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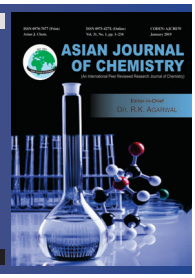

REVIEW

An Assortment of Synthesis Methods of Silver Nanoparticles: A Review

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Silver nanoparticles (AgNPs) have received much attention in the recent decades due to their peculiar physical, chemical and biological properties. These properties made AgNPs as potential material in several fields. Silver nanoparticles have been exploited to the great extent, since it is being used as "colloidal silver" from the last century. This paper involves significantly reviewing the AgNPs from the perception of research trends such as number of publications in year wise, article types, publication title, country wise publication, patented filed and also different synthesis methods. Normally, nanoparticles are synthesized by top-to-bottom method and bottom-to-top method, which include physical, chemical, and biological/green methods. These methods are having numerous advantages and disadvantages. In this review, perspectives of research trends and various synthesis methods of AgNPs have been demonstrated with recent publication for current research focus. These AgNPs could be used in various fields such as pharmaceuticals, cosmetics, foods and medical applications.

Keywords: Silver nanoparticles, Synthetic methods, Applications.

INTRODUCTION

In last few decades, synthesis of metal nanoparticles such as silver, gold, copper, platinum and iron has been spotlighted with much interest among the material scientists due to their peculiar properties such as tunable optical property, electrical property, good chemical reactivity, thermal stability, large surface areas to volume ratio, magnetic property, high catalytic activity and easy handling [1,2]. They have been used in diverse fields such as cosmetics, medical diagnosis, therapy, energy, electronic devices, catalysis, sensors and waste treatment process [3-6]. Among the metal nanoparticles, silver nanoparticles (AgNPs) have much interest due to their exclusive physical, chemical and biological properties compared to bulk material. It has been used in inks [7], microelectronics [8], catalyst [9], sunscreen lotions [10], sensor [11], food [12], textiles [13], agriculture [14], diagnosis [15], antimicrobial agent [16], *etc*. For example, Pataila *et al*. [9] have used AgNPs as catalyst for oxidation of metronidazole which is a pharmaceutical contaminant in the environment. Mohamed *et al*. [10] have produced AgNPs by *in situ* method with the cotton fabric surface using a simple green one-pot UV-reduction. The UV-irradiation supports reducing of Ag^+ ions and the cotton fabrics act as seed medium for AgNPs formation by heterogeneous nucleation. The treated cotton fabrics show high protecting functions against UV-transmission and *Escherichia coli* growth [10]. The AgNPs have also applied on cotton fabric by Zhang *et al*. [17]. In medicine, AgNPs are used as antibacterial, antiviral, antimalarial, anti-cancer and antifungal agents. Silver nanoparticles are very smaller than the microorganisms like *Bacillus cereus*, *Citrobacter koseri*, *Klebsiella pneumonia*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella typhii*, *Escherichia coli* and fungus, *Candida albicans*. Therefore, AgNPs could diffuse easily into cells and generate reactive oxygen species (ROS), which will

rupture and subsequently kill the cells [18]. The toxicity of AgNPs is exactly depending on the size, concentration, pH of the medium and exposure time to pathogens. Gu *et al*. [7] had compared the thermal decomposition of silver organic salts and chemical reduction of silver salts. They produce to formulate a particle-free silver ink. The resistivity of printed silver patterns made by chemical reduction was lower than the silver patterns made by thermal decomposition because of less porosity. It is concluded that a polymer additive may provide the silver film more uniform and easier to be sintered [7]. Lorestani *et al*. [11] had produced a novel sensing composite of AgNPs-reduced graphene oxide-carbon nanotube by a simple one-step hydrothermal method without any reducing agents. The synthesized composite showed an excellent electrocatalytic activity for the reduction of H_2O_2 with a fast amperometric response time less than 3 s. Singh *et al*. [19] have developed photo-induced, eco-friendly, low cost method for biosynthesis of the stable silver nanoparticles using aqueous extract of *Dunaliella salina*, which act as reducing as well as stabilizing agent. The synthesized AgNPs showed toxicity towards cancer cell line and there was no impact on normal cells at the same time [19].

In general, shape and size of AgNPs significantly affect its property. Hence, controlled synthesis of AgNPs with desired shape and size has potential interest. In this regard, top-to-bottom and bottom-to-top approaches are available. Laser ablation process, evaporation-condensation, ball milling, arc discharge method are some examples of top-to-bottom or physical method. Examples of bottom-to-top approach are chemical and biological reduction methods. In chemical methods, various organic and inorganic reducing agents are used for the reduction of Ag(I) ions in various medium such as aqueous or non-aqueous. Furthermore, capping or stabilizing agents are used to prevent the agglomeration of AgNPs. However, it is necessary to present all synthetic methods for AgNPs with their merits and demerits. With this motivation, we have attempted to explore possible synthetic routes for AgNPs in this review article.

In this regard, we have reviewed in literature for synthesis of silver nanoparticles (AgNPs). Synthesis methods are classified under three categories, *viz*. physical, chemical and biological method. In earlier, this review also explains the perspectives of research trends in worldwide on AgNPs.

Research trends in worldwide on silver nanoparticles : To know research trend on AgNPs in worldwide, the Scopus database (www.scopus.com) have used. Pacioni *et al*. [20] have also used Scopus database to collect information about number of publications from 1992-2014. We have collected information from 1994 to 11 January, 2019 by using the keyword "silver nanoparticles". Total 49120 articles of AgNPs have been published, in which 5634 articles are under open access (11 %) and 43486 articles are under closed access (89 %) journals. The number of papers published on year-wise is given as Fig. 1. It reveals that studies on AgNPs related works become famous in the past one decade, especially enhanced from 2006 onwards. Fig.1 is also a clear proof that studies on AgNPs are interesting and being repetitively pursued even today. In the initial stage, synthesis and characterization of AgNPs using chemical methods were focused. Physical and biological methods were further developed due to their safe and eco-friendly nature. Nowadays,

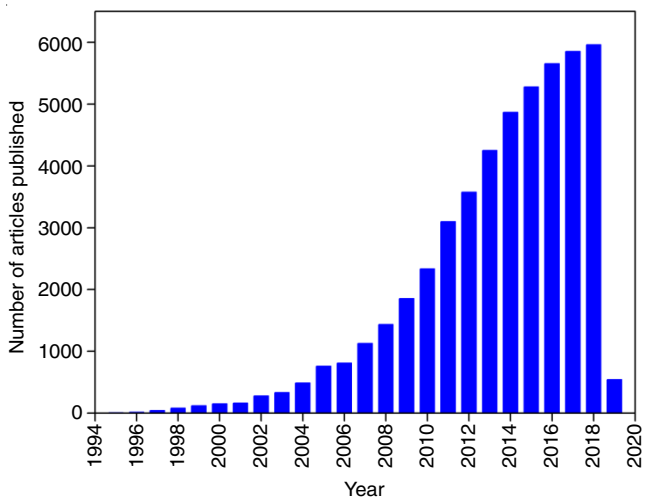

Fig. 1. Number of articles published in the period of 1994-2019 as per the Scopus database with the term 'silver nanoparticles' as keyword

many researchers are working on biological methods for synthesis of AgNPs and focusing their applications for several purposes.

The publication type on AgNPs includes articles (41047), Review s(1448), Conference papers (5145), Book Chapters (524), Articles in Press (406), Conference Reviews (254), Erratums (90), letters (56), notes (49), short surveys (49), books (26), editorials (24), business Articles (1) and retracted (1). Fig. 2 revealed that the articles related on AgNPs published in the different subject fields such as Materials Science (23685), Chemistry (20123), Physics and Astronomy (15912), Engineering (14044), Chemical Engineering (11172), Biochemistry, Genetics and Molecular Biology (6976), Environmental Science (3879), and so on. Materials chemistry has highly involved in the research areas of silver nanoparticles (AgNPs). Huge number of practical applications by using AgNPs in consumer products is being developed along with study of synthesis and properties.

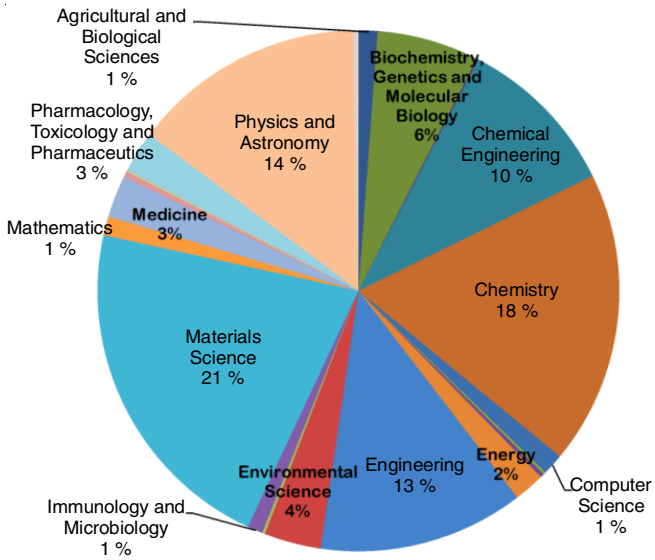

Fig. 2. Articles published in the different subject fields

Fig. 3 revealed that the number of articles published in the different countries, in which China (12299), India (6878) and United States (6856) have published articles on AgNPs with

appreciable quantity. Inserted figure in Fig. 3 shows that number of articles published in the different languages, in which English covers almost 98 % and others are very low.

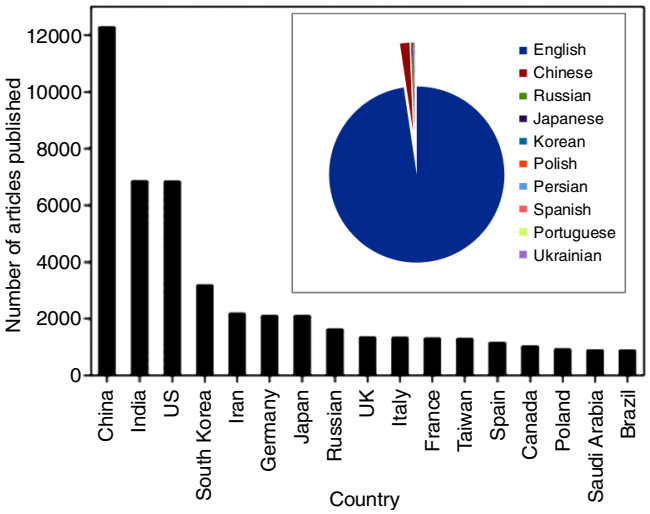

Fig. 3. Articles published in the different countries on AgNPs. Insert figure: Articles published in the different languages on AgNPs

Fig. 4 gives an idea about number of patent as of now in silver nanoparticles. There are totally 72,284 patented have been filed on AgNPs in worldwide as per Scopus database, in which US Patent & Trademark Office (44548), Japan Patent Office (15805), World Intellectual Property Organization (7039), European Patent Office (4575) and UK Intellectual Property Office (317) had been reported for filed. Fig. 5 displays the number of patent filed year-wise in the world on AgNPs. Based on the above trends on AgNPs, it is the most important to know about the synthesis and applications of AgNPs.

Methods of synthesis of silver nanoparticles (AgNPs)

(a) **Physical method:** Silver nanoparticles (AgNPs) are synthesized by using physical method including laser ablation, ball milling, evaporation/condensation, sputtering, lithography, arc discharge, electrodeposition, pulse wire discharge and

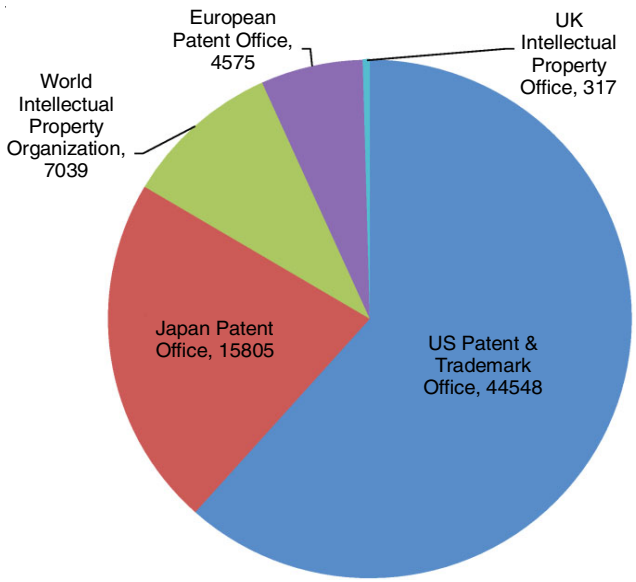

Fig. 4. Patent filed in different office in worldwide on AgNPs

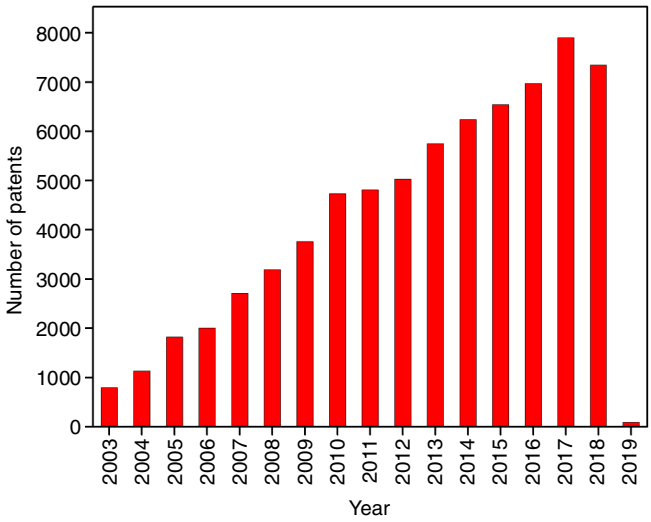

Fig. 5. Patents filed globally on AgNPs year wise

sonochemical method. The description for each method is as follows:

Laser ablation: In this method, silver target is ablated by pulsed laser beam in liquid medium. For instance, Sportelli *et al*. [21] have synthesized AgNPs by using laser ablation in the presence of isopropanol without any additional capping agents. The synthesized AgNPs were more stable over several months due to coating of isopropanol molecules with the pulsed, high-energy laser beam. This coating prevents any chemical reaction on colloidal AgNPs and thus achieved larger stability than naked metallic nanoparticles. Boutinguiza *et al*. [22] have deposited AgNPs on titanium substrates by using laser ablation in open air. The AgNPs were obtained by ablating silver foil using two different lasers. One was an inert gas jet to prevent oxidation and another one was to direct the ablated material to the substrate. Verma *et al*. [23] have synthesized AgNPs in aqueous solutions of trisodium citrate by using liquid phase pulsed laser ablation followed by their photo-mediated shape transformation into triangular nanoplates by visible light irradiation. This method produced very stable AgNPs, which were highly efficient seeds for nanoplates. Alva *et al*. [24] have produced AgNPs in ethanol by laser ablation method with pulsed photoacoustic technique, which is used to determine the production rate per laser pulse and concentration of synthesized AgNPs. Amendola *et al*. [25] have been produced AgNPs without using any reducing and stabilizing/capping agents in presence of pure acetonitrile and *N*,*N*-dimethylformamide by laser ablation of the bulk metal. They had synthesized AgNPs with a carbon shell or included in a carbon matrix.

Evaporation-condensation method: In this method, bulk silver is heated at high temperature which produces silver vapours. The produced silver vapours are condensed as nanoparticles by flowing in inert gas. Raffi *et al*. [26] have synthesized AgNPs by using an inert gas condensation method, in which helium was flowing in the process chamber. Nucleation, growth mechanism and the kinetics of nanoparticles formation in vapour phase were also discussed. Harra *et al*. [27] had been generated AgNPs with an evaporation-condensation technique followed by size selection and sintering with a differential mobility analyzer and a tube furnace.

Sputtering method: Silver target was bombarded by inert gas ions and thus silver particles were ejected. Chandra *et al.* [28] have used high pressure sputtering method to fabricate silver nanoparticles (3-60 nm).

In ball milling method, size reduction is executed by dropping a ball from near the top of the container. This container is cylindrically hollow, which rotates about its horizontal axis. The inner surface of the cylindrical container might be lined up with abrasion-resistant material (*i.e*. rubber). The diameter of the ball mill is approximately equal, which is filled partially in the cylindrical container to grind the bulk silver. The factors such as rotational speed, milling time and size of balls are affecting the quality of the dispersion. In certain conditions, the particles could be prepared as small as 100 nm. Silver nanoparticles were also prepared by mechanochemical reduction of Ag_2O along with graphite. Silver nanoparticles with average crystallite size of 28 nm was achieved after 22 h of milling process [29]. Yadav *et al*. [30] reviewed the details of the ball milling methods.

Electric discharge method: In this method, an electrode and a workpiece are kept close to each other, in which pulse voltage is applied between them. Dielectric breakdown takes place at a certain distance between them, which causes high heating of the workpiece to melt away small amount. The excess workpiece material is removed with the help of steady flow of the dielectric fluid and also cooling in the machining. If current flows through a workpiece, even a hard metal can be machined. Electric arc discharge method was also extensively utilized for synthesis of AgNPs [31].

Sonochemical method: Sonochemical effects are the phenomenon of acoustic cavitation in liquids. Cavitation is the formation, growth and collapsing of bubbles in a liquid. Cavitational collapse gives up an intense heating. Vinoth *et al*. [32] have reported sonochemical method for AgNPs containing reduced graphene oxide.

Lithography method: In this method, nanoparticle arrays were prepared on glass slips. The resolution of the lithography is approximately 20 nm with an accelerating voltage of 50 kV. 10 nm of gold was deposited on glass slips prior to exposure. After exposure, the gold film was removed by etching and the patterns were then developed. Silver was deposited thermally on both the pattern and resist. Simultaneously it is removed, leaving patterned nanoparticles behind. Zhang *et al*. [33] have reported nanospheres lithography technique to fabricate silver nanoparticles.

Electrochemical method: In this method, a reduction reaction is between a simple two-electrode as cathode and anode with required volume of the electrolyte in an electrochemical cell in the presence of stabilizing agent. Formation of silver particles and silver deposition on cathode occurs during the reaction. For example, an electrochemical method was reported for the synthesis of AgNPs by Sánchez *et al*. [34].

Thermal method: This method is a rapid way to produce AgNPs in powder form with high yield. However, thermal method could exhibit several constraints, such as large space requirement, high energy consumption and also raising the surrounding temperature, taking a long time to achieve thermal stability. Adner *et al*. [35] have synthesized hexagonal AgNPs by thermal decomposition of silver(I) 2-phenyl-3,6,9-trioxadecanoate in *n*-hexadecylamine at 100-165 ºC. Mashkani and Ramezani [36] have produced cubic AgNPs by thermal decomposition of [Ag(Hsal)] precursor at 400 ºC for 3 h in an argon atmosphere.

Photoreduction method: The photoreduction of $AgNO_3$ in the presence of sodium citrate was directly carried out at room temperature with different light sources such as UV, white, blue, cyan, green and orange coloured LED bulbs. The light-modification process leads to changes in optical properties, which could be related to the size and shape of AgNPs. The advantages of photo-assisted synthesis are clean process, high spatial resolution, convenience to use, controllable *in situ* generation of reducing agents, photo-irradiation triggers the formation of AgNPs, great versatility, various mediums such as emulsion, surfactant micelles, polymer films, glasses, cells, *etc*. may be used to synthesis. The main disadvantage is requirement of special arrangement for doing this photo assisted synthesis. Goncalves *et al*. [37] had synthesized AgNPs as coating along with other materials by photo assisted approach. This coated material shows an excellent antibacterial activity due to AgNPs.

Physical methods have some advantages such as less time consuming for preparation, and no hazardous chemicals. The comparison of required device, reaction condition of physical methods is given as Table-1. It is clear that physical methods required special devices, high pressure, temperature, long time for thermal stability, light energy which requiring high energy for production of AgNPs [38,39]. Therefore, alternative methods are required for cost effective synthesis with large scale production of AgNPs. In this regard, chemical method is pronounced.

Chemical methods

Chemical method is based on reduction of silver ions in aqueous or non-aqueous solutions using reducing agents. Depending on the conditions, silver ions may favour either the process of nucleation or aggregation to form nanoparticles. Silver nitrate, silver acetate, silver citrate and silver chlorate are usually used as silver source. For example, Zaheer *et al*. [40] have prepared AgNPs by reduction of $AgNO_3$ solution with aniline in presence of CTAB. They suggested experimentally that shape, size and the size distribution of AgNPs were not changed appreciably with concentration of aniline. Among various reducing agents, the most frequently used reducing agents are sodium borohydride, citrate, ascorbate and compounds containing hydroxyl or carbonyl groups like alcohol, aldehydes, carbohydrates and their derivatives [41]. To prevent agglomeration, it is necessary to use protective or stabilizing or capping agents to stabilize dispersed AgNPs during preparation of nanoparticles. Hence, polymeric compounds like polyvinyl pyrrolidone (PVP), polyethylene glycol (PEG), poly(methyl methacrylate) (PMMA), poly(N-isopropylacrylamide) (PNIPA) and poly(methacrylic acid) (PMAA) were used as a capping or stabilizing agents for synthesis of AgNPs. Khatoon *et al*. [42] synthesized colloidal AgNPs by using $NaBH_4$ as reducing agent and trisodium citrate as a stabilizing agent. Chahar *et al*. [43] have prepared AgNPs by using different stabilizing agents like gelatin, polyvinyl alcohol (PVA) and polyvinyl pyrrolidone (PVP). Ye *et al*. [44] had synthesized

TABLE-1
COMPARISON OF PHYSICAL METHODS FOR SYNTHESIS OF Ag NPs

Method	Device	Reaction condition	Form of Ag	Ref.
Laser ablation	Q-Switched Nd:YAG Laser	Wavelength: 1064 nm, pulse frequency: 20 Hz, a maximum pulse energy: 120 mJ and a nominal pulse duration: 4 ns	Nanocolloids	[21]
	(i)Pulsed Nd:YAG laser	(i) 1064 nm, 10 Hz, 3.2 ms of pulse width, and pulse energy of 12 J.	Deposited on Ti substrates	[22]
	(ii) Diode-pumped Nd:YVO_4 laser	(ii) 10 ns pulses at 532 nm, 20 kHz, and 0.30 mJ of pulse energy.		
	Second harmonic Nd:YAG laser	Wavelength: 532 nm; pulse duration: 9 ns; and pulse repetition rate: 10 Hz;	Dispersion	[23]
	Pulsed Nd:YAG laser	Wavelength: 1064 nm pulse duration: 7 ns	Colloidal	[24]
Evaporation-condensation	Process chamber	Inert gas condensation method using flowing helium	Solid or liquid	[26]
	Ceramic work tube of a tube furnace (Carbolite TZF 15/50/610)	At temperatures between 1,300 and 1,400 °C, inert gas streams of nitrogen (N_2)	Collected on a glass substrate	[27]
Sputtering	High pressure magnetron sputtering	High pressure of inert gas and at low substrate temperatures (77–300 K).	Both in the thin film and powder forms	[28]
Ball-milling	High planetary ball mill	22 h milling	Powders	[29]
Electrochemical	Using metallic anode	Aprotic solvent	Colloidal	[34]
Arc discharge	Pulse voltage	Close distance between electrodes	Moulded	[31]
Lithography	Nanosphere lithography	$H_2O/NH_4OH/30\%$ H_2O_2 (5:1:1) with sonication for 1 h	On an indium tin oxide (ITO) electrode surface	[33]
Sonochemical	(Standing wave sonication system	Frequency: 38 kHz; power: 50 W	Settled on reduced Graphene oxide nanosheets	[32]
Thermal	Muffle furnace	100-165 °C	Monodispersed	[35]
	Furnace	At 400 °C for 3 h in an Ar gas	Solid-state	[36]
Photochemical	Solar Light Simulator with a Xe arc lamp	Maximum irradiance: 750 W m^{-2}	Formed on ormosil substrates	[37]

AgNPs by using gelatin as a reducing agent and stabilizing agent. The obtained AgNPs were mixed with chitosan (CS), cross linked tannic acid and then freeze-dried to obtain a new composite gelatin/CS/Ag, which has a dense pore structure with a pore size of about 100-250 µm. Gelatin/CS/Ag composite could have antibacterial and wound healing properties and found to be good biocompatible material [44]. Nersisyan *et al*. [45] had prepared nanosized uniform silver powders and colloidal dispersions from $AgNO_3$ by a chemical reduction method in the presence of sodium dodecyl sulfate as a surfactant. Wang *et al*. [46] have discussed to produce AgNPs from silver nitrate and glucose as a reducing agent in presence of polyvinyl pyrrolidone (PVP) solution, whereas NaOH was used to enhance the reaction rate. Ocwieja [47] has synthesized AgNPs by using sodium borohydride as a reducing agent and cysteine as a capping agent. This was used for construction of antireflection materials and in the biology as mimics of such proteins as human serum albumin. The comparison of silver nanostructures synthesis by chemical method is given in Table-2.

Table-2 inferred that the longer reaction time is required to achieve AgNPs. In order to fasten the reaction, microwave radiation energy can be used. For example, Jayaprakash *et al*. [49] reported a synthesis of AgNPs by simple microwave irradiation method using Triton X 100 as a reducing agent and also acted as a capping agent. One-step microwave assisted AgNPs synthesis was also achieved with threonine and polyvinylpyrrolidone as a reducing and capping agent respectivley [50]. The main advantage of chemical reduction method is that a large quantity of nanoparticles can be synthesized within a short period of time. However, the drawbacks are usage of toxic chemicals, costlier chemicals and production of toxic by-products. Hence, there is a need to develop eco-friendly

TABLE-2
COMPARISON OF Ag NANOSTRUCTURES SYNTHESIS BY CHEMICAL METHOD

Shape of Ag NPs	Reducing agent	Capping agent	Reaction time (h)	Reaction temp. (°C)	Solvent	Ref.
Spherical	$NaBH_4$	Trisodium citrate	1	Room temp.	Water	[42]
Rod	Starch	Cetyl trimethyl ammonium bromide	2	25	Water	[48]
Spherical	Starch	Cetyl trimethyl ammonium bromide	12	27	Water	[48]
Hexagonal	Starch	Cetyl trimethyl ammonium bromide	12	30	Water	[48]
Flower	Starch	Cetyl trimethyl ammonium bromide	20	27	Water	[48]
Spherical	$NaBH_4$	Poly-vinylpyrollidine	24	70	Water	[43]
Spherical	$NaBH_4$	Gelatin	3	90	Water	[43]
Spherical	$NaBH_4$	Polyvinyl alcohol	24	0	Water	[43]
Spherical	Aniline	Cetyl trimethyl ammonium bromide	Slow	Room temp.	Water	[40]
Spherical	Gelatin	Gelatin	24	-80	Water	[44]
Spherical	$NaBH_4$	Cysteine	1	Room temp.	Water	[47]

and cost effective route for synthesis of AgNPs. In this regard, green synthesis of AgNPs has gaining significant importance.

Biological method

Silver nanoparticles could be produced by using biological agents, which is very helpful for reducing and stabilizing of AgNPs with peculiar properties. Biological agents are having antioxidant or reducing properties and thus easily reduce silver ions into metallic silver. These biological agents are free from toxic chemicals as well as offering natural capping agents for the stabilization of AgNPs. Various parts of plant like seed, stem, leaf and flower are extensively used for production of AgNPs. For example, Wang *et al*. [51] have synthesized silver nanoflowers by using leaf extracts. Jayaprakash *et al*. [6] have produced AgNPs by using the extract of *Piper nigrum* (black pepper) as a reducing as well as capping agent in aqueous medium without addition of any other chemicals. Rolim *et al*. [52] have biogenically synthesized AgNPs using a commercial green tea extract (*Camellia sinensis*), which acts as a reducing and stabilizing agents for AgNPs due to presence of polyphenols in green tea. Again Jayaprakash *et al*. [53] had produced AgNPs using *Tamarindus indica* fruit extract, which acts as a reducing and capping agent. Carbone *et al*. [54] have prepared AgNPs using white grape pomace aqueous extract (WGPE) as both reducing and capping agent. Synthesis of silver nanostructures by using various parts of plant extract as reducing agents is listed in Table-3.

To accelerate the reaction rate, microwave or solar energy was also used in biological method. For example, Vijaya *et al*. [55] have synthesized AgNPs for the first time by using dried *Zingiber officinale* (ginger) root extract as a reducing agent as well as capping agent in the presence of microwave irradiation. Bhardwaj *et al*. [56] have reported a novel approach enabling direct sunlight and oyster mushroom (*Pleurotus citrinopileatus*) extract for synthesis of AgNPs. It is also observed that a smaller wavelength of sunlight produces smaller sized AgNPs with a narrow size distribution [56].

Microorganisms like bacteria, fungi, yeasts and actinomycetes have also used for synthesis of silver nanostructures. For example, Khan *et al*. [57] have recently produced AgNPs by using bacterial mediated synthesis. This kind of bacterial mediated synthesis could be an alternative approach for chemical (toxic) and physical (high energy required) synthesis methods. It is also explained that these AgNPs may be used for the treatment strategies for drug resistant pathogens [57]. Yin *et al.* [58] have reported that biosynthesis of AgNPs by human gut microbiota. In this route, human gut microbiota is exposed to aqueous $AgNO_3$ solution, resulted in the intracellular reduction of silver(I) ions and led to the formation of approximately spherical AgNPs with dimensions of 34 ± 10 nm. Al-Dhabi *et al*. [59] have produced AgNPs by biosynthetically using the extracellular metabolites of marine derived actinomycetes. The reducing potential of *Streptomyces* sp. Al-Dhabi-89 cell surface extracts was involved for the green synthesis of AgNPs without any external capping substances or agents. They concluded that AgNPs produced from marine *Streptomyces* sp. Al-Dhabi-89 has shown potential activity against both standard and clinical drug resistant microbial pathogens [59]. Moustafa [60] have produced AgNPs by the extracellular synthesis using two filamentous fungi *Penciillium citreonigum* Dierck and *Scopulariopsos brumptii* Salvanet-Duval isolated from Lake Burullus. Synthesized AgNPs revealed an excellent antibacterial property on both gram positive and gram negative bacterial strains. Saravanan *et al*. [61] have reported that extracellular synthesis of AgNPs from *Phenerochaete chrysosporium* (MTCC-787). The biosynthesized AgNPs proved considerable antibacterial activity against *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Staphylococcus aureus* and *Staphylococcus epidermidis* at a high concentration. Ansari *et al*. [62] have discussed that a green, simple and effective approach for synthesizing antibacterial AgNPs using fungal exopolysaccharide as both a reducing and stabilizing agent. The combination of bacteriocin with AgNPs established to be more effective due to broad antibacterial potential with possibly lower concentration [62]. Gudikandula *et al*. [16] had reported on the production, characterization and antibacterial studies of AgNPs. Extracellular biosynthetic method was adopted for the synthesis of AgNPs by culture filtrate extracts made from two white rot fungi as a reducing agents.

Advantages of the biological methods are low cost, eco-friendly, easily scaled up for large scale synthesis and moreover no need of high temperature, pressure, energy and toxic chemicals. The main disadvantage of the method is that synthesis of microbe mediated silver nanoparticles (AgNPs) is not industrial feasibility due to their maintenance and highly aseptic conditions.

Conclusion

This paper has reviewed AgNPs from the perspectives of research trends and synthesis. Commonly, three methods are available for synthesizing AgNPs, such as physical, chemical and biological methods. Each method has been discussed with recent publications for current research focus. The physical method has few drawbacks, such as large space requirement,

TABLE-3
SYNTHESIS OF SILVER NANOSTRUCTURES BY USING VARIOUS PART OF PLANTS EXTRACT AS REDUCING AGENTS

Shape of Ag NPs	Source of reducing agent	Reaction time	Reaction temp. (°C)	Application	Ref.
Flower	Ho leaf	24 h	60	General	[51]
Sphere	*Piper nigrum* (black pepper)	1 h	RT	Antibacterial activity	[6]
Sphere	Dried *Zingiber officinale* (ginger) root extract	60 s	–	Antibacterial activity	[55]
Spherical	*Tamarindus indica* fruit extract	180 s	–	Antibacterial activity	[53]
Spherical	Green tea extract (*Camellia sinensis*)	10 min	RT	Cytotoxicity study and antibacterial activity	[52]
Dendritic	White grape pomace aqueous extract	40 s	–	Antifungal agent and biosensing applications	[54]
Spherical	Oyster mushroom (*Pleurotuscitrinopileatus*) extract	24 h	RT	Bactericidal efficacy	[56]

RT = Room temperature

high energy consumption and long time for thermal stability. The chemical method offers an easy way to produce AgNPs. But in this method, toxic chemicals are used. Sometimes by-products may be toxic in nature. Green synthesis of AgNPs is most appropriate method. This method is more popular due to eco-friendly, simplicity and cheap. All the above these methods can be adapted to synthesis of AgNPs for various uses such as pharmaceuticals, cosmetics, foods and medical applications.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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