycin (zones of inhibiton were between 13 and 15 mm at 400 μg ml-1 respectively)	No information available	Patil and Taranath, 2018.
	Aqueous extract of *Grewia flaviscences* plant leaf	Active against *Bacillus* sp.and *P. aeruginosa*	Spherical particles with average size of 60 nm	Sana et al., 2015.
	Plumeria alba (frangipani) flower extract	Active against *E. coli* (bacteriostatic effect was observed)	Spherical particles of 36.19 nm	Mata et al., 2015.
	Tephrosia purpurea leaf extract	Inhibit *Pseudomonas* sp. and *Penicillium* sp.	Spherical crystalline particles of ∼20 nm	Ajitha et al., 2014.
	Plectranthus amboinicus leaf extract	Active against *E. coli* and *Penicillium sp.*	Spherical crystalline particles	Ajitha et al., 2014.
	Pre-hydrolyzed liquor of Eucalyptus wood	Active against *P. aeruginosa, S. aureus, E. coli, C. oxysporum, P. chrysogenum, C. albicans* and *A. niger* (MICs ranged from 50–100 μg ml-1)	Spherical crystalline particles with a diameter in the range of 25 – 30 nm	Shivakumar et al., 2017.
	Leaf extract of *Rauvolfia serpentina*		Spherical crystalline particles with a size of 7–10 nm	Panja et al., 2016.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		Active against human pathogenic microbes (free radicals produced by the Ag-NPs damage the microbial cells)		
	Aqueous leaf extract of *Lippia citriodora*	Activity against *E. coli, S. typhi, B. subtilis, S. aureus* and *C.* albicans; also larvicidal activity	Spherical particles with an average size of 24–25 nm based on the two temperatures of synthesis in the present work (50°C and 90°C)	Elemike et al., 2017.
	Endophytic fungus*Guignardia mangiferae*isolated from the leaves of *Citrus* sp.	Active against *P. mirabilis, K. pneumoniae, P. aeruginosa, S. aureus, E. coli, S. epidermidis, B. subtilis* and *E. faecalis* (MICs for different microorganisms ranged from ~3 –12 μg ml^{-1} and the probable reason might be pore formation in membrane with cellular leakage) also active against *C. lunata, Fusarium* sp.*Colletotrichum* sp. and *R. solani*(zones of inhibiton ranging from 9–12 mm at 1 mg ml^{-1} AgNP concentration)	Spherical crystalline particles of size between 5–30 nm	Balakumaran et al., 2015.
	Aqueous extract of ripened fruit of *Nothapodytes nimmoniana*	Activity against *B. subtilis, P. aeruginosa, K. pneumoniae, S. aureus, S. paratyphi, P. vulgaris, E. coli* and *A. hydrophila* (MICs for different microorganisms ranged from ~3 –12 μg ml^{-1})	Spherical crystalline particles of size between 46–235 nm	Mahendran and Kumari, 2016.
	*Terminalia chebula*aqueous extract	Good antimicrobial activity towards *S. aureus* and *E. coli*	Spherical crystalline particles	Kumar et al., 2012.
	Aqueous extracts of *Maclura pomifera* leaf	Active against clinical isolates of Gram-negative bacteria and fungi	Spherical crystalline particles with size around 12 nm	Azizian-Shermeh et al., 2017.
	Cell free supernatant of *Pseudomonas veronii*	Antibacterial activity against human and environmental pathogens including MRSA (methicillin resistant *S. aureus*)	Spherical crystalline particles with size around 5–50 nm	Baker et al., 2015.
	Aqueous leaf-extract of the aquatic fern*Salvinia molesta*	Active against both Gram positive and negative bacteria	Spherical crystalline particles with size around 12 nm	Verma et al., 2016.
	Medicago sativa seed exudates	Bacterial growth inhibition	Spherical crystalline particles with size around 50 nm	Lukman et al., 2011.
	Aqueous extract of *Caltropis procera* fruit and leaves	Antimicrobial activity against *V. cholerae* and enterotoxigenic *E. coli* (5×10^6–1.2×10^7 per ml concentrations of NPs required for inhibiting the microbes); biofilms of these two bacteria were also reduced	Average particle size of 90–100 nm	Salem et al., 2015.
	Aqueous leaf extract of *Wedelia chinensis*	Active against clinically isolated pathogenic bacteria*E. coli* and *L. monocytogenes* (zone of inhibitions ranged from 11–25 mm at NP concentrations between 12.5–200 μg ml^{-1})	Spherical crystalline particles with size between 18–68 nm	B. Das et al., 2018; M. P. Das et al., 2018; S. Das et al., 2018.
	Streblus asper	Active against human pathogenic *E. coli* (MIC and LD_{50} against *E. coli*were 2 nM and 1 nM respectively)	Spherical crystalline particles with size around 13 nm	B. Das et al., 2018; M. P. Das et al., 2018; S. Das et al., 2018.
	Aqueous *Abutilon indicum* leaf extract	Potent antibacterial activity against a panel of microorganisms	Spherical crystalline particles with size between 5–25 nm	Mata et al., 2015.
	Leaf extract of *Prosopis glandulosa*	Active against *A. calcoaceticus* and *B. cereus* (zone of inhibitions ranged from 8–12 mm)	Spherical crystalline particles with size between 32–600 nm	Ali et al., 2017.
Silver nanoparticles (Ag-NP)[o]	Bark extract of *Prosopis juliflora*	Active against *E. coli* and *P. aeruginosa* (growth rate of both decreases as the concentration of Ag-NP increases from 0.25–1 μg)	Spherical with size around 10–50 nm	Arya et al., 2018
	Aqueous extract of *Boswellia serrata*	Activity against bacteria exhibiting both Gram characters	Spherical crystalline particles with size between 7–10 nm	Kora et al., 2012.
	Fruit peel extract of three *Citrus* sp.	Active against *S. aureus* and *E. coli*	Spherical crystalline particles with a size range of 9–46 nm	Annu Ahmed et al., 2018.
	Chenopodium murale leaf extract	Active against *S. aureus*	Spherical crystalline particles with a size range of 30–50 nm	Abdel-Aziz et al., 2013.
	Essential oil present in the leaves of *Coleus aromaticus*	Active against *S. aureus* and *E. coli*	Spherical crystalline particles	Vilas et al., 2016a.
	Streptacidiphilus durhamensis	Active against *P. aeruginosa, S. aureus, P. mirabilis, E. coli, K. pneumoniae* and *B. subtilis* (also showed synergistic activity with standard antibiotics)	Spherical crystalline particles with a size range of 8–48 nm	Buszewski et al., 2018.
	Marine red algae *Gelidium amansii*	Active against pathogenic *S. aureus, B. pumilus, E. coli, P. aeruginosa, V. parahaemolyticus, Aeromonas hydrophila*(antimicrobial activity as well as anti-biofilm activity was observed)	Spherical crystalline particles	Pugazhendhi et al., 2018.
	Endosymbiont P. fluorescens inhabiting *Coffea arabica*	Active against *K. pneumoniae* and *Xanthomonas campestris* (activity of the standard antibiotic kanamycin against *K. pneumoniae* increased by more than 58% in synergism with the NPs)	Crystalline particles of various shapes with a size range of 5–50 nm	Baker et al., 2016.
	Pigment within aqueous extract of the diatom *Amphora* sp.	Active against *E. coli, B. stearothermophilus* and *S. mutans* (zones of inhibition ranging from 12–17 mm)	Polycrystalline spherical particles with a size range of 20–25 nm	Jena et al., 2015.
	Butea monosperma bark extract			Pattanayak et al., 2017.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
		Potent antibacterial activity against human bacteria of both Gram types (at 100 μg ml^{-1} zones of inhibition against the test strains ranged from 16 – 17 mm)	Spherical crystalline particles with size around 35 nm	
	Aqueous extract from *Justicia spicigera*	Active against foodborne bacteria like *B. cereus, K. pneumoniae, E. aerogenes* (zones of inhibition ranged from 7–10 mm at 100 mg ml^{-1}); also active against phytopathogenic fungi like *A. alternata, Macrophomina phaseolina, Colletotrichum* sp. and *Fusarium solani* (inhibition of fungal mycelial growth ranged from 35–80%)	Spherical crystalline particles of size in the range of 86–100 nm	Bernardo-Mazariegos et al., 2018.
	Extracts of sixteen commonly available plants	Active against *E. coli, S. paratyphi, S.aureus* and *B. subtilis*	Spherical crystalline particles of size in the range of 5–25 nm	Firdhouse and Lalitha, 2016.
	Aspergillus tamarii	Antibacterial and antifungal activities (mostly active against *C. albicans* and *S. aureus* but *E. coli* was found to be resistant)	Crystalline particles of size ~40 nm	Nanda et al., 2018.
	Melia azedarach leaf extract	Active against *E. coli, K. pneumonia, S. aureus, P. aeruginosa* and *Proteus* sp. (MICs ranged from 2.5–10 μg ml^{-1})	Spherical crystalline particles of size in the range of 34–48 nm	Mehmood et al., 2017.
	Bark extract of the traditional medicinal plant *Acacia leucophloea*	Active against *S. aureus, B. cereusShigella flexneri* and *L. monocytogenes* (zones of inhibition increased with increasing concentrations from 5–20 μg ml^{-1})	Spherical crystalline particles of size in the range of 17–29 nm	Murugan et al., 2014.
	Synthesized by fungi	Active against toxigenic *Aspergillus* sp. (MICs ranged from 4–8 μg ml^{-1}); also acted in synergism with simvastatina semi-synthetic drug	Spherical crystalline particles	Bocate et al., 2019.
	Cladosporium cladosporioides isolated from brown algae *Sargassum wightii*	Significant antimicrobial activity	Spherical crystalline particles of ~100 nm	Hulikere et al., 2019.
	Aqueous leaves extract of *Skimmia laureola*	Potent agent against tested human pathogens	Crystalline spherical particles	Ahmed et al., 2015.
	Extract of *Prosopis farcta*	Significant antibacterial activity against MDR clinical isolates	Spherical crystalline particlesof 8–11 nm	Miri et al., 2015.
	Coral-associated bacteria *A lcaligenes* sp.	Active against urinary tract infection causing clinical isolates like *E. coli, S. aureus, Bacillus* sp.*K. pneumoniaeP. aeruginosa* and *C. albicans* (inhibited growth and also biofilm formation)	Spherical crystalline particles of 30–50 nm	Divya et al., 2019.
	Aqueous extract of *Alternanthera dentata*	Activity against *E. coli, P. aeruginosa, K. pneumoniae* and *E. faecalis*	Spherical crystalline particles	Kumar et al., 2014.
	Mimusops elengi fruit extract	Active against *S. aureus* and *E. coli*	Spherical crystalline particles	Kumar et al., 2014.
	*Boerhaavia diffusa*extract	Active against pathogenic *A. hydrophila, P. fluorescens* and *Flavobacterium branchiophilum*	Spherical crystalline particles with a mean size of 25 nm	Kumar et al., 2014.
	Sunlight mediated synthesis from *Azadirachta indica* leaf extract	Active against plant pathogen *Xanthomonas oryzae* and action was better than streptocycline (at 10 and 20 μg ml^{-1}zones of inhibition ranged from 14–27 mm and 20–30 mm respectively)	Particles with sze between 67 and 133 nm	Mankad et al., 2018.
	Honeysuckle (*Lonicera* sp.) extract	Active against *E. coli* and *S. aureus*	Crystalline particles	Zhou and Tang, 2018.
	Exopolysaccharide of *Streptomyces violaceus*	Activity against *E. coli, P. aeruginosa, S. aureus* and *B. subtilis* (MIC was significantly lower than standard antibiotics)	Spherical crystalline particles	Sivasankar et al., 2018.
	Terminalia bellerica fruit extract	Effective against *P. aeruginosa* and *K. pneumoniae*	Spherical crystalline particles of size ~10 nm	Andra et al., 2019.
Silver nanoparticles (Ag-NP)[o]	Leaf extracts of *Litchi chinensis*	Active against Gram positive and negative bacteria	Spherical crystalline particles with size in the range of 41–55 nm	Iqbal et al., 2018
	Aqueous extract of *Salicornia brachiata*	Active against pathogenic isolates of *S. aureus, B.subtilis* and *E. coli* (MICs of NPs is lower than the antibioticciprofloxacin)	Crystalline highly diverse shaped particles but mostly spherical shaped upon addition of sodium hydroxide to the extract	Seralathan et al., 2014.
	Caruluma edulis extract	Antibacterial action (MIC against B. *subtilis* and *S. aureus*was 125 μg ml^{-1}and that against *E. coli* was 250 μg ml^{-1})	Spherical in the range of 2–10 nm	Khan et al., 2016a, 2016b, 2016c, 2016d.
	Stem bark extract of *Soymida febrifuga*	Active against both Gram positive and negative bacterial isolates	Crystalline particles with size ranging from 10–30 nm	Sowmyya and Lakshmi, 2018.
	Aqueous extract of *Maytenus royleanus*	Low to moderate activity of AgNPs against *Candida* sp. (zones of inhibition being in the range of 4–8 mm)	Well dispersedspherical particles with an average size of 10 nm	Ahmad et al., 2016.
		Enhanced activity of amphotericin B- conjugated AgNPs against *Candida sp.* (zones of inhibition being in the range of 16–18 mm)	Spherical particles with an average size of 15 nm	
	Trichoderma viride	Activity against *Shigella sonnei, E. coli*MDR-*S. marcescens, S. aureus* and *P. aeruginosa* (40–60% inhibition)	Crystalline spherical particles with size ranging from 2–5 nm	Kumari et al., 2017.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Phyllanthus amarus leaf extract	Antimicrobial activity	Crystalline flower-shaped particles	Ajitha et al., 2018.
	Aqueous extract of turmeric powder	Activity against potential pathogenic food-borne pathogens*E. coli* O157:H7 and *L. monocytogenes*	Crystalline spherical particles with an average size of ~18 nm	Alsammarraie et al., 2018.
	Solanum trilobatum	Antimicrobial activity (zone of inhibitions ranging from 17–26 mm for different types of bacteria and from 11–20 mm for pathogenic fungi for NP concentrations ranging from 25–100 μg ml^{-1})	Crystalline particles with size ranging from 15–20 nm	Pant et al., 2013.
	Aqueous extract of palm date fruit pericarp extract	Active against clinical MDR-*S. aureus, E. coli* and *C. albicans* (all of these isolates are resistant to various antibiotics)	Crystalline spherical particles with size ranging from 3–30 nm	Zaheer, 2018.
	Leaf decoction of tea (*Camellia sinensis*)	Antibacterial and anti-biofilm activity against *E. coli* and *S. aureus* (impairment of bacterial cell-cell adhesion)	Crystalline spherical particles	Goswami et al., 2015.
	Tea (*Camellia sinensis*) extract	Active against *E. coli* (complete inhibition beyond 1.56 mg ml^{-1})	Crystalline spherical particles of size around 20–90 nm	Sun et al., 2014.
	Cassia fistula fruit extract	Active against *E. coli* and *K. pneumoniae* (20^{-1} NPs was required for 100% potency against *E. coli* and 80 μg ml^{-1} was required to promote the same in *K. pneumoniae*)	Spherical crystalline particles with average size of ~69 nm	Rashid et al., 2017.
	Aqueous crude extracts of aerial parts of *Callistemon citrinus*	Activity against both gram positive and negative bacteria (MICs of ~7–8 mg ml^{-1} was noted against all isolates)	Crystalline spherical particles with an average size of 29 nm	Larayetan et al., 2019.
	Capsicum annuum	Antibacterial as well as anti-biofilm activity on *S. aureus* (~50% biofilm inhibited at sub-MIC levels)	Crystalline spherical particles	Lotha et al., 2018.
	Carica papaya peel	Active against human pathogens like *E. coli* and *S. aureus* (zones of inhibition ranged from 30–75 mm)	Crystalline spherical particles of size around 15–20nm	Balavijayalakshmi and Ramalakshmi, 2017.
	Seaweed*Cladophora fascicularis*	Activity against *Aeromonas hydrophila* (zone of inhibition was 10 mm and 19 mm at 25 and 150 μg ml^{-1} respectively)	Crystalline spherical particles with an average size of 45 nm	Rajasekar et al., 2019
	Aqueous leaf extractof *Adhathoda vasica*	Active against *V. parahaemolyticus* (highest zone of inhibition was obtained at 50 μg ml^{-1})	Crystalline spherical particles with size ranging from 10 –50 nm	Latha et al., 2016.
	Extract of *Phoenix dactylifera* leaves	Active against *E. coli* and *K. pneumoniae* (nearly 100% inhibition of *E. coli* was noted with only 8 μg ml^{-1} whereas to achieve the same potency in *K. pneumoniae*64 μg ml^{-1} was needed)	Spherical crystalline particles with size ranging from 30–85 nm	Rashid et al., 2016.
	Root extract of *Phoenix dactylifera*	Control the growth of *C. albicans* and *E. coli*(zones of inhibition were 20 and 22 mm at a concentration of 80 μg/well against *C. albicans* and *E. coli*respectively)	Crystalline spherical particles with size ranging from 21.6–41.05 nm	Oves et al., 2018.
	Peel extract of dragon fruit (*Hylocereus undatus*)	Antibacterial activity against both Gram negative and Gram positive bacteria but effective stronger activity against Gram positive than Gram negative	Spherical crystalline particlesaverage diameter of the particle prepared at pH 3.354.35 and 5.35 were 26.2 ± 8.225.7 ± 8.7 and 25.3 ± 7.9 nm respectively	Phongtongpasuk et al., 2016.
	Carica papaya latex	Active against human pathogenic microbes like *B. subtilisE. coliE. faecalisV. choleraeK. pneumoniae* and *P. mirabilis* (concentrations used were 50–100^{-1})	Crystalline polydispersed spherical particles with size ranging from 2–33 nm	Chandrasekaran et al., 2016.
	Canna indica extract	Action against *S. aureus, S. pyogenes, E. coli, P. aeruginosa, C. albicans* and *T. rubrum* (MICs ranged from 12.5–100 mg ml^{-1} for different test organisms)	Average diameter of the particles was 9.10 ± 1.12 nm	Akinsiku et al., 2018.
	Artemisia haussknechtii leaf aqueous extract	Active against MDR-*S. aureus, S. epidermidisSerratia marcescens* and *E. coli* (growth of *E. coli* and *S. aureus* was inhibited at 10 μg ml^{-1} as MIC and completely inhibited at 60 μg ml^{-1} as MBC; for *S. marcescens* MIC was 4 μg ml^{-1} and MBC was 20 μg ml^{-1}; MIC and MBC for *S. epidermidis* were 4 and 20 μg ml^{-1})	Triangle-shaped crystalline particles with average diameter sizes of 100 particles being 10.69 ± 5.55nm	Alavi and Karimi, 2018.
	Mentha piperita extract	Active against clinically isolated human pathogens*S.* aureus and *E. coli*	Crystalline spherical particles with a size of 90 mm	Ali et al., 2011.
Silver chloride nanoparticles (AgCl-NP)[p]	Aqueous root extract of the medicinal plant*Glycyrrhiza uralensis*	Active against pathogenic *S. aureus, S. entericaE. coli* and *P. aeruginosa* (zones of inhibition ranged from 8 to 17 mm at concentrations like 500, 1000 and 1500 μg ml^{-1})	Crystalline spherical particles ranging from 5–15 nm in diameter	Huo et al., 2018.
	Commercially valuable microalgae species*Chlorella vulgaris*	Inhibit *S. aureus* and *K. pneumoniae* (growth decreased by 98% with abnormal arrangement of the chromosomal DNA)	Spherical particles with average diameter of 9.8 ± 5.7 nm	Ferreira et al., 2017.
Silver sulphide nanoparticles (Ag-sulphide-NP)[q]	*Cochlospermum gossypium*	Active against both Gram positive and Gram negative bacteria	Spherical particles with a diameter of 25 nm	Ayodhya and Veerabhadram, 2016.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
Tellurium nanoparticles (Te-NP)[r]	*Shewanella baltica*	Anti-biofilm activity against potential human pathogens	Nano-rods with diameter ranging from 8–75 nm.	Vaigankar et al., 2018.
	Bacillus sp. BZ	Active against different clinical isolates	Rod-shaped nanoparticles with hexagonal crystal structure and dimensions of about 20 nm × 180 nm	Zare et al., 2012.
Tin oxide nanoparticles (SnO_2-NP)[s]	*Saraca indica* flower	Activity against *E. coli*	Spherical crystalline particles of size from 2.1–4.1 nm	Vidhu and Philip2015.
Titanium dioxide nanoparticles (TiO_2 –NP)[t]	Leaf extract of *Morinda citrifolia*	Active against *S. aureus, E. coliBacillus subtilisP. aeruginosaC. albicans* and *Aspergillus niger* (zones of inhibiton against the different test strains varied from 6–14 mm at NP concentrations of 50–150 µg ml^{-1})	Spherical crystalline particles with size between 10–20 nm	Sundrarajan et al., 2017.
	Aqueous leaf extracts of *Psidium guajava*	Active against *S. aureus* and *E. coli* (20 µg ml^{-1} TiO_2-NP showed maximum zone of inhibition against *S. aureus* and *E. coli*; synthesized NP showed more antibacterial activity than the standard antibiotic tetracycline; antibacterial activity of TiO_2 was related to reactive oxygen species production)	Spherical shape and clusters with an average size of 32.58 nm	Santhoshkumar et al., 2014.
	Aqueous leaf extracts of *Thuja occidentalis*	Active against *S. aureus* and *E. coli* (zones of inhibition ranged from 15–16 mm)	Well-dispersed particles with a size range of 7–14 nm	Barua et al., 2013.
	Artemisia haussknechtii leaf aqueous extract	Active against MDR-*S. aureus* and *E. coli* (MIC and MBC were 40 and 60 µg ml^{-1} respectively for *E. coli*; 20 and 60 µg ml^{-1} respectively for *S. aureus;* 4 µg ml^{-1} and 20 µg ml^{-1} for *S. marcescens*; 4 and 20 µg ml^{-1} for *S. epidermidis*)	Spherical crystalline particles with average diameter sizes of 100 particles being 92.58 ± 56.98 nm	Alavi and Karimi, 2018.
	Root extracts of *Glycyrrhiza glabra*	Potent antibacterial activity	Spherical shaped particles with an average size of 69 nm	Bavanilatha et al., 2019.
	Trigonella foenum-graecum leaf extract	Potent antibacterial activity	Spherical particles and few aggregates with size in the range of 20–90 nm	Subhapriya and Gomathipriya, 2018.
Zinc oxide nanoparticles (ZnO –NP)[u]	Medicinal plant*Monsonia burkenea*	Active against *S. aureus, E. coliE. faecalis* and *P. aeruginosa*	Crystalline hexagonal structure of size between 5–15 nm	Ngoepe et al., 2018.
	Azadirachta indica leaf extract	More potent activity than bare ZnO and leaf of *A. indica*against Gram positive and Gram negative bacteria as well as yeast	Crystalline spherical particles	Elumalai and Velmurugan2015.
	Leaf extract of a medicinally important plant*Passiflora caerulea*	Active against urinary tract infection pathogens *K. pneumoniae, B. subtilis, E. coli, Serratia* sp. and *Streptococcus* sp.	Crystalline spherical particles with mean average diameter of 70 nm	Santhoshkumar et al., 2017.
	Aqueous extract of olive leaves	Active against plant pathogen*Xanthomonas oryzae* (inhibition zone of 2.2 cm at 16.0 µg/ml and biofilm inhibition by ~83%)	Cubic shaped crystalline structures with a mean size range of 40.5–124 nm	Ogunyemi et al., 2019.
	Extract of the seaweed *Ulva lactuca*	Anti-biofilm activity against *B. licheniformisB. pumilisE. coli* and *P. vulgaris* (biofilm reduction by > 80%)	Crystalline agglomerated sponge-like asymmetrical particles of average size of 15 nm	Ishwarya et al., 2018a.
	Hot water extract of *Sargassum wightii*	Bactericidal and anti-biofilm activity against *B. subtilis, S. aureus, Shigella sonnei* and *P. aeruginosa*	Spherical crystalline particles	Ishwarya et al., 2018.
	Tabernaemontana divaricata greenleaf extract	Activity against *S. paratyphiE. coli* and *S. aureus* (higher activity against *S. aureus* and *E. coli* than *S. paratyphi* in comparison to standard pharmaceutical formulation)	Spherical crystalline particles with size ranging between 20–50 nm	Raja et al., 2018.
	Leaf extracts of *Plectranthus barbatus*	Active against *B. subtilis* (at all concentrations tested) and against *P. vulgaris* and *V. parahaemolyticus* (at 100 µg ml^{-1})	Spherical crystalline particles with size between 32–36 nm	Vijayakumar et al., 2017.
Zinc oxide nanoparticles (ZnO –NP)[u]	*Raphanus sativus* root extract	Activity against MDR strains	Spherical crystalline particles	Kumar et al., 2018.
	Leaf extract of *Glycosmis pentaphylla*	Active against *S. aureus, B. cereus S. paratyphi S. dysenteriaeA. niger* and *C. albicans*	Spherical crystalline particles with size ranging between 32–36 nm	Vijayakumar et al., 2018a.
	Atalantia monophylla leaf extract	Antimicrobial activity better than plant extracts and standard drugs against *P. aeruginosa* and *S. aureus*	Spherical crystalline particles	Vijayakumar et al., 2018b.
	Aqueous floral extract of *N yctanthes arbortristis*	Active against *Alternaria alternata, A. niger, Botrytis cinerea, Fusarium oxysporum* and *Penicillium expansum* (MICs ranged from 16–128 µg ml^{-1})	Spherical crystalline particles with size ranging between 12–32 nm	Jamdagni et al., 2018.
	Trianthema portulacastrum extract	Antibacterial activity against *S. aureus* and *E. coli* and antifungal activity against *Aspergillus niger, A. flavus, and A. fumigatus*	Crystalline particles of size range 25–90 nm	Khan et al., 2019.
	*Conyza canadensis*leaves extract	Active against *S. aureus* and *E. coli*	Spherical	Ali et al., 2018.
	Aqueous extract of *Calotropis procera* fruit and leaves	Active against enterotoxigenic *E. coli* and *V. cholerae* (1.6 × 10^5–1.2 × 10^6 per ml concentrations required for killing the microbes)	Average particle size of 90–100 nm	Salem et al., 2015.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
	Leaf extract of *Laurus nobilis*	Affected planktonic and biofilm cells of *S. aureus* and *P. aeruginosa* (inhibited the biofilm growth of *S. aureus* and *P. aeruginosa* at 75 μg ml^{-1}; while the zone of inhibitions against *S. aureus* ranged from 11–14 mm at concentrations 25–75 μg $ml^{-1}$the same for *P. aeruginosa* was 9–11 mm at the same concentrations)	Crystalline hexagonal shaped particles with a mean particle size of 47.27 nm	Vijayakumar et al., 2016.
	Limonia acidissima leaf	Activity against *M. tuberculosis* (growth was inhibited beyond 12.5 μg ml^{-1})	Spherical crystalline particles with a mean szie of 12–53 nm	Patil and Taranath, 2016.
	Plant extract of *Passiflora caerulea*	Antibacterial activity against urinary tract infection pathogen like *E.coliStreptococcus* sp.*Enterococcus* sp.*Klebsiella* sp. (zone of inhibition ranged from 7–13 mm)	Spherical crystalline particles with a mean size of 30–50 nm	Santhoshkumar et al., 2017.
	Artocarpus gomezianus fruit extract	Antimicrobial activity (significant activity against *S. aureus* and *A. niger*)	Spherical crystalline particles with average crystallite sizes of 30 – 40 nm	Anitha et al., 2018.
	Averrhoa carambola	Active against *B. subtilis, S. aureus, E. coli, P. aeruginosa, Alternaria alternata* and *Fusarium oxysporum*(antibacterial activity ranged from 0.25 to 0.0025 μg ml^{-1} and antifungal activity ranged from 100–700 μg ml^{-1})	Spherical crystalline particles	Begum et al., 2018.
	Bacillus megaterium	Active against MDR-*H. pylori* (MIC for two different strains ranged from 16–17 μg ml^{-1})	Crystalline rod and cubic shaped particles with diameter ranging between 45–95 nm	Saravanan et al., 2018.
	Leaves extract of *Cordia myxa*	Activity against *E. coli* and *S. aureus* (zone of inhibition against *E. coli* ranged from 6–17 mm with 50–200 μg ml^{-1} of zinc oxide while that for *S. aureus* ranged from ~7 to ~20 mm with 50–200 μg ml^{-1} of zinc oxide)	Crystalline particles with shapes ranging from hexagonal to pyramid-shaped to round-shaped depending on extract concentrations used	Saif et al., 2019.
	Hydnocarpus alpina	Antimicrobial activity (more active against *P. vulgaris* and *S. enterica typhimurium* compared to other organisms)	Spherical particles ith diameter of 38.84 nm	Ganesh et al., 2019.
	Coccinia abyssinica tuber extract	Active against *S. aureus, S. paucimobilis, B. coagulans, S. dysenteriae* and *S. typhimurium*(zone of inhibiton against the isolates ranged from 9–21 mm for concentrations between 10–30 μg ml^{-1})	Hexagonal shaped crystalline particles with an average size of ~10 nm	Safawo et al., 2018.
	Tecoma castanifolia leaf extract	Activity against both Gram positive and negative bacteria	Crystalline spherical particles with size of 70–75 mm	Govindasamy et al., 2019.
	Endemic plant *Ceropegia candelabrum*	Inhibited *S. aureus, B. subtilisE. coli* and *S. typhi*	Hexagonal shaped crystalline particles with a size of 12–35 nm	Murali et al., 2017.
	Pithecellobium dulce peel extract	Antifungal activity (growth inhibition of *A. flavus* by 37.81% at 500 ppm and by 63.57% at 1000 ppm40.21% and 43.04% of growth inhibition of *A. niger* at 500 and 1000 ppm NP respectively)	Crystalline spherical particles	Madhumitha et al., 2019.
	Lagenaria siceraria extract	Anti-dandruff activity (inhibited *Malassezia furfur* and *M. pachydermatis* with zone of inhibition ranging from 15–1 9 mm) and also antimicrobial activity (highest activity against *E. coli* followed by *S. aureusK. pneumoniaeSalmonella* sp. and *L. monocytogenes*)	Crystalline spherical particles with size of 25–55nm	Kalpana et al., 2017.
	Serratia ureilytica	Active gainst *E. coli* and *S. aureus* (antibacterial activity of loaded cotton fabrics was found to be substantially higher than the bare cotton samples)	Spherical crystalline particles	Dhandapani et al., 2014.
	Solanum nigrum	Significant antibacterial activity	Quasispherical crystalline particles with size of ~30 nm	Ramesh et al., 2015.
	Terminalia arjuna bark extract	Active against *E. coli* and *S. aureus*	Spherical crystalline particles with size in the range of 20–40 mm	Saha et al., 2018.
Zinc oxide nanoparticles (ZnO –NP)[u]	*Aloe barbadensis* leaf extract	Active against ESBL (+) *E. coli, P. aeruginosa* and MRSA i.e. methicillin resistant *S. aureus* clinical isolates (MICs ranged from 2000–2300 μg ml^{-1} and MBCs ranged from 2200–2800 μg ml^{-1})	Crystalline particles of different shapes like spherical oval and hexagonal in size range of 8–18 nm	Ali et al., 2016.
	Aqueous solution of *Rhamnus virgata*	Antibacterial activity (*B. subtilis* and *S. aureus* were most susceptible with MICs of 7.8 μg ml^{-1} each while *P. aeruginosa* was least susceptible with MIC of 62.5 μg ml^{-1})antifungal activity (*A. flavus* was the least susceptible strain with MIC 125 μg $ml^{-1}$and*A. niger* was most susceptible strains with MIC of 15.62 μg ml^{-1}) as well as anti-parasitic activity (while IC_{50} against *L. tropica* promastigotes was 8.34 μg ml^{-1}that for the amastigotes was 13.6 μg ml^{-1})	Crystalline particles of hexagonal shape with a mean size of ~20 nm	Iqbal et al., 2019.

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Table 1 (*continued*)

Nanoparticle	Green reductant used	Biological activities	NP morphology (size/ shape)	Reference
Zirconium oxide nanoparticles (ZrO2 –NP)[v]	Extract of the marine brown algae (seaweed)*Sargassum wightii*	Significant effect against *B. subtilisE. coli* and *S. typhi*	Spherical crystalline fairly monodispersed particles with a mean size of 5 nm.	Kumaresan et al., 2018.–>

[a] Monometallic (copper) nanoparticles (Cu-NP)
[b] Monometallic (copper oxide) nanoparticles (CuO-NP)
[c] Monometallic (gold) nanoparticles (Au-NP)
[d] Monometallic (iron) nanoparticles (Fe-NP)
[e] Monometallic (iron oxide) nanoparticles (FeO-NPFe2O3-NP or magnetic Fe3O4-NP)
[f] Monometallic (iron oxide) nanoparticles (magnetic Fe3O4-NP)
[g] Monometallic (lead oxide) nanoparticles (PbO-NP)
[h] Monometallic (magnesium oxide) nanoparticles (MgO-NP)
[i] Monometallic (manganese) nanoparticles (Mn-NP)
[j] Monometallic (nickel) nanoparticles (Ni-NP)
[k] Monometallic (nicekel oxide) nanoparticles (NiO-NP)
[l] Monometallic (palladium) nanoparticles (Pd-NP)
[m] Monometallic (platinum) nanoparticles (Pt-NP)
[n] Monometallic (selenium) nanoparticles (Se-NP)
[o] Monometallic (silver) nanoparticles (Ag-NP)
[p] Monometallic (silver chloride) nanoparticles (AgCl-NP)
[q] Monometallic (silver sulphide) nanoparticles (Ag2S-NP)
[r] Monometallic (tellurium) nanoparticles (Te-NP)
[s] Monometallic (tin oxide) nanoparticles (SnO2-NP)
[t] Monometallic (titanium dioxide) nanoparticles (TiO2-NP)
[u] Monometallic (zinc oxide) nanoparticles (ZnO-NP)
[v] Monometallic (Zirconium oxide) nanoparticles (ZrO2-NP)

the advantage that it can be easily scaled up for large-scale synthesis without the requirement of high pressure, energy, temperature and toxic chemicals (Jagtap and Bapat, 2013); further making the process fast, environment-friendly, cost-effective and energy efficient (Mittal et al., 2013; Kulkarni and Muddapur, 2014; Narayanan and Sakthivel2008; Sathishkumar et al., 2009a, 2009b).

2. Green metallic nanoparticles

The discipline of 'Nanobiotechnology' interlaces nanotechnology and biotechnology since bio-based technology is used for nanoparticle synthesis (Thomas and Narvaez, 2006). Biological resources like plants, algae, bacteria, fungi and even human cells have been used for reduction of metal ions resulting in synthesis of green nanoparticles (Venkataraman et al., 2005). Phytochemicals present in plants and whole microbial cells or their products act as capping as well as stabilizing agents for nanoparticle synthesis thereby eliminating the extra step required for the prevention of particle aggregation (Zhang et al., 2016). Using plants for nanoparticle synthesis can be even more advantageous because it eliminates the elaborate process of maintaining cell cultures and suitable scaling up for the large-scale synthesis of nanoparticles under a non-aseptic environment (Veerasamy et al., 2011). Out of the different metallic nanoparticles synthesized via the green route, silver and gold nanoparticles are of marked importance in the biomedical sector (Wong and Liu2010*) as they* find potential applications in different arenas of medical biology like targeted drug delivery, cancer treatment, as antibacterial agents, antioxidant agents and as biosensors (Nath and Banerjee, 2013; Khan et al., 2017a, 2017b; Khan et al., 2018). However, most of these methods are still in their infancy and various problems are often experienced with the stability of nanoparticle preparations, control of crystal growth and aggregation of particles.

Metallic nanoparticles are categorized as monometallic, bimetallic and trimetallic, based on the number of metals used as ingredients in their synthesis. Various metals have been used to date for synthesizing these nanoparticles using various plant extracts (Gebru et al., 2013). Plant extracts can influence the sizeshape and morphology of the nanoparticles synthesized (Kora et al., 2010; Kavyashree et al., 2015) based on their activities which might also differ. Methods used for synthesizing the multimetallic nanoparticles might involve either co-reduction or successive reduction strategies (Sumbal Nadeem et al., 2019).

2.1. Mono-metallic nanoparticles

Monometallic nanoparticles are generated through reduction of a single metal solution by reducing and stabilizing agents of biological origin. In Table 1, biomedical potentials of such mono-metallic nanoparticles have been detailed.

2.2. Bi-metallic nanoparticles

Bi-metallic nanoparticles (BMNs), because of their composition, exhibit remarkable biological potential probably because of the synergistic activities of both the metals (G. Sharma et al., 2019; T. S. K. Sharma et al., 2019). It can be hypothesized that the BMNs have different intensity of configuration, strength, binding and interaction that make them more reactive. It is also possible that the BMNs are more potent antibacterial agents in contrast to their monometallic counterparts (Sumbal Nadeem et al., 2019). Even though was observed that whereas in combination with the monometallic ones, activity of the standard antibiotics rose to only 10–25% with AuNP and 25–50% with AgNP, ~50%–80% rise in activity of standard antibiotics has occurred in synergy with the BMNs against human pathogens like *C. albicans* and biofilm producers like *S. aureus* and *P. aeruginosa* (Yallappa et al., 2015). Extensive studies on bimetallic nanoparticles started just a decade back (Sharma et al., 2019a) and Table 2 indicates the biomedical potentials of such bimetallic nanoparticles.

2.3. Tri-metallic nanoparticles

The tri-metallic nanoparticles exhibit efficient antibacterial activity and were found to be better agents than bi-metallic and mono-metallic ones at a very low concentration as mentioned by Yadav et al., (2018). Scanty information is available about synthesis of this type of nanoparticle via the green route. The following table (Table 3) sums up the

Table 2
Biomedical potentials of bi-metallic nanoparticles.

Nanoparticles	Green reductant used	Biological activities	NP Morphology (size/ shape)	Reference
Cobalt ferrites NP[a]	Sesame extract (*Sesamum indicum*)	Antimicrobial activity against *E. coli, S. aureusP. aeruginosaE. faecalis* and *C. albicans* in both planktonic and adherent state (MICs against the test microorganisms ranged from 0.125 to > 1 mg ml^{-1}*C. albicans* proving to be most resistant to the tested compoundswith MIC values > 1 mg ml^{-1}; biofilms of *S. aureusE. faecalis* and *E. coli* were inhibited at concentrations ranging from 0.031 to 0.002 mg ml^{-1}1 to 0.063 mg $ml^{-1}$and 0.008 to 0.002 mg ml^{-1}respectively, while for *P. aeruginosa*the biofilm was inhibited at the highest tested concentration i.e. 1mg ml^{-1})	Crystalline spherical particles of uniform size ranging between 3 and 7 nm	Gingasu et al., 2016.
Copper/Platinum NP[b]	*Agrimoniae herba* extract	Active against both Gram-positive and Gram-negative bacteriayeasts and dermatophytes (inhibition and biocidal effects were observed at concentrations ranging from 40.0 ± 0.0% to 53.3 ± 23.1% and from 40.0 ± 0.0% to 66.7 ± 23.1% respectively).	Spherical particles of about 30 nm	Dobrucka and Dlugaszewska, 2018.
Lead/Selenium NP[c]	Marine *Aspergillus terreus* extract	Active against various Gram positive and Gram negative bacteria (anti-bacterial activity comparable to that of standard antibiotics against pathogens like *B. cereus* and *E. coli*)	Quantum rods	Jacob et al., 2016.
Iron oxide/Silver NP[d]	Waste material of *Vitis vinifera* stem extract	Antibacterial activity towards bacteria of both Gram characters	Polycrystalline core-shell structuresize of about 50 nm	Venkateswarlu et al., 2015.
	Aqueous extract of *Crataegus pinnatifida*leaves	Active against *S. aureus* and *E. coli*	Spherical crystalline particles of size of ~200 nm	Li and Yang, 2016.
	Rhizome extract of ginger (*Zingiber officinale*)	Antibacterial and fungicidal properties (active against both Gram negative and Gram positive bacteria at 100 µg ml^{-1} whereas against yeast cells it was active at 500 µg ml^{-1})	Both NPs had crystalline structure with the size of 5–25 nm for Ag and 1–3 nm for Fe-oxide	Ivashchenko et al., 2017.
Silver/Gold NP[e]	*Gloriosa superba* leaf extract	Antibacterial activity (probably due to interference with the bacterial intercellular signalling and and malfunction of metabolism)and anti-biofilm activities (thickness of biofilm reduced from 30 µm to 8 µm in *S. aureus* and 35 µm to 9 µm in *K. pneumoniae*)	Spherical crystalline particles with a size ranging from 10 to 20 nm.	Gopinath et al., 2016.
	Aqueous extract of *Annona squamosa*	Active against*B. subtilisE. coliS.typhi* and *S. aureus* (MICs ranged from 31.25 to 250 µg ml^{-1})	Crystalline particles of different size and shapessize ranging between 30 and 50 nm	Baker et al., 2018.
	Culture supernatant of *Pseudomonas veronii*endosymbiont of *Annona squamosa*	Activity against *E. coli, K. pneumoniae* and *B. subtilis*enhanced activity of standard antibiotics in synergism (> 80% increase in activity of antibiotics)	Various shapes of particles like spherical triangularpentagonal and hexagonal planarwith an average size of 30 nm.	Baker et al., 2017.
	Bark extract of *Terminalia arjuna*	Active against malaria vector*Anopheles stephensi*(100% susceptibility of III and IV instar larvae at 0.25% NP concentration)	Spherical crystalline particles with diameter ranging from 20 to 50 nm	Gopinath et al., 2013.
	Aqueous extract of roots of the medicinally important plant *Plumbago zeylanica*	Antimicrobial activity (MIC aganst the test organisms ranged from 4 – 16 µg/disk); biofilm inhibition (upto 94% for *A. baumannii*98% for *E.coli* and 99% for *S. aureus).*	Blunt ended polygonal NPs	Salunke et al., 2014.
	Jasminum sambac leaf extract	Enhanced activity of standard antibiotics in synergy (1 to 4 fold) against human pathogens like *C. albicans* and biofilm producers like *S. aureus* and *P. aeruginosa*	Near spherical shape (20–50 nm size)	Yallappa et al., 2015.
	Fruit juice of *Punica granatum*	Nitric oxide and hydroxyl radical scavenging activity (potential application in the biomedical field)	Alloy as well as core-shell nanostructures	Kumari et al., 2015.
	Essential oil from *Coleus aromaticus*leaves	Efficacious against *E. coli* and *S. aureus* (prominent activity against *E. coli* with an inhibition zone of 28 mm)	Crystalline spherical particles	Vilas et al., 2016b.
Silver/Iron NP[f]	Extract of fruits of palm date (*Phoenix dactylifera*)	Antibacterial activity against human pathogens	Spherical crystalline particles	Al-Asfar et al., 2018.
Silver/Nickel NP[g]	*Canna indica* extract	Action against *S. aureus, S. pyogenes, E. coli, P. aeruginosa, C. albicans* and *T. rubrum* (MICs ranged from 6.25–100 mg ml^{-1} for different test organisms)	Average diameter of the particles was ~10 nm	Akinsiku et al., 2018.
Silver/Palladium NP[h]	Aqueous fruit extract of *Terminalia chebula*	Activity against *P. aeruginosa* and methicillin resistant *S. aureus*	Face centered cubic crystalline structure with average size of 20 nm	Sivamaruthi et al., 2019.
	Extracts of almond nuts (*Prunus dulcis*) Extracts of blackberry fruits (*Rubus fruticosus*)	Activity against *E. coli, S. aureus* and *C. albicans* (activity was better when compared to standard antibiotics)	Spherical crystalline particles	Abdel-Fattah et al., 2017.

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Table 2 (*continued*)

Nanoparticles	Green reductant used	Biological activities	NP Morphology (size/ shape)	Reference
Silver/Zinc oxide NP[i]	*Prosophis farcta*	Marked antibacterial activity of the cotton wound bandages impregnated with NP-combinations (MIC of Ag-NP against *P. aeruginosa* was 3.12 μg ml^{-1}that of ZnO-NP was 12.5 μg ml^{-1} but that of Ag/ZnO-NP against the same bacterium was 3.12 μg ml^{-1})	Both Ag-NP and ZnO-NP are of spherical shapewhile the size of Ag-NP is in the range of 5–35 nmZnO-NP is in the range of 5–40 nm	Khatami et al., 2018b.
	Extract of leaves of *Mirabilis jalapa*	Antileishmanial activity and antibacterial activity against *S. aureus* and *K. pneumoniae*	Varied shapes of bimetallic NP (platessheetsand spherical) depending upon concentration of salts used	Sumbal Nadeem et al., 2019.

[a] Bimetallic nanoparticles of Cobalt ferrites (CoFe2O4)
[b] Bimetallic nanoparticles of Copper and Platinum (Cu/Pt)
[c] Bimetallic nanoparticles of Lead and Selenium (Pb/Se)
[d] Bimetallic nanoparticles of Iron oxide and Silver (FeO/Ag)
[e] Bimetallic nanoparticles of Silver and Gold (Ag/Au)
[f] Bimetallic nanoparticles of Silver and Iron (Ag/Fe)
[g] Bimetallic nanoparticles of Silver and Nickel (Ag/Ni)
[h] Bimetallic nanoparticles of Silver and Palladium (Ag/Pd)
[i] Bimetallic nanoparticles of Silver and Zinc oxide (Ag/ZnO)

Table 3
Biomedical application potentials of green trimetallic nanoparticles.

Nanoparticles	Green reductant used	Biological activities	NP Morphology (size/shape)	Reference
Cerium oxide/copper oxide/zinc oxide nanoparticles (CeO/CuO/ZnO NP)[a]	—	Antimicrobial activity against pathogenic microbes including marked biofilm producers like *S. aureus* and *P. aeruginosa*	Crystallite size is found to be in range of 15.34–44.81 nm.	Subhan et al., 2015.
Copper/chromium/nickel NP[b]	*Eryngium campestre* and *Froriepia subpinnata*	Significant activity against *E. coli* and *S. aureus*	With E. campestre extractCuO-Cr_2O_3-NiO nanocomposites with average crystallite size of 29.2 nm resulted. With F. subpinnata extractbinary and ternary Cu-Cr-Ni-O nanoalloys of averaged 9.8 nm crystallite size resulted.	Vaseghi et al., 2018a, 2018b; Varghese et al., 2019.

[a] Trimetallic nanoparticles of Cerium oxideCopper oxide and Zinc oxide (CeO/CuO/ZnO)
[b] Trimetallic nanoparticles of Copper/Chromium/Nickel (Cu/Cr/Ni)

information available to the best of our knowledge about the green trimetallic NP, green reductants used for their synthesis along with their morphology and biomedical potentials.

3. Conclusion

The current review, to the best of our knowledge, focuses on biogenic synthesis of green nanoparticles along with their biomedical potentials. These nanostructures, because of their antimicrobial as well as anti-biofilm roles, are sure to pave the way for new avenues of controlling infections, especially on the face of uprising incidence of multidrug resistance as multidrug-resistant microorganisms have also been found to be inhibited by the nanoparticles and currently there are no reports on resistance to these nanoparticles. The scientific community is hopeful that these particles might play a big role in the future and though mechanisms by which the green nanoparticles act have been deciphered in many cases, studies need to be undertaken to identify the detailed mechanism by which the 'green' synthesis empowers all the nanoparticles to kill the pathogenic microbes.

Declaration of Competing Interest

The authors, Dr. Palashpriya Das & Ms. Vijayshree Karankar declare no conflict of interest.

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