Green synthesis of silver nanoparticles (AgNPs) for optical and photocatalytic applications: a review

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Abstract

Nano-sized particles of silver (Ag) whose diameter falls within 1-100 nm range possess an exceptional physico-chemical, biological and antimicrobial properties. As a result of their unique properties, silver nanoparticles (AgNPs) have been vigorously investigated. In the last decade, several trials have been made to heighten the green methods of formulating AgNPs to reduce the danger of the by-products from chemical methods. A clear understanding of AgNPs properties is absolutely necessary in order to make the best use of these nanoparticles in various fields, while their effect on man and environment is reduced to the least achievable. This review aims to discuss the green methods of preparing AgNPs and its numerous applications in the area of opto-electronics and environmental remediation. Many natural biomolecules in plants and microorganism were involved in formation, stabilization and bio-reduction of AgNPs. Over the years, several discoveries have reiterated that the catalytic and optical properties of AgNPs are dependent on the size, size-distribution and shape, which show variation by differing their synthetic approaches, stabilizers and reducing agents. In this review, silver nanoparticles have been reported to produce a desired result as a promising photocatalytic material and with a viable application in opto-electronic device. Thus silver nanoparticles are considered useful for having diverse range of applications for the benefits of man.

Keywords: Silver Nanoparticles, Photocatalytic, Degradation, Green synthesis, Stabilizers, Reducing agents
1. Introduction

Nanotechnology is a very swift growing field that has been used worldwide probably in a large number of different economic product by producing nanoparticles (NPs) and nano products with novel and size-related physico-chemical characteristics that are significantly different from bulk matter [1]. In the last few years, the scientific community has recorded an outstanding progress in the area of nanoscience and nanotechnology [2]. Nanoparticles possess enhanced properties considering particular characteristics, that is, shape, size (1-100 nm) and structure. NPs are of two broad categories, organic and inorganic nanoparticles. Inorganic nanoparticles are semi-conductor nanoparticles (ZnO, ZnS, CdS), metallic NPs (Au, Ag, Cu, Al), and magnetic NPs (Co, Fe, Ni), while organic NPs are carbon nanoparticles such as quantum dots, fullerenes and carbon nanotubes. Several interests for gold (Au) and silver (Ag) NPs increase rapidly as a result of their superior characteristics and flexible properties [3]. In this review, AgNPs is of interest because of its unique and distinctive superior physico-chemical properties which include high thermal and electrical conductivity, surface-enhanced Raman scattering, catalytic activity, chemical stability, biological properties [4] and non-linear optical behaviour [5]. Their superiority is as a result of their shape, size, crystallinity, composition and structure compared to the bulk forms [6, 7]. These novelties have been utilized in a large scope of potential applications such as biomedical devices, medicine, renewable energies, cosmetics, environmental remediation, food, consumer, and industrial purposes [8, 9].

The metal nanoparticles exhibit Surface Plasmon Resonance (SPR) whose strong observation of light is used for producing the optical devices [10]. The SPR is dependent on the free electrons oscillation of the particles and the medium surrounding it and form the conduction band as a result of the electromagnetic field [11]. The spectral and geometrical attributes of silver nanoparticle, such as shape, size, environment and the inter-particle spacing provide important control over the linear and nonlinear optical properties [12], and these properties make them useful in medical imaging, microelectronics, and inks [13]. Besides, silver nanoparticles possess a broad spectrum of bactericidal and fungicidal activities [14] which made them more common in a various order of consumer products such as soaps, plastics, food, pastes and textiles, thereby magnifying their market quality [15, 16].

In other to achieve a desired AgNPs, several methods of synthesis have been improvised including physical, biological and chemical as illustrated in Figures 1 and 2. Generally, a conventional physical and chemical method of synthesis has been shown to be very costly and toxic [17]. There is possibility to achieve desired particle characteristics, nevertheless the
use of reducing and stabilizing agents which are expensive and toxic in physical and chemical methods of synthesis, makes them unlikely to bring about a favourable result [18, 19]. Among the numerous methods that have been adopted to synthesise nanoparticles, the biologically prepared AgNPs shows a high yield, high stability and solubility. Stable nanoparticles are achieved by reducing silver ions into silver elements by the use of reducing agents and then by nucleation and growing processes [20]. Biological method of production is a very simple, harmless, reliable, and a green approach capable of producing a specified size, morphology under more desirable conditions for translational research in short time. In this regard, green synthesis method of nanoparticles has drawn significant attention of researchers in recent years; extracts from microorganisms, plants and enzymes have been discovered to be a good replacement for reagents used in the synthesis of nanoparticles [21]. The use of green materials has numerous advantages such as low consumption of energy and moderate operation conditions (e.g. temperature and pressure) beyond the use of hazardous chemicals [22]. Therefore, the green method of synthesis utilizing biological organisms such as bacteria, yeast, algae, moulds and extracts from plant have been designed for synthesising nanoparticles [23]. The small size nature and surface configuration of AgNPs increases their surface to volume ratio and make them to exhibit amazing antimicrobial and physico-chemical properties [24]. In comparison with other methods, biosynthesis of nanoparticles using extracts of plant is cost effective, eco-friendly and makes the intended nanoparticles suitable for therapeutic use [25] and as economic and valuable alternative for the mass production of silver nanoparticles.
Figure 1. General methods of synthesis of silver nanoparticles

2. Silver nanoparticles (AgNPs)
AgNPs among several other metal nanoparticles have drawn attention as a result of their unique properties which include chemical stability, electrical conductivity, antimicrobial and catalytic activities [26]. Nanosilver portrays properties that are totally different from bulk material as a result of high surface to volume ratio [27].

AgNPs are produced from various chemical, physical and biological approaches that results in different sizes and shapes employed in numerous applications. Hence, the syntheses methods are grouped into two main categories; bottom-up and top-down approaches. In the top-down approach, as shown in Figure 2, the bulk size of silver metal is reduced by mechanical means to nano-scale through the use of sophisticated procedures such as laser ablation and lithography. Bottom-up approach otherwise called self-assembly technique involves dissolution of silver salt into a solvent and reduction of Ag\(^+\) to their element by adding reducing agent and stabilizing agents to stabilize the forming AgNPs to avoid agglomeration [28]. The bottom-up approach produces nanostructures with little or low defects, better long and short range ordering and chemical composition that are more homogenous [29]. AgNPs of desired morphology, size, and shape can be produced by the several physical and chemical methods (such as arc discharge, surface deposition, plasma...
polymerization, emulsion polymerization, laser CVD (Chemical Vapour Deposition), and thermal decomposition in organic solvents, chemical reduction and photo reduction in reverse micelles [30].

Figure 2. Diverse synthesis approaches of silver nanoparticles (AgNPs) [31]

3. **Green synthesis of silver nanoparticles**

The conventional synthetic methods of synthesizing NPs are costly, toxic, and not friendly to the environment. In an attempt to bypass these challenges, researchers have found green routes in which natural sources and their outcomes can be employed for synthesising NPs. Figure 3 shows the green synthesis approach of silver nanoparticle utilizing microorganisms (such as yeasts, fungi, actinomycetes and bacteria) and the use of plants and its extracts [32]. It was reported that microorganisms (bacteria and fungi) are used to reform the toxicity of materials by reduction of metal ions, the molecules produced by living organisms are replaced by stabilizer and the reducing agent [33].
3.1 Synthesis of AgNPs by using bacteria

The production of inorganic materials using bacteria by extracellular or intracellular makes them a potential bio-factory for producing noble metal NPs whether Au or Ag. Silver nanoparticles have been shown to be biocompatible whereas some bacteria are resistant to silver [34]. Since these bacteria are capable of gathering Ag on the cell walls, they are then recommended industrially for use in recovery of Ag from ore material [35]. There are many bacteria that have been used for synthesising AgNPs (Table 1).

Klaus et al. [36] worked on the AgNPs synthesis by the use of *Pseudomonas stutzeri* AG259, Ag resistant bacteria strains. It was reported that the cells accumulate AgNPs in large quantity up to 200 nm [36]. In 2008, the production of AgNPs was also investigated using *Bacillus licheniformis* [37]. From the study, AgNO₃ solution was imparted into the biomass of *B. licheniformis*, and appearance of a brownish colour confirmed the formation of AgNPs within the range of 50 nm on the average and stabilized by the use of nitrate enzyme. Nanda and Saravanan [38] also reported AgNPs produced by utilizing culture supernatants from *Staphylococcus aureus*. It was revealed from their study that culture supernatants of any form of bacteria from Enterobacteriaceae make synthesis of AgNPs to be fast [38].

Suresh et al. [39] biosynthesized silver nanoparticles by exploiting a bacterium (*Shewanella oneidensis*) capable of reducing metals and incorporated with a solution of silver nitrate. The study revealed a nearly mono-dispersed spherical AgNPs whose size ranges between 2 to 11
nm and possesses important properties such as being stable, hydrophilic and having a large surface area [39].  

In another study [40], stable AgNPs were synthesized by the use of *Bacillus* sp., an airborne bacterium and silver nitrate. The biogenic NP was investigated between the outer and inner cell membranes of the bacterial cells and the obtained diameter was found between 5-15 nm. According to report [41], AgNPs is produced by reducing aqueous Ag⁺ via different culture supernatants of bacteria (*Klebsiella pneumoniae*, *Enterobacter cloacae*, and *Escherichia coli*). It was concluded that the synthesis rate is much faster, as AgNPs forms within 5 minutes after adding Ag ions to the cell filtrate.  

Also, Sintubin et al. [42] utilized *Lactobacillus* spp. as capping and reducing agent in the production of AgNPs. The study was conducted with varieties of *Lactobacillus* spp to gather and afterwards reduces Ag⁺. The analysis confirmed the lactic acid bacteria to have the ability to produce Ag. It was concluded that, particle localization and distribution relied on *Lactobacillus* species inside the cell and a mean diameter (11.2 nm) of the AgNPs produced.  

### 3.2 Synthesis of AgNPs by using fungi  

Fungi possess a unique ability for synthesizing metallic NPs; this is because of their high binding capacity, metal bioaccumulation ability, intracellular uptake and tolerance [43]. Fungi can be used to synthesis NPs whereby it secretes enough enzymes capable of reducing AgNO₃ solution through various methods [44]. Kumar et al. [45] investigated a rationale of an *in vitro* enzymatic scheme for synthesizing AgNPs. NADPH (nicotinamide adenine dinucleotide phosphate) subjected to phytochelatin and nitrate reductase [45]. The purified nitrate reductase obtained from the fungus, *Fusarium oxysporum* was employed *in vitro* with NADPH. Their study revealed that hydroxyquinoline acts as an electron shuttle to enable Ag formation and a stable silver hydrosol with size range of 10 to 25 nm was produced and stabilized using capping peptide.
Table 1. Green synthesis of AgNPs using bacteria

| Bacteria                  | Intracellular/Extracellular | Precursor   | Size (nm) | Morphology     | Reference |
|---------------------------|----------------------------|-------------|-----------|----------------|-----------|
| Marine Ochrobactrum spp.  | Intracellular              | AgNO₃      | 38–85     | Spherical      | [46]      |
| Exiguobacterium mexicanum | Extracellular              | AgNO₃      | 5–40      | Spherical and cubic | [47]      |
| Shewanella oneidensis     | Extracellular              | AgNO₃      | 4.15      | Spherical      | [48]      |
| Lactobacillus spp.        | Extracellular and intracellular | AgNO₃  | 2–20      | Spherical      | [49]      |
| Lactobacillus HG-C3 sp.   | Extracellular              | AgNO₃      | 8–25      | Crystalline and spherical | [50] |
| Serratia nematodiphila    | Extracellular              | AgNO₃      | 10–31     | Spherical and crystalline | [51] |
| Pseudomonas putida NCIM 2650 | Extracellular              | AgNO₃      | 70        | Spherical      | [52]      |
| Bacillus methylotrophicus | Extracellular              | AgNO₃      | 10–30     | Spherical      | [53]      |
| Rhodococcus spp.          | Intracellular              | AgNO₃      | 5–50      | Spherical      | [54]      |
| Vibrio alginolyticus      | Extracellular and intracellular | AgNO₃  | 50–100    | Spherical      | [55]      |

Also, Trichoderma viride was extracellularly utilised for the synthesis of AgNPs from aqueous AgNO₃. It was reported that T. viride has a biological component that is useful for extracellular biosynthesis of Ag and the micrographs revealed that the AgNPs produced have varying morphology with rod-like and spherical NPs; the NPs obtained are in the range of 5–40 nm [56]. In another study, Naqviet al., [57] produced AgNPs and reported the use of A. flavus incorporated with antibiotics so as to improve the biocidal efficacy against multidrug-resistant bacteria [57]. Also, Ahmad et al. [58] in their studies reported that when aqueous Ag⁺ ions are in contact with Fusarium oxysporum, they are reduced in solution through an
enzymatic process leading to highly stable Ag hydrosol formation. The formed NPs are stabilized in solution by protein-secreted fungus and are found in the range of 5 to 15 nm [58]. Mono-dispersed AgNPs are accomplished by extracellular synthesis from Aspergillus fumigatus and the synthesis was reported to be very fast [59]. Furthermore, Li et al. [60] synthesized spherical AgNPs from Aspergillus terreus, and an average diameter of 1-20 nm was reported [60]. Also, the extracellular production of AgNPs by the use of F. oxysporum and the antibacterial effect on textile fabrics was investigated [61]. Vigneshwaran et al. [62] reported that mono-disperse AgNPs was achievable using fungus Aspergillus flavus. In their study, transmission electron microscopy (TEM) revealed the NPs size to be in the range of 8.92 ± 1.61nm [62]. In addition, the extracellular production of AgNPs by utilizing Cladosporium cladosporioides was studied by Balaji et al. [63]; the size of the synthesised NPs as measured using TEM are found in the range of 10-100 nm [63].

Summarily, the cell walls of microorganism employed in the biological synthesis plays a vital role in the intracellular production of NPs. Interaction between the positive charged metal ions and negative charged cell wall electrostatically bio-reduces metal ions to NPs [64]. There are numerous fungi that are usable in the synthesis of AgNPs as presented in Table 2.

3.3 Synthesis of AgNPs using plant extracts

Bar et al. [65] studied the use of seed extract of Jatropha curcas in their attempt to produce AgNPs. The concentration of AgNO₃ used varied from 10⁻³ to 10⁻²M and the solutions become reddish after a continuous heating for 15 min at 80 °C temperature. The study revealed the size of AgNPs in the range 15-50 nm at different concentrations with spherical shape. It was concluded that by varying the concentration of AgNO₃, AgNPs of any size is achievable [65]. AgNPs synthesis using leaf extract of Acalypha indica was investigated by Krishnaraj et al. [66] in Erlenmeyer flask, 100 mL of AgNO₃ and 12 ml of the extract in aqueous form was combined and the synthesis process was performed under stable conditions in the dark at a temperature of 37°C. The synthesised AgNPs was reported to exhibit a spherical shape of 20-30 nm diameter [66].
Table 2. Green synthesis of AgNPs using Fungi

| Fungi              | Intracellular/Extracellular | Precursor | Size (nm) | Morphology            | Reference |
|--------------------|-----------------------------|-----------|-----------|-----------------------|-----------|
| Aspergillus niger  | Extracellular               | AgNO$_3$ | 1-20      | Spherical and Polydispersed | [67]      |
| Trichoderma harzianum | Extracellular             | AgNO$_3$ | 34.77     | Ellipsoid and Spherical | [68]      |
| Fusarium acuminatum | Extracellular             | AgNO$_3$ | 13        | Spherical             | [69]      |
| Penicillium fellutanum | Extracellular          | AgNO$_3$ | 5-25      | Spherical             | [70]      |
| Aspergillus clavatus | Extracellular and intracellular | AgNO$_3$ | 10-25     | Polydispersed and Spherical | [71]      |
| Fusarium oxysporum | Extracellular             | AgNO$_3$ | 10-25     | Not reported          | [72]      |
| Aspergillus flavus | Extracellular             | AgNO$_3$ | 8.92 ±1.61 | Monodispersed         | [73]      |
| Schizophyllum commune | Extracellular and intracellular | AgNO$_3$ | 51-93     | Spherical             | [74]      |

Raveendran and colleagues also synthesized AgNPs in a gently heated system using D-glucose as a reducing agent and starch as capping agent. The study discovered that starch and AgNPs have weak binding interactions which can be reversed at a high temperature to allow separation of the particles synthesized [75, 76]. Alternatively, AgNPs produced in a biosynthetic approach using Mentha piperita as a bioreducing agent for chloroauric acid (HAuCl$_4$) and silver nitrate. The plant extract (1.5 ml) was mixed with 30 ml of AgNO$_3$ per 1 mM/ml solution. The process was carried out at 28 °C for 24 h and the solution was then centrifuged at 6000 rpm for 10 min. The outcome of the investigation is a spherical AgNPs of about 90 nm [77].

Also, Rumex hymenosepalus was used by Rodríguez-Leónto et al. [78] as reducing agent to synthesize AgNPs using ethanol as stabilizer and AgNO$_3$ as precursor. The research analysis revealed the obtained diameters of the synthesized AgNPs to be 2-40 nm range [78].
Recently, Dhand et al. [79] synthesized AgNPs using tea or coffee extract. In their work, spherical nanoparticles ranging from 20 to 60 nm was formulated and extracts from black tea was reported to possess the ability to break AgNO$_3$ to spherical shaped AgNPs, nano prisms, nanorods and other morphologies in the 20 nm size range [79, 80]. More recently, the green and Arabica coffee beans were investigated [81]; the coffees were found to have the characteristics of reducing and stabilizing agents. Both study concluded that the green coffee beans produced spherical AgNPs of 10 to 30 nm range, while the ellipsoidal nanoparticles ranging from 20 to 30 nm were produced by Arabica coffee. Also, a biological approach of synthesizing Ag nanoparticles was verified in a study by Ali et al. [82]. In their method, silver nitrate of different concentrations from 20 to 0.62 mM was mixed with extract from plant with concentration ranging from 100 to 0.79 mg/ml. Their study confirmed the irregularity in the shapes of Ag particles produced in the range of 5-20 nm and concluded that plant extract with higher concentration will yield larger silver particles [82].

Another researcher synthesized AgNPs by using leaf extract of Polyalthia longifolia as reducing agent alongside D-s orbital to improve the stability of nanoparticles [83]. Also, AgNPs produced by Maqdoom and associates [84] through the Papaya fruit extract were characterized by FTIR and Absorption spectroscopy. Rout and colleagues [85], also synthesized AgNPs from leaf extract of Ocimum sanctum. In their study, it was reported that a spherical-shaped AgNPs was revealed from XRD, UV-vis spectroscopy and SEM analysis. Awwad et al.[86] reported that 5 to 40 nm spherical AgNPs was achieved in their study using carob leaf extract and characterized by the use of UV-vis spectroscopy, XRD, SEM and FTIR. The SPR analysis for AgNPs is at 420 nm and XRD showed FCC geometry with crystalline shape [86].

Furthermore, Kasthuri et al. [87] synthesized AgNPs from phyllantin as reducing and capping agent. The TEM investigation showed that the AgNPs have an average diameter of 21-39 nm [87]. In 2012, Awwad and Salem discovered mono-dispersed spherical AgNPs as produced by utilizing Mulberry leaves extract to have adiameter of about 20 nm. It is concluded that the SEM history revealed the effective antibacterial activity of silver nanoparticles towards Shigella sp and Staphylococcus aureus [88].

Moreover, Khalil et al. [89] produced AgNPs by the reducing solution of AgNO$_3$ through olive leaf extract. The characterization was done by employing XRD, UV-vis spectroscopy, SEM and TGA. The analysis confirmed that the NPs are almost spherical with size of 20-25 nm in range and exhibits effective antibacterial activity against drug-resistant bacteria isolates [89].
Table 3. Green synthesis of AgNPs using Plant Extracts

| Plant Extracts     | Reducing/Capping Agent | Precursor | Size (nm) | Morphology                  | Reference |
|--------------------|------------------------|-----------|-----------|------------------------------|-----------|
| *Catharanthus roseus* | Root extract           | AgNO$_3$  | 35-55     | Spherical, FCC and crystalline | [90]      |
| *Trilobata*        | Leaf extract           | AgNO$_3$  | 70        | Spherical and FCC            | [91]      |
| *Aloe vera*        | Leaf extract           | AgNO$_3$  | 70        | Spherical, cubical and triangular | [92]      |
| *Lens culinarl*    | Seed exudate           | AgNO$_3$  | 13        | Crystalline and spherical    | [93]      |
| Banana             | Peel                   | AgNO$_3$  | 23.7      | Crystalline and spherical    | [94]      |
| *Macrotyloma uniflorum* | Seed extract         | AgNO$_3$  | 12        | FCC and nearly spherical     | [95]      |
| *Achillea bieberstennii* | Flower extract     | AgNO$_3$  | 12 ± 2    | Spherical and pentagonal     | [96]      |
| *Terminalia arjuna* | Bark extract           | AgNO$_3$  | 2-100     | Spherical                    | [97]      |
| *Ziziphora tenuior* | Leaves extract         | ----      | 8-40      | Spherical                    | [98]      |
| *Trachy spermumammi* | Seed extract           | AgNO$_3$  | 87-99.8   | ----                         | [99]      |
| *Solanum lycopersicum* | Fruit                | ----      | 10        | Spherical                    | [100]     |
| Honey              | honey solution         | ----      | 4         | Crystalline and spherical    | [101]     |
| *Catharanthus roseus* | Leaf extract           | AgNO$_3$  | 20        | Spherical                    | [102]     |
4. **Applications of silver nanoparticles**

As a result of the unique properties of silver nanoparticles, they have become vigorously investigated and used extensively in various fields for different application as shown in Figure 4.

![Figure 4. Schematic diagram representing various applications of AgNPs](image)

**Figure 4.** Schematic diagram representing various applications of AgNPs

4.1 **Optoelectronic Application**

Xie *et al.* [103] worked on substrates of homogeneous silver-coated nanoparticles for enhancement of fluorescence detection. In their study, a monolayer of fluorescein isothiocyanate (FITC)-conjugated Human Serum Albumin (FITC-HSA) was used to investigate the degree of the fluorescence enhancement and it was tested by the help of laser scanning microscopy at excitation wavelength of 488 nm. The factor for the enhancement was obtained from the spectrofluorometer spectra and it was reported that Au Core-Ag shell nanostructures on the surface of the glass are good substrates with outstanding macroscopic homogeneity when it comes to fluorescence enhancement [103]. Also, Tagad and co-workers investigated the green method of synthesising silver nanoparticles for the fabrication of optical fibre based on hydrogen peroxide sensor ($\text{H}_2\text{O}_2$). The characterization of AgNPs was done with UV-vis spectroscopy and atomic force microscopy (AFM). The size of AgNPs was found to vary from 18-51 nm based on LBG and AgNO$_3$ concentration. It was concluded that the fabrication of a sensor based on optical fiber for detection of $\text{H}_2\text{O}_2$ was successful through the use of stabilized AgNPs and that the fabricated sensor is a simple, portable and cost effective sensor which is usable in various industrial applications [104].
In another study, biomediated silver nanoparticles were applied in highly selective copper (II) ion sensor [105]. The consequence of temperature and pH on silver nanoparticles formation was verified and checked by surface plasmon spectra with the help of UV-vis spectrophotometer. The sample characterization was done by TEM and XRD techniques. It was reported from the investigation that the produced AgNPs having no surface modification were successfully utilized in detection of even smallest possible amount of heavy metal copper (II) ion and with efficient specific metal ion detection [105].

4.2 Photocatalytic Application

The effective use of silver nanoparticles in catalytic media depends on the magnitude of the surface energy as well as the surface area. Several researches have established that smaller silver particles are more active catalysts compared with stable colloidal particles. The reduction rate in organic dyes catalysed by growing AgNPs compared to stable and bulk AgNPs is faster [106]. In a study, the results of the photocatalytic investigation of ZnO:Ag composite revealed that the AgNPs and their composites exhibit high catalytic performance in degrading and removing dye [107]. Yao et al. [107] in another study formed a visible light photocatalyst Ag₃PO₄/TiO₂ composite by depositing AgNPs onto TiO₂ surface. It was reported that the Ag₃PO₄/TiO₂ hetero-structured photocatalyst have an enhanced activity and is more stable than unsupported Ag₃PO₄. The enhanced activity was ascribed to the effective separation of electron hole and the larger surface area of Ag₃PO₄/TiO₂ composite and also the stability is due to the chemical adsorption of O⁻ anions and Ag⁺ cations in TiO₂ and Ag₃PO₄ respectively [108].

Bi and colleagues reported AgX/Ag₃PO₄ (X=Cl, Br, I) heterocrystals, prepared by in-situ ion-exchange method to have some advantages over the single Ag₃PO₄ and was reported to be more hopeful and captivating visible-light-determined photocatalyst than pure Ag₃PO₄ [109]. As reported by Roy et al. [110], the photocatalytic reduction of methylene blue dye by biogenic silver nanoparticles produced from yeast (Saccharomyces cerevisiae) extract showed that the produced silver nanoparticles were almost spherical in shape with diameter of 10 nm on the average. Also, the photocatalytic study revealed that the biogenic AgNPs exhibit the potential to reduce methylene blue in the presence of solar irradiation and are considered applicable in environmental remediation and textile industry [110].

In addition, Hosseini et al. [111] studied the effects of Ag doping on optical, photocatalytic, and structural properties of ZnO nanoparticles. The photocatalytic properties of the samples were examined by decomposing methyl violet in solution and exposed to UV light. It was
concluded that the XPS analysis showed that the photocatalytic activity of zinc oxide nanoparticles was enhanced by doping ZnO with Ag and also, decolourisation extent of methyl violet is based on the quantity of silver [111]. Recently, the photocatalytic and antibacterial degradation efficacy of nanosilver synthesized from leaf extracts of *Cordia dichotoma* studied by Kumar *et al.* [112], showed that a solution containing methylene blue (MB) was exposed for 6 h and the UV-vis spectra for photocatalytic degradation of MB have a significant reduction in the peak intensity and makes them capable of degrading methylene blue dye and congo red. It was concluded that AgNPs formed from leaf extract of *Cordia dichotoma* have the ability to degrade dye under sunlight [112].

More recently, Guiwei *et al.* [113] developed an easy and green hydrothermal method for the production of Ag₃PO₄ with different morphologies by the use of Ag₃PO₄ as a sacrificial precursor. The analyses of the prepared catalyst were done and the photo-catalytic oxygen production tests showed that a rough-spherical Ag₃PO₄ particles embedded with small particles has the best performance of all the photo-catalytic samples analysed [113]. Moreover, Lateef *et al.* [114] worked on phytosynthesis of silver nanoparticles (AgNPs) utilizing *Synsepalum dulcificum* (miracle fruit plant) for thrombolytic, catalytic, antimicrobial, and anticoagulant applications, the catalytic analysis showed that the malachite green was degraded by approximately 80% in 24 h by the use of silver nanoparticles [114].

5. Conclusion

Naturally occurring sources are capable of converting silver ions (AgNO₃) into AgNPs. It is evident from this review that the various compounds which are naturally embedded in plant extracts can be used as reducing as well as stabilizing agents during the synthesis of silver nanoparticles. Green synthesised AgNPs are stable because they possess natural capping agents that do not allow the particles to agglomerate. Green approach of producing AgNPs involving the use of plant extracts have numerous importance such as producing stable products in less time, reduced wastage, serene working environment, ecological friendly and low cost. It is therefore concluded that the possession of these unique characteristics make silver nanoparticles an important factor in advancing nanotechnology processes.

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