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Review Article

A Review on Biomimetic Synthesis of Ag_2O Nanoparticles using Plant Extract, Characterization and its Recent Applications

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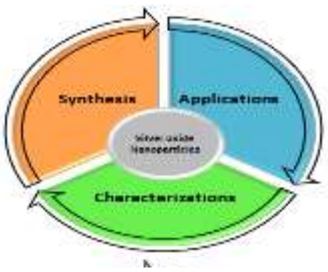
GRAPHICAL ABSTRACT



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ABSTRACT

Nanotechnology is a swiftly growing field due to its huge range of uses in various branches of science and technology. Divergent types of routes are employed for the production of nanoparticles (NPs) because of their broad applications. The conventional physical and chemical approaches have certain constraints with them either in the form of chemical contaminations during their syntheses methodology or use of higher amount of energy. During the last one or two decades research have been concentrated on creating facile, safe, non-noxious, affordable and eco-accommodating procedures for synthesis of NPs. In order to get this purpose, green synthesis approaches have been improved in order to fill this lacuna. The biogenic synthesis of NPs is facile, one pot, eco-benevolent, sustainable and a green methodology. The different biological specimens like plant tissues, yeast, bacteria, fungi, etc. are used for green synthesis for metal oxide NPs. In this review, we summed up recent literature on biomimetic synthesis of silver oxide (Ag_2O) NPs which have revolutionized method of fabrication for their stupendous applications in various sectors. Due to biocompatibility of Ag_2ONPs, it has found its efficacious applications in biomedical field. The characterization techniques and mechanism of green synthesis of Ag_2O NPs along with diverse applications have also been investigated.

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Nanotechnology is a significant rising domain of research that has been extending enthusiasm which focuses on the improvement of biological and synthetic approaches of engineering NPs across the globe with immense momentum in creating nano revolution due to their remarkable applications [1-2].

Due to implicitly novel or improved features and/or properties of NPs, their essential applications are growing swiftly on diverse fronts like agriculture, biomedical, transportation, pharmaceutical, energy, catalysis, defense and drug delivery, etc. [1-10]. NPs are finding their utilizations in different fields such as ceramics, health care, textiles, biomedical, fuel, tissue engineering, paint technology, gene delivery, pharmaceutical industry, space industry, food industry, environmental, agriculture, in fact in every sector many more to count on [1-25]. The NPs among all the aforementioned purposes are considered as generally encouraging as they contain significant antibacterial performance due to their enormous surface area to volume ratio. Due to the expanding microbial resistance against the selective antibiotics and improvement of resistant strains, there is astounding enthusiasm for scientists towards antimicrobial effect of NPs [3-4]. The several types of NPs have gained tremendous consideration in recent times due to their imperative contribution in global development [1-30]. These NPs have achieved huge consideration in recent times because of their imperative and innovative significance. Among the aforementioned NPs, Ag_2O NPs is played overriding role in the discipline of catalysis and biomedical. These NPs have been used for various applications (Fig. 1) including sensing [31], catalysis [32], drug delivery [33], antioxidant, cytotoxic activity [34], photocatalytic [35], antibacterial [36], anti-leishmaniasis [37], antifungal and wound healing activity [38].The green synthesis of Ag_2O NPs has been investigated using plant tissues [38], bacteria [39], etc.

Eco-benevolent approaches are becoming more conspicuous in branch of green chemistry, when the researchers are becoming more sensible about diverse ecological issues. The sustainable progression of bio-inspired experimental protocols for the syntheses of NPs is improving as an essential branch of nanotechnology. The phytogenic synthesis of NPs is creating more impact due to its straightforwardness, its swift rate of formation of metal oxide NPs and eco-accommodating methodology.

In the present review, the recent developments for the preparation of the Ag_2O NPs using few plant broths and their astonishing application are consciously discussed. It is believed that this summarized overview will play significant and imperative roles in future advancements in the field of "*nanobiotechnology*".

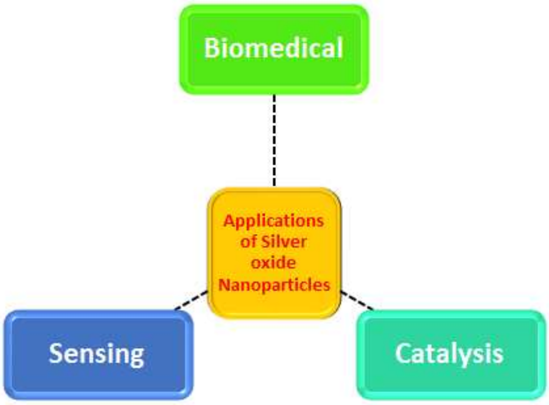

Fig. 1. Applications of Ag_2O NPs.

Biomimetic Synthesis of Ag_2O NPs

Eco-benign synthesis of NPs is a methodology that is consistent with principles of green chemistry approaches (Fig. 2) in which the phytochemicals discharged by the bio-molecules can act as both reducing and capping/stabilizing agents during the experiment. In recent years, plant-mediated fabrications of NPs are achieved lot of consideration due to its swiftness and its straightforwardness [1]. In NPs preparation utilizing plant extracts, the broth of plant is simply blended with the water solution of the silver metal salt precursor at normal room temperature, so that these protocols may be considered as a green chemistry approach [4-5]. Silver metal salt containing of silver metal ions are first reduced by atoms by means of reducing agents. The obtained atoms then agglomerated and form tiny clusters that grow into Ag_2O NPs [34].

Many studies have been done on this field. In this outlook, Ravichandran *et al*. [34] reported the biosynthesis using leaf extract of *Callistemon lanceolatus* for the bioreduction of Ag_2O NPs. They found that leaf extract successfully synthesize hexagonal shaped Ag_2O NPs with size ranging from 3-30 nm.

Centella asiatica and *Tridax* were also used to prepare Ag_2O NPs at room temperature [35]. Similarly, Yu *et al.* [38] synthesized Ag_2O NPs using leaves extracts of *Lippia citriodora*. Apart from these, Ag_2O NPs were also biogenically synthesized using leaves extract of *Artocarpus hetrophyllus*. As-synthesized Ag_2O NPs were spherical in shape and were 14 nm in size. Later, Sharma *et al.* found that flavonoids present in leaves were accountable for the successful synthesis of Ag_2O NPs [40]. A few numbers of plants are investigated for biomimetic synthesis of Ag_2O NPs, which are referenced in Table 1, and are discussed concisely in this overview.

Fig. 2. Advantages of green approaches for the synthesis of NPs.

Table 1. Biomimetic synthesis of Ag_2O NPs using various plant extracts with size and shape

Sr. No.	Name of the plants	Part used	Morphology	Size (nm)	Characterization techniques	Reference
1.	*Artocarpus hetrophyllus*	Leaves	Spherical	14	XRD, UV-vis, FTIR, DLS, TEM	*40*
2.	*Azadirechta indica*	Leaves	Spherical and sheet	60-100	UV-Vis, FTIR, XRD, SEM, Zeta potential	*41*
3.	*Callistemon lanceolatus*	Leaf	Spherical and hexagonal	3-30	UV-Vis, FTIR, XRD, SEM, HRTEM	*34*
4.	*Centella asiatica*	Leaves	Spherical	11-12	XRD, UV-Vis, SEM, EDS, FTIR	*35*
5.	*Tridax*	Leaves	Spherical	11-12	XRD, UV-Vis, SEM, EDS, FTIR	*35*
6.	*Dragon fruit*	Peel	Spherical	25-26	UV-Vis, FTIR, XRD, EDX, TEM, Zeta potential	*36*
7.	*Fenugreek*	Leaves	Spherical	31.5	UV-Vis, FTIR, Zeta potential, TEM,	*42*
8.	*Ficus benghalensis*	Root	Spherical	16	UV-Vis, XRD, TEM, FTIR, SEM	*37*
9.	*Ficus benghalensis*	Root	Spherical	42.7	UV-Vis, FTIR, HRTEM, XRD	*43*
10.	*Lippia citriodora*	Leaves	Spherical	20	XRD, TEM, EDS, FTIR, TGA	*38*
11.	*Paeonia emodi*	Leaves	Spherical	38.29	XRD, TEM, SEM, EDX, FTIR, UV-Vis	*44*
12.	*Pavetta indica*	Leaf	Distorted square shape	49.8	XRD, Zeta potential, SEM, EDAX	*45*
13.	*Pinus longifolia*	Leaves	Spherical and sheet	1-100	UV-Vis, SEM	*46*
14.	*Telfairia occidentalis*	Leaves	Spherical	8-10	SEM, XRD, UV-Vis, FTIR	*47*

Characterization Techniques for NPs

The phytogenically synthesized NPs are generally characterized using several techniques including, UV– vis spectroscopy [48], Thermal Gravimetric Analysis (TGA) [49], differential scanning calorimetry (DSC) [50], X-ray diffraction (XRD) [51], Fourier transform infrared spectroscopy (FT-IR) [52], scanning tunneling microscope (STM) [53], scanning electron microscopy (SEM) [54], transmission electron microscopy (TEM) [55], energy dispersive spectroscopy (EDX) [56], Brunauer-Emmett-Teller (BET) [57], vibrating sample magnetometer (VSM) [58], magnetic force microscopy (MFM) [59], X-ray absorption spectroscopy (XAS) [59], X-ray photon spectroscopy (XPS) [60], atomic force microscopy (AFM) [61], zeta potential and dynamic light scattering (DLS) [62]. Aforesaid characterization techniques provide the information about stability, size, shape, surface charge, elemental composition, purity, crystallinity, surface area and magnetic behavior of the NPs (Fig. 3).

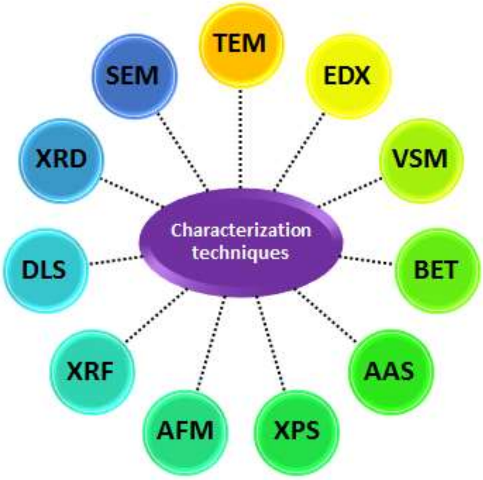

Fig. 3. Characterization tools for NPs.

Proposed Mechanism for Ag_2O NPs Formation Using Plant Extract

The biological ability of NPs synthesized using various plant extracts is surprisingly upgraded due to the eco-benevolent nature of this methodology and the eclectic one pot protocol with a mechanism, which includes synergistic reduction and stabilization of the NPs, based on published reports. Nonetheless, a few reports have been recently published on the biomimetic synthesis of Ag_2O NPs with the help of diverse plant extracts, only a few reports have been depicted the probable mechanism.

Sharma *et al*. [40] synthesized Ag_2O NPs by using *Artocarpus hetrophyllus* leaves extract. He reported from his studies that the phytochemicals like flavonoids present in the leaves extract works as reducing and/or stabilizing compounds which lead to the successful formation of Ag_2O NPs. He critically depicted the plausible mechanism for the formation of Ag_2O NPs in Fig.4.

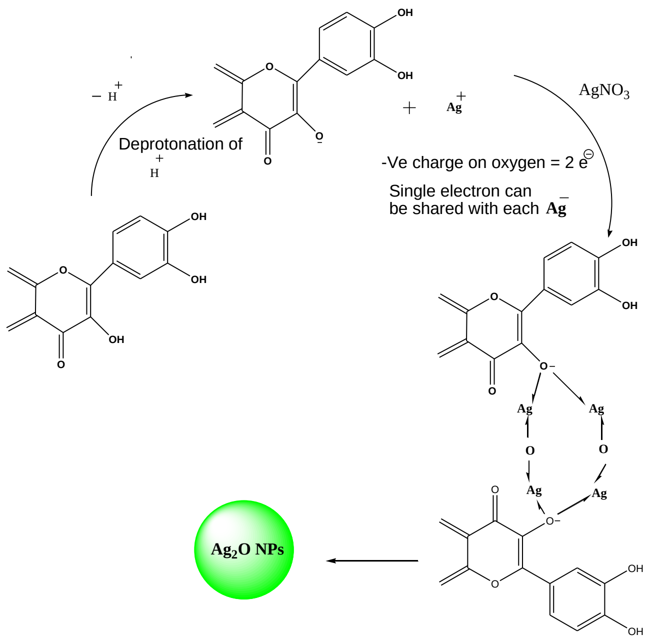

Fig. 4. Plausible mechanism of biomimetic synthesis of Ag_2O NPs by using *Artocarpus hetrophyllus* leaves extract [Reproduced from ref. 40].

Applications of Bio-mimetically Synthesized Ag_2O NPs

Ag_2O NPs have lot of remarkable uses in several discipline of catalysis and biomedical. Nevertheless, the bio-sensing, biomedical and catalytic applications of the bio-mimetically synthesized Ag_2O NPs are very effective nowadays (Table 2).

Ravichandran *et al.* [34] described biosynthesis of Ag_2O NPs using *Callistemon lanceolatus* leaf extract and reported their antioxidant and cytotoxic study [58]. This study reported that, the synthesized Ag_2O NPs exhibited significant cytotoxic activity towards brine shrimp nauplii and showed significant dose-dependent antioxidant activity in different *in vitro* antioxidant protocols including DPPH, total antioxidant, reducing power and β-carotene bleaching assay.

Ravikumar *et al.* [35] synthesized spherical shaped Ag_2O NPs using *Centella asiatica* and *Tridax* leaves extract and studied the electrochemical, photocatalytic, antibacterial and antifungal activity of as-prepared NPs. They carried out the antibacterial and antifungal activity of Ag_2O NPs against *Staphylococcus aureus*, *Staphylococcus epidermidis, Aspergillus aureus* and *Aspergillus fumigates* respectively. Synthesized Ag_2O NPs exhibited considerable antimicrobial performance. Also, they evaluated the photocatalytic activity of green synthesized Ag_2O NPs using acid orange 8 (AO8) dye and a result indicatesAg_2O NPs exhibits good photocatalytic activity.

Phongtongpasuk *et al.* [36] reported the eco-friendly synthesis of Ag_2O NPs using dragon fruit peels extract and also reported their antibacterial efficacy using disc diffusion method. This antibacterial activity revealed that the synthesized Ag_2O NPs evinced great antibacterial performance against *Escherichia coli, Pseudomonas aeruginosa* and *Staphylococcus aureus*.

Balakumar *et al.* reported the green synthesis of Ag_2O NPs using *Fenugreek* leaves extract and described their hemolysis properties [42].

Ismail *et al.* [37] synthesized Ag_2O NPs using prop root extract of *Ficus benghalensis* and examined their anti-leishmaniasis activity against *Leishmania donovani*. Same plant was reported for the green synthesis of Ag_2O NPs and examined their antibacterial activity [43].They showed excellent antibacterial efficacy against the two dental bacteria *Streptococcus mutans* and *Lactobacilli sp*.

Yu *et al.* [38] described the biosynthesis of Ag_2O NPs using *Lippia citriodora* leaves extract were in the size of 20 nm and evaluated their photocatalytic, antibacterial, antifungal and wound healing study. As-prepared Ag_2O NPs exhibited good photocatalytic in the degradation of AO8 dye under UV light irradiation. Antibacterial and antifungal activity displayed that Ag_2O NPs have more effective against *Staphylococcus aureus and Aspergillus aureus*. Further, wound healing activities in excision skin wound model in albino wistar rats exhibited the effective wound healing performance of Ag_2O NPs compared to untreated and leaves extract treatments.

Shah *et al.* [44] reported green synthesis of Ag_2O NPs using *Paeonia emodi* leaves extract and evaluated its photocatalytic activity using methylene blue dye and results indicate Ag_2O NPs exhibits excellent photocatalytic performance (degraded up to 97.78% in 180 min.) Moreover, they examined antibacterial activity of Ag_2O NPs against *Bacillus subtilis, Staphylococcus aureus, Escherichia coli* and *Pseudomonas aeruginosa*.

Table 2. Applications of Ag_2O NPs as-prepared using various plants extracts

Sr. No.	Name of the plants	Various applications	Reference
1.	*Callistemon lanceolatus*	Antioxidant and cytotoxic activity	*34*
2.	*Centella asiatica*	Electrochemical, photocatalytic, antibacterial and antifungal activity	*35*
3.	*Tridax*	Electrochemical, photocatalytic, antibacterial and antifungal activity	*35*
4.	*Dragon fruit*	Antibacterial activity	*36*
5.	*Fenugreek*	Hemolytic activity	*42*
6.	*Ficus benghalensis*	Anti-leishmaniasis activity	*37*
7.	*Ficus benghalensis*	Antibacterial activity	*43*
8.	*Lippia citriodora*	Photocatalytic, antibacterial, antifungal and wound healing study	*38*
9.	*Paeonia emodi*	Photocatalytic and antibacterial activity	*44*
10.	*Pinus longifolia*	Antibacterial activity	*46*
11.	*Telfairia occidentalis*	Antibacterial activity	*47*

Khatunn *et al*. [46] stated that the Ag_2O NPs synthesized *via* green approach using *Pinus longifolia* leaves extract showed considerable antibacterial activity against *Escherichia coli* and *Streptococcus aureus.*

Aisida *et al*. [47] reported the biosynthesis of Ag_2O NPs using *Telfairia occidentalis* leaves extract and also examined their antibacterial activity using disk diffusion method. They showed that, Ag_2O NPs possess momentous antibacterial activity against *K. Pneumonia.*

CONCLUSION

Natural precursors have the ability to reduce silver metal ions into Ag_2O NPs. It is understood that the variety of natural bio-compounds that are exist in plant broths can work as both reducing and/or stabilizing agents for the fabrication of Ag_2O NPs. Plants assisted Ag_2O NPs are stable due to the presence of herbal capping agents such as flavonoids, proteins and phenols which resist the NPs from agglomeration. Biomimetic synthesis of Ag_2O NPs using plant extracts has many merits such as non-noxious, eco-friendliness, sustainable, biocompatibility, straightforwardness and cost-effectiveness. It is concluded that due to these eclectic properties, Ag_2O NPs will have a significant and imperative role in many of the nanotechnology based protocols.

FUTURE PROSPECT

As has been observed, biomimetic syntheses of Ag_2O NPs provide an alternative to the known conventional approaches of Ag_2O NPs synthesis. Further, this protocol may be improved if more special emphasis would be paid on the investigation of lucid mechanisms involved, control the parameters of experiments for optimization of size and shape of the Ag_2O NPs, growth of applications more towards the photocatalytic performance and biomedical field.

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