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REVIEW ARTICLE

# An overview of the phytosynthesis of various metal nanoparticles

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**Abstract**

Nanotechnology is an emerging branch of science wherein various valuable molecules with altered properties can be synthesized and utilized for numerous technological applications. Nowadays, nanotechnology is the preferred tool for the agriculture, food, and medicine industries. However, consistent accumulation of toxic by-products during the synthesis of nanoparticles from the established physical and chemical methods imposes an unprecedented danger to the environment and human well-being. The biological route for the synthesis of nanoparticles offers a potential option over the conventional chemical synthesis process due to the involvement of non-toxic and environmentally friendly materials, such as plants, fungi, bacteria, etc. Phytosynthesis, a type of biological synthesis, utilizes various combinations of secondary metabolites from different plant parts (whole plant, leaves, fruit peel, root, bark, seeds, and stem) for non-toxic and environmentally friendly nanoparticles fabrication. Non-toxic and environmentally friendly secondary metabolites derived from plants are the sources of reducing and capping agents during the biosynthesis of nanoparticles which proceeds in a controlled manner with desired characteristics. Phytosynthesis of nanoparticles is also a simple, economic, durable, and reproducible process. The present article is a comprehensive depiction of the synthesis of different metal nanoparticles from diverse plant species.

**Keywords** Phytosynthesis · Silver nanoparticles · Gold nanoparticles · Zinc nanoparticles · Magnesium nanoparticles · Titanium nanoparticles · Copper nanoparticles

## Introduction

Nanomaterials ranging from 1 to 100 nm sizes have found usages in wide range of aspects (Iravani 2011; Mittal et al. 2013; Ahmed et al. 2017; Saratale et al. 2018). Synthesis of nanoparticles employing different approaches has drawn attention of researchers. Recently, phytosynthesis of nanoparticles has attained prominence owing to its merits like environmentally friendly, lesser toxicity, cost-effective, less energy consumption and easy scalability (Singh et al. 2018). Green synthesis of nanoparticles can be accomplished through the biomolecules of the extract of microbes (bacteria, fungi, algae) and various parts of the plants (Ali et al. 2020) and collectively these are termed as biogenic nanoparticles (Singh et al. 2018). Among the various green synthesis approaches, phytosynthesis approach offers several advantages for nanomaterial production due to the involvement of various primary and secondary plant metabolites like polysaccharides, proteins, amino acids, poly-phenols, flavonoids, terpenoids, alkaloids, etc. in the reduction and capping of metallic ions. Moreover, process of phytosynthesis is quick, easily scalable and leads to the development of stable nanoparticles (Ali et al. 2020). Diverse plant parts, such as root, fruit, seed, callus, leaves, flowers, etc. are generally used for the phytosynthesis of nanoparticles having varied shapes and sizes. The size and shape of nanoparticles can be altered by wide range of plant extract and metal concentration in the reaction medium (Dubey et al. 2010a). Synthesis of silver

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nanoparticles (AgNPs) using stem extract of *Callicarpa maingayi* was reported by Shameli et al. (2012) wherein aldehyde group is responsible for the reduction of silver ions ($Ag^+$) into metallic AgNPs. Similarly, stem extract of *Cissus quadrangularis* was applied for the synthesis of AgNPs by Vanaja et al. (2013), which showed antibacterial activity for the *Klebsiella planticola* and *Bacillus subtilis*. The synthesis of AgNPs by fruits was reported by Gopinath et al. (2012) wherein extracts derived from *Tribulus terrestris* fruit bodies were mixed with 1 mM silver nitrate and the phytochemicals, present in the extract, reduced the silver ions. Synthesized AgNPs by the extract of *T. terrestris* showed antimicrobial activity against multidrug-resistant human pathogens. Similarly, using polyphenols derived from grapes were used to synthesize palladium nanoparticles which were found to be effective against bacterial diseases (Amarnath et al. 2012). Likewise, for the formation of nanoparticles, extract of *Rumex hymenosepalus* was used as reducing and stabilizing agent (Kuppusamy et al. 2016). The syntheses of nanoparticles using seeds have also been reported. The fenugreek seed extract has been used for the synthesis of nanoparticles. Fenugreek seed extract contains flavonoids and other natural bioactive products (vitamins, saponin, lignin) which act as strong reducing agent for the reduction of chloroauric acid. Functional groups present in metabolites of fenugreek seed extract act as a surfactant of gold nanoparticles (AuNPs) and the electrostatic stabilization of AuNPs can be achieved by flavonoids (Mittal et al. 2013). Eco-friendly way of synthesis of nanoparticles of gold by rose petals has been reported by Noruzi et al. (2011). Plentiful sugars and proteins were used in extract medium, which acted as a chief source for the reduction of tetrachloroaurate salt into bulk AuNPs. Likewise, other sources like *Catharanthus roseus* and *Clitoria ternatea* have been used for the formation of metallic nanoparticles with desired shape and size. AuNPs synthesized from *Nyctanthes arbortristis* have shown to be effective in controlling pathogenic bacteria (Das et al. 2011). *Mirabilis jalapa* flowers act as reducing agent for production of AuNPs with environmentally friendly approach (Vankar and Bajpai 2010). Similarly, leaves of different plants have also proven to be effective for the synthesis of nanoparticles. Leaves of *Centella asiatica*, *Murraya koenigii*, *Alternanthera sessilis* and extracts of leaves of many plants have been used for the fabrication of nanoparticles. The AgNPs obtained from *P. nigrum* leaves have been found to be effective drug in cancer medicine and other dreadful diseases (Kuppusamy et al. 2016). The present review summarizes the phytosynthesis of some metal nanoparticles that may provide benefits to the researchers working in this emerging concept of nanoscience. Now there is an exhaustive exploration of potential plant extracts to achieve the phytosynthesis of metal nanoparticles considering its eco-friendly and economic benefits.

## Phytosynthesis of nanoparticles

Various types of metal nanoparticles have been fabricated using several plants and their parts wherein phytosynthesized metal nanoparticles have inimitable properties as compared to the bulk material. Figure 1 represents the general approach of phytosynthesis of nanoparticles and the frequently used characterization methods. Undermentioned are a comprehensive depiction of the phytosynthesis of various types of metal nanoparticles.

### Silver nanoparticles

AgNPs find applications in areas, such as cosmetics, food, and medicine. Antibacterial, antifungal and antioxidant properties are also possessed by AgNPs (Priyadarshini et al. 2013). AgNPs synthesized from *Artemisia nilagirica* demonstrated the enhanced antimicrobial activity as compared to their bulk complements (Vijayakumar et al. 2013). AgNPs fabricated from *Pongamia pinnata* are also reported to be active against numerous microbes, such as *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Klebsiella pneumoniae* (Raut et al. 2010). AgNPs generated from the root extract of *Morinda citrifolia* exhibited enhanced cytotoxicity on HeLa cell lines (Suman et al. 2013). AgNPs were synthesized within 1 h when 5 ml of silver nitrate (0.001 M) was reacted with 100 mg of *Cinnamomum camphora* biomass at 30 °C (Steinitz et al. 2010). Two absorption peaks were attained from the absorption spectrum of the reduced material encompassing diverse magnitudes of the leaf extract, a resilient peak at 440 nm and a fragile peak at 360 nm due to the presence of two distinctive shape. The size of the green-synthesized AgNPs was recorded between 55 and 80 nm through scanning electron microscope (SEM) and transmission electron microscope (TEM). Small quantity of the biomass resulted in the better quality of nanocrystals. The nanoparticles got aggregated with the increase in the magnitude of biomass and they remained segregated at the lower magnitude of biomass. The distinctive absorption maxima indicated formation of different types of nanocrystals. It has been recommended that $Ag^+$ gets precipitated in the form of colloidal silver chloride (AgCl), which alters colour when exposed to sunlight (Tsai and Frasch 1982; Costa-Coquelard et al. 2008). Further, they mentioned that size and chemical composition of nanoparticles determine the colour change of AgCl. The configuration of AgCl does not change, and it settles down at the base by aggregating together. The reduction of $Ag^+$ is hampered in the absence of some reductants in that medium. It is observed that

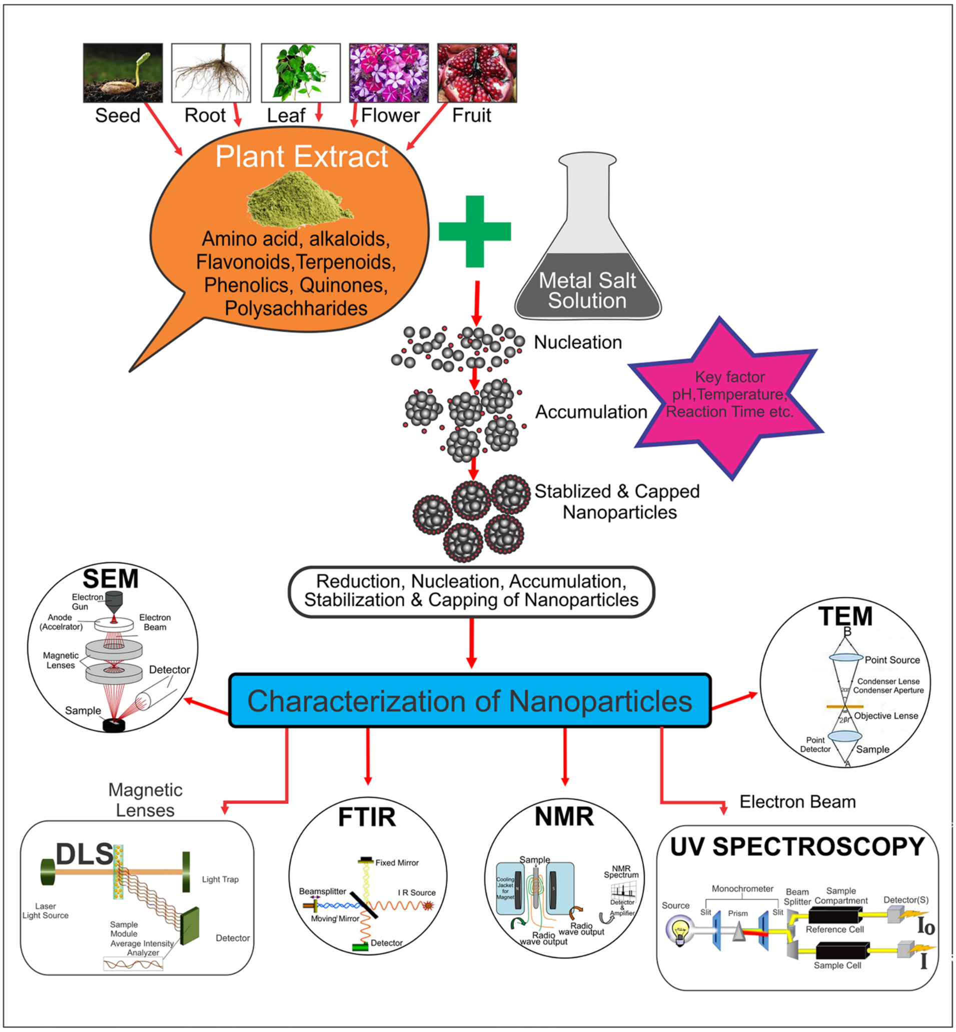

**Fig. 1** Schematic of the phytosynthesis of metal nanoparticles and its characterization methods

formation of nanoparticles may result from the interaction of $Ag^+$ with various primary and secondary metabolites (polysaccharides, amino acids, proteins, nucleic acids, etc.). However, several times $Ag^+$ might form a complex with electron donors instead of forming AgNPs. Occurrence of $Ag^+$ precipitation as AgCl in agar gel medium was noticed due to the existence of HCl as a contaminant (Harris and Bali 2008). Free $Ag^+$ ion required for the formation of nanoparticles will be available only when surplus of silver nitrate is added to liquid medium. In spite of this, it has also been observed that $Ag^+$ furnished by both silver nitrate ($AgNO_3$) and silver thiosulphate ($Ag_2S_2O_3$) having the same effect on the root growth, if the influence of nitrate ion ($NO_3^-$) and thiosulfate ion ($S_2O_3^{2-}$) is overlooked. Aqueous extract of lemon leaves (*Citrus limon*) was utilized for the synthesis of AgNPs by Vankar and Shukla (2012) wherein biomolecules present in aqueous extract acts as a reducing agent and encapsulating cage for the AgNPs. These AgNPs find application in giving durable textile finish on cotton and silk fabrics and bestowing antifungal activity in the treated fabrics. Furthermore, Vankar and Shukla (2012) opined that antifungal activity could be due to the synergistic effect of AgNPs and essential oil components of lemon leaves. Synthesis of AgNPs by green chemistry approach using *Acalypha indica* leaf extract as reducing agents was reported by Krishnaraj et al. (2012). Different concentrations of AgNPs were observed for inhibitory effect on the growth of various plant pathogens, such as *Alternaria alternata*, *Sclerotinia sclerotiorum*, *Macrophomina phaseolina*, *Rhizoctonia solani*, *Botrytis cinerea*, *Curvularia lunata*. It was found that 15 mg of AgNPs was found to be inhibitory to all plant pathogens. Standardization of AgNPs synthesis from the root of *Morinda citrifolia* in an eco-friendly approach was established by Suman et al. (2013). Phytosynthesized materials were characterized by UV–Vis absorption spectroscopy and the spherical nature of AgNPs having a size range of 30–55 nm were determined by field emission-scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM). Moreover, these nanoparticles showed cytotoxicity on HeLa cell. Similarly, latex of Jatropha plant (*J. gossypifolia*) for the synthesis of

AgNPs was reported by Borase et al. (2014). It was observed that there was a rapid formation of AgNPs following addition of latex in $AgNO_3$ solution, which was confirmed by colour change (colourless to yellowish red) and the characteristic surface plasmon resonance (SPR) peak at 430 nm in UV–Vis spectroscopy. The process of AgNPs using the leaf and stem extract of *Piper nigrum* was standardized by Paulkumar et al. (2014). The synthesized nanoparticles were characterized by UV–vis spectroscopy, X-ray diffraction (XRD), SEM, TEM, energy-dispersive X-ray analysis (EDAX), and Fourier-transform infrared spectroscopy (FTIR). Presence of peak at 460 nm in the UV–vis spectra for leaf- and stem-synthesized AgNPs revealed reduction of silver metal ions into AgNPs. Further, the antibacterial activity of the green-synthesized AgNPs was examined against agricultural plant pathogens. Potential of AgNPs synthesized with aqueous extract of *Artemisia absinthium* against several species of *Phytophthora* was investigated by Ali et al. (2015). The findings of in vitro dose–response experiment confirm the high potential and efficiency of phytosynthesized AgNPs in inhibiting *P. parasitica and P. capsici*. Synthesis of AgNPs in *Aloe vera* plant extract is prepared by a hydrothermal method (Tippayawat et al. 2016). The synthesized AgNPs were found to be crystalline having size ranges from (70–192 nm) and were inhibitory to pathogenic bacteria. *Azadirachta indica* extract for the synthesis of AgNPs was synthesized by Ahmed et al. (2016). These nanoparticles exhibited antibacterial activities against *Staphylococcus aureus* (*S. aureus*) and Gram-negative *Escherichia coli* (*E. coli*). Similarly, synthesis of AgNPs using dried roasted *Coffea arabica* seed extract was reported (Dhand et al. 2016). UV–Vis spectroscopy result showed maximum absorption at 459 nm, which represented the characteristic surface plasmon resonance of nanosilver. Production of phytosynthesized AgNPs from *Mangifera indica* inflorescence aqueous extract was documented by Qayyum et al. (2017). Ag nanoparticles showed minimum inhibitory concentrations of 8 mg $ml^{-1}$ and 16 μg $ml^{-1}$ for *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and *E. coli* and *Streptococcus mutans* and *S. aureus* strains, respectively. Synthesis of AgNPs from the root extract of *Phoenix dactylifera* to test their anti-microbial and anti-cancer potential was performed by Oves et al. (2018). Low cost, green synthesis of AgNPs using fresh fruit extract of *Phyllanthus emblica* was documented by Masum et al. (2019). It was noted that synthesized nanoparticles (20 mg $ml^{-1}$) were potent against *Acidovorax oryzae* strain RS-2 of rice bacterialbrown stripe. Synthesis of AgNPs using pomelo (*Citrus maxima*) fruit extract as a biological capping and reducing material was also reported (Ali et al. 2020). Authors concluded that AgNPs can play an important role in controlling *A. oryza*. A list of AgNPs synthesized from different plant parts are mentioned in Table 1.

## Gold nanoparticles

Various factors affect the biosynthesis of AuNPs, such as strength of metal salt, strength of plant extract, temperature of the solution, and pH of the solution (Husen and Siddiqi 2014). It has been reported that numerous types of AuNPs are phytosynthesized with altered structures (face-centred cubic, icosahedral and irregular rod-shaped) using leaf extract of *Avena sativa* (Gardea-Torresdey et al. 1999). Gold (Au) nanoparticles have been synthesized from Geranium leaf, Neem leaf, and lemongrass (Shankar et al. 2004a, b). AuNPs were developed by chloroauric acid and citric acid at 100 °C (Kimling et al. 2006). Efficiency of the AuNPs synthesis by chloroauric acid and citric acid was further improved by Kurtjak et al. (2017), and Nirmala Grace and Pandian (2007). Various surfactants were evaluated by Yeh et al. (2012) to overcome the agglomeration during the application of citric acid for the synthesis of AuNPs. Jayaseelan et al. (2013) reported the synthesis of AuNPs using aqueous extract of *Abelmoschus esculentus* seeds. Antifungal activity of Au nanoparticles was also tested against *Puccinia graministritci*, *Aspergillus flavus*, *Aspergillus niger* and *Candida albicans* using standard well diffusion method. The results suggested that the synthesized Au nanoparticles act as an effective antifungal agent. Jayaseelan et al. (2013) confirmed that Au nanoparticles could render high antifungal efficacy and hence has a great potential in the preparation of drugs used against fungal diseases. The process of green synthesis of AuNPs was also optimized through the application of *Solanum nigrum* leaf extract, starch polymer, *Hyllanthus emblica* leaf extract, and cinnamon bark extract as an effective source of reducing and stabilizing biomolecules (Muthuvel et al. 2014; Ramdayal and Balasubramanian 2014; Emam et al. 2017; Emam et al. 2017). A list of AuNPs synthesized from different plant parts is mentioned in Table 1.

## Zinc oxide nanoparticles

Zinc oxide nanoparticles (ZnONPs) are extensively used for the variety of purposes due to its negligible toxicity [generally recognized as safe (GRAS)] and size-dependent characteristics. Green synthesis of ZnONPs has been proven to be superior over other metal nanoparticles based on efficiency and productivity for medical uses (Sushma et al. 2016). Similar to the other nanoparticles, ZnONPs also get affected by the type and part of the plant used for the green synthesis. Rajiv et al. (2013) reported synthesis and characterization of ZnONPs from weed plant (*Parthenium hysterophorus* L.) by a novel method, which was inexpensive and eco-friendly. Highly stable, spherical and hexagonal zinc oxide (ZnO) nanoparticles were synthesized using different concentrations (50% and 25% v/v) of *Parthenium* leaf extracts. Both

**Table 1** A selected representation of different types of phytosynthesized nanomaterials

| Plant species | Plant part | Nano-material | Nano-material (shape) | Nanomaterial size (nm) | UV absorption (nm) | References |
|---|---|---|---|---|---|---|
| *Aloe barbadensis* | Leaves | Au | Triangular, truncated, hexagonal | 50–350 | 560–810 | Chandran et al. (2006) |
| *Anacardium occidentale* | Leaves | Au | Spherical | 6.5–17 | 259–529 | Sheny et al. (2011) |
| *Annona squamasa* | Fruit peel | Pd | Spherical | 80 | 250–400 | Roopan et al. (2012a, b) |
| *Andrographis paniculata* | Leaves | Ag | Cubic | 40, 60 | 432 | Sinha and Paul (2015) |
| *Antigononleptopus* | Leaves | Pd | Spherical | 5–70 | 415 | Ganaie et al. (2016) |
| *Astraglmanna* | Whole plant | Pd | Spherical | 15 | 420 | Farhadi et al. (2013) |
| *Cacumen platyclade* | Leaves | Au–Pd | Spherical | 7.4 | 531 | Zhan et al. (2011) |
| *Calendula offcinalis* | Leaves | Ag | Spherical | 30–50 | 435 | El-Kemary et al. (2016) |
| *Camellia sinensis* | Leaves | Au | Spherical | 30–40 | 550 | Vilchis-Nestor et al. (2008) |
| *Cinnamomum camphora* | Leaves | Au | Triangular and spherical | 10–40 | 520–570 | Huang et al. (2007) |
| *Cinnamomum camphora* | Leaves | Pd | Spherical | 3.2–6 | 250–300 | Yang et al. (2010) |
| *Cucumis anguria* | Leaves | Ag | Spherical | 11–27 | 420 | Muchanyereyi-Mukaratirwa et al. (2017) |
| *Gardenia jasmineids* | Fruit | Pd | Spherical, rod, polyhedral | 3–5 | 238, 322, 440 | Jia et al. (2009) |
| *Glycine max* | Leaves | Pd | Spherical | 15 | 200, 240, 270 | Kumar Petla et al. (2012) |
| *Lansium domesticum* | Fruits | Au<br>Ag<br>Au–Ag alloy | Hexagonal, triangular | 20–40<br>10–30<br>150–300 | 420, 540 | Shankar et al. (2014) |
| *Memecylon edule* | Leaves | Au | Triangular and hexagonal | 20–50 | 530–555 | Elavazhagan and Arunachalam (2011) |
| *Mentha piperita* | Leaves | Au | Spherical | 5–150 | 540 | MubarakAli et al. (2011) |
| *Moringa oleifera* | Peel | Pd | Spherical | 27 ± 2 | _ | Surendra et al. (2016) |
| *Mucuna pruriens* | seeds | Au | Spherical | 6–17.7 | 537 | Arulkumar and Sabesan (2012) |
| *Persea americana* | Bark | Ag/Pd | Irregular | 1–16 | 400, 450, 421 | Meva et al. (2019) |
| *Piper betle* | Leaves | Pd | Spherical | 4 ± 1 | 320, 600–700 | Mallikarjuna et al. (2013) |
| *Potamogeton pectinatus* | Whole plant | Au | Spherical | 8.4 | 542.5 | Abdelhamid et al. (2013) |
| *Quercus brantii* | Leaves | Ag | Spherical | 6 | 45 | Korbekandi et al. (2015) |
| *Rosa rugosa* | Leaves | Au | Spherical | 50–250 | 578 | Dubey et al. (2010a) |
| *Sapium sebiferum* | Leaves | Pd | Irregular | 2–14 | 274 | Tahir et al. (2016) |
| *Solanum trilobatum* | Leaves | Pd | Spherical | 60–100 | 200, 240, 270 | Kanchana et al. (2010) |
| *Tanacetum vulgare* | Fruit | Au | Triangular, spherical | 10–40 | 546 | Dubey et al. (2010b) |
| *Terminalia catappa* | Leaves | Au | _ | 10–35 | 524 | Ankamwar (2010) |
| *Vitis vinifera* | Fruit | Pd | Spherical | 44–50 | 652 | Baruwati and Varma (2009) |
| *Ziziphora tenuior* | Leaves | Ag | Spherical | 8–40 | 460 | Sadeghi and Gholamhoseinpoor (2015) |
| *Ziziphus jujube* | Leaves | Ag | Various shapes | 20–30 | 434 | Mane Gavade et al. (2015) |
| *Ziziphus oenoplia* | Leaves | Ag | Spherical | 10 | 436 | Soman and Ray (2016) |

the concentrations of the leaf extract acted as reducing and capping agent for the conversion of ZnONPs. Optimization of size and concentration of synthesized ZnONPs was evaluated against plant fungal pathogens (*Aspergillus flavus* and *Aspergillus niger*) and highest zone of inhibition was observed with a size of 27 nm at 25 µg $ml^{-1}$ concentration. Hossain et al. (2019) synthesized ZnONPs by mixing solution of ZnO with lemon fruit extract at room temperature, which showed antibacterial activities against *Dickeyadadantii*, a causative agent of sweet potato stem. Selim et al. (2020) reported the green synthesis of nanoparticles by the reduction of zinc acetate di-hydrate using the leaf extract of *Cassia fistula* and *Melia azadarach*. A list of ZnONPs synthesized from different plant parts is mentioned in Table 1.

## Magnesium- and manganese-based nanoparticles

Limited reports are available on the phytosynthesis of magnesium and manganese nanoparticles. Magnesium oxide (MgO) nanoparticles have acquired the attention of the researcher owing to its economical and environmentally fabrication approach as well as wide spectrum of applications, such as anticancer and anti-microbial activity (Salehifar et al. 2016; Suresh et al. 2018; Abdallah et al. 2019a). Abdallah et al. (2019b) reported synthesis of magnesium oxide nanoparticles (MgONPs) using aqueous rosemary extract with stirring conditions at 70 °C for 4 h and the presence of nanoparticles was checked by UV–Vis spectrum. Similarly, Ogunyemi et al. (2019a) also reported synthesis of MgONPs and manganese dioxide nanoparticles ($MgO_2$NPs) which were found to be antibacterial. In another study, Ogunyemi et al. (2019b) used aqueous rosemary extract to synthesise MgONPs with stirring conditions at 70 °C for 4 h. Presence of nanoparticles was confirmed by UV–Vis spectrum. Synthesized MgONPs remarkably inhibited *Xanthomonas oryzae*, a causative agent of bacterial blight disease in rice. A list of magnesium and manganese nanoparticles synthesized from different plant parts is mentioned in Table 1.

## Titanium- and copper-based nanoparticles

Numerous plant species have been utilized for synthesis of titanium dioxide nanoparticles ($TiO_2$NPs) having different shapes. Synthesis of $TiO_2$NPs starts when $TiO_2$ salt is mixed with plant extract and subsequent colour change indicates the synthesis of nanoparticles and is further confirmed by spectroscopic techniques. The colour varied from light green to dark green (Dobrucka 2017; Rajakumar et al. 2012, 2013). Hossain et al. (2019) synthesized $TiO_2$NPs by mixing solution of titanium dioxide ($TiO_2$) with lemon fruit extract at room temperature. These nanoparticles exhibited antibacterial activities against *Dickeya dadantii*, a causative agent for sweet potato stem and root rot disease. Roopan et al. (2012b) reported synthesis of spherical $TiO_2$NPs when *Annona squamosa* L. extract was mixed with aqueous solution of $TiO_2$ salt at room temperature. Similarly, leaf extract of *Calotropis gigantea* (L.) Dryand fabricated TiO2NPs from $TiO_2$ within 6 h due to the rapid bio-reduction by primary amines (Nadeem et al. 2018). Similarly, in case of copper-based nanoparticles, several studies revealed that phytochemicals present in plant extracts form complexes with iron salts and then lead to reduction of ions to form nanoparticles. In particular, copper ions ($Cu^{2+}$) react with biomolecules of extract, which causes the reduction and then transformed into copper nanoparticles (CuONPs) (Akintelu et al. 2020). Rajesh et al. (2018) reported synthesis of CuONPs using *Syzygium aromaticum* (clove) bud extract through simple and eco-friendly green route. The synthesized nanoparticles were subjected to structural, morphological, optical, and antimicrobial studies. A list of titanium and copper nanoparticles synthesized from different plant parts is mentioned in Table 1.

## Nickel, platinum and palladium nanoparticles

The formation of platinum nanoparticles (PtNPs) by means of biological system is limited. A few plant species are used for the synthesis of PtNPs. Bali et al. (2010) used alfalfa and brown mustard plant biomass for the formation of PtNPs from platinum (Pt) (II). Acidic medium having a pH between 2 and 3 was used for the study of transformation of Pt(II) to PtNPs. The concentration of platinum metal exhibited the accumulation of Pt between 0.77 and 36.83 mg of Pt $g^{-1}$ of dry biomass of alfalfa. Jeyaraj et al. (2019) reported fabrication of PtNPs derived from tea polyphenol which was extracted from *Camellia sinensis*. They concluded that tea polyphenol acted as reducing and stabilizing agent and was able to induce programmed cell death of cervical cancer cells. Recently, spherical PtNPs were synthesized from the coral vine *Antigonon leptopus* and was found to be stabilizing and reducing agent for the formation of PtNPs (Jeyaraj et al. 2019). Jeyaraj Pandian et al. (2016) reported synthesis of nickel nanoparticles (NiNPs) using leaf extract of *Ocimum sanctum*. In a similar report by Chen et al. (2014), phytosynthesis of NiNPs from the extract of *Medicago sativa* was achieved in which the flavonoids and reducing sugars are the key reducing biomolecules. By exploiting the biomolecules of *Annona squamosa* peel extract, sphere-shaped palladium (Pd) nanoparticles have been obtained (Bali et al. 2010; Roopan et al. 2012a, b). Green synthesis of palladium oxide nanoparticles (PdONPs) and nickel oxide (NiONPs) was attempted using biomolecules of *Aspalathus linearis* leaf extract as reducing and capping agent (Mayedwa et al. 2018). A list of nickel, platinum and palladium nanoparticles synthesized from different plant parts is mentioned in Table 1.

## Conclusion

Phytosynthesis of nanoparticles has gained interests among the researchers. Studies conducted by different workers have demonstrated the possibility of formation of nanoparticles by plant extracts. Moreover, these phytosynthesized nanoparticles have shown potential role in wide areas ranging from agricultural productivity to disease control management of plant and animal systems. Future studies of phytosynthesis of nanoparticles may consider few factors like exploration of diverse plant systems for synthesis of nanoparticles, evaluation of toxicity of nanoparticles on any system (plants, animals and microbes) and scalability of phytosynthesized nanoparticles to industrial level.

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## Declarations

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