Review Article

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Chemical and Biological Approaches for the Synthesis of Silver Nanoparticles; A mini Review

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Abstract

Since ancient time silver and silver based compound have been used as a powerful antimicrobial agent in medicine. Discovery of antibiotics pushes the silver away from medicine and pharmaceutical sciences. By emerging resistance strains and reducing the efficiency of antibiotics, silver became point of attentions again, but in a novel form of silver nanoparticles (AgNPs). AgNPs are the most effective and powerful novel antimicrobial with ancient roots. Chemical synthesis is one of the first techniques for synthesis of AgNPs. In this technique silver ions reduced to AgNPs by using chemical reducing agents such as sodium borohydride (NaBH4) and sodium citrate ($Na_3C_6H_5O_7$). Later investigations have shown that biological molecules from living organisms such as bacteria, fungi, algae, and plants can also be used as more safe and in some cases sheep reducing agent for biosynthesis of AgNPs.

Keywords: Algae, Bacteria, Bioreduction, Chemical reduction, Plants, Silver nanoparticles.

1. Introduction

Silver is one of the most known and applied element in ancient and novel pharmaceutical sciences. Silver ions have ancient applications as a potent antimicrobial agent for wounds, burns, and ulcers treatment. Application of silver compounds in ancient medicine and pharmaceutical sciences was due to empirical findings without any knowledge about microbial life and microbiology. Silver ion was commonly used for gonococcal ophthalmia neonatorum (GON) prevention. The solution of silver ion was used in about one hour after birth as ophthalmic drop. It is interesting that Roman ancient physicians accidently found that silver is effective for treatment of epilepsy. Beside all ancient medical and pharmaceutical applications of silver ions and silver compound, silver based compounds were also used as food preservative in ancient cultures (1).

Along with these applications of silver compounds, ancient medicine was used antibiotics against microbial infection without any knowledge about microbes and antibiotics. For instance, moulds and plants were used against infec-

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tions in ancient Greek and India. Also, in Greece and Serbia mouldy bread was used as a healer for wounds and infections. By discovery of penicillin in 1928 by Sir Alexander Fleming a new era was opened in antimicrobial agents. Over last century, a huge variety of antibiotics have been discovered and used to save billions of lives. Discovery and development of antibiotics push the silver and silver compounds away from medicine and pharmaceutical sciences. On the other hand, silver ions and silver based compounds have side effects such as chemical conjunctivitis, pain and visual impairment which intensify the process of forgetting silver by medical scientists. But, power of antibiotic was not long lasting and over decades of applying antibiotics resistance bacterial strains emerged. This situation is getting worse and worse since World Health Organization (WHO) declared antimicrobial resistance as the theme for the World Health Day 2011, the day of WHO foundation on the 7th April. This problem appeared from the mechanism which antibiotics used against microbial cells. Antibiotics target exact physiological points in microbial cells such as particular point in cell wall and ribosome. A simple nonlethal mutation in these target points is sufficient to provide the gate for scape and distribution of a resistance strains (2). Silver based antimicrobials acts in a completely different way, silver ion is a potent oxidant which can oxidise and affect all physiological points in a microbial cell (3). So, there is no easy way to scape to.

In modern medical and pharmaceutical sciences silver appeared in a novel form of silver nanoparticles (AgNPs). AgNPs do not show side effects of silver ions and silver complexes. Since now, vast investigations have shown the antimicrobial potency of AgNPs (4, 5) and so there is increasing demand for AgNPs in science and technology. Know a days, the main approaches for the synthesis of AgNPs are chemical or biological reduction of silver ions (6-8). Usually silver nitrate is used as silver precursor and so a reducing agent along with a capping agent is just all we need for synthesis of AgNPs. In the following we have a short review on main chemical and biological approaches for the synthesis of AgNPs.

2. Chemical synthesis of silver nanoparticles

Sodium borohydride ($NaBH_4$) is one of the most applied reducing agent which has been used for chemical synthesis of AgNPs (9). In this reaction silver nitrate ($AgNO_3$) is used as silver precursor to provide silver ions. In the reduction reaction as shown in the equation 1, silver ions reduced to metallic silver and so AgNPs (10). As shown in Figure 1 the obtained AgNPs can be stabilized with adsorbed borohydride ions (BH_4^-). Adsorption of the anions on the surface of AgNPs can provide a negative surface charge and so can stabilize nanoparticles from agglomeration and sedimentation (Eq. 1).

$$AgNO_3 + NaBH_4 \rightarrow Ag^0 + \tfrac{1}{2} H_2 + \tfrac{1}{2} B_2H_6 + NaNO_3 \qquad \text{(Eq. 1)}$$

Sodium borohydride is severally corrosive and irritant and can be potentially hazardous in case of skin and eye contact, ingestion, or inhalation. So, scientists have tried to use other chemical reducing agents such as ethylene glycol, ascorbic acid ($C_6H_8O_6$) and sodium citrate ($Na_3C_6H_5O_7$) instead of sodium borohydride (6, 7, 11). Among all chemical reducing agents sodium citrate remains as the most popular for synthesis of AgNPs with accessible surface due to the weak interaction of citrate molecules with metal surfaces (12). Through the reduction of Ag^+ ions sodium citrate oxidized into dicarboxyacetone and then further decomposed to acetoacetate. Citrate

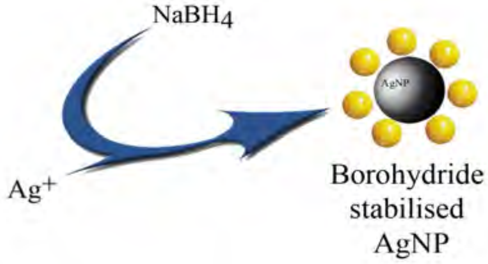

Figure 1. Borohydride ions (BH_4^-) from sodium borohydride ($NaBH_4$) can stabilise AgNPs.

ions interact with positively charged silver ions and make a relatively stable complex. Formation of this stable complex to some extend hinder reduction of Ag^+ ions and so leads to heterogeneous nucleation of AgNPs and formation of non-uniform and polydisperse nanoparticles. This event is usually considered as the major drawback of sodium citrate for chemically synthesis of AgNPs (12).

In addition to chemical reducing agents, organic compounds such as glucose, maltose and starch, have also been used for AgNPs synthesis (6, 7). Just like chemical reducing agents, organic compound can act as both reducing and capping agent. For instance, AgNPs which synthesised by using glucose are shown to be D-Gluconic acid coated (13). The fundamental reaction of AgNPs synthesis by using reducing sugars which is known as Tollens reaction can be simplified as equation (2) (14). Biologic polymers such as gelatine, Poly-L-lysine, and even DNA molecules have also been used as reducing and capping agent for synthesis of AgNPs. As illustrated in Figure 2, biopolymers have the capability to bend around prepared particles and make an efficient hydrophilic coating (15-17). This coating makes nanoparticles more stable from physicochemical and colloidal point of view (Eq. 2) (15-17).

$$Ag\,(NH_3)_2^{\;+} + RCHO \rightarrow Ag^0 + RCOOH \qquad \text{(Eq. 2)}$$

3. Biological synthesis of silver nanoparticles

Biosynthesis of nanoparticles is based on the application of biochemical species which produced by living organisms as reducing and capping agent. A vast variety of biologic compounds such as carbohydrates, proteins, phenols, polyphenols, alcohols and aromatic compounds can be involved in this process (4, 5, 8, 18-22). Nowadays, bacteria and fungi are among the main organisms that have been used for biosynthesis of AgNPs. Since now various bacterial and fungal genus such as *Morganella, Pseudomonas, Bacillus, Lactobacillus, Geobacillus, Escherichia, Vibrio, Salmonella, Klebsiella, Streptomyces, Rhodococcus, Cladosporium, Fusarium, Aspergillus, Candida* and *Penicillium* have been used for AgNPs biosynthesis (23-33). The major drawback of using bacterial and fungal strain is this fact that almost of the used strains are pathogen or opportunistic. So, an expanding enthusiasm for the improvement of the AgNPs biosynthesis by utilizing safe microbial cells (i.e. microalgae) has emerged (4, 34, 35). Algae do not require complex carbon and nitrogen sources. They utilize daylight as vitality source, carbon dioxide as carbon source and ammonium salts as nitrogen source. So these life forms are totally financial for biotechnological applications (36). The potential for reduction of Ag^+ ions to AgNPs have been found in many microalgal cells such as *Chlorella vulgaris, Spirulina platensis, Amphora* sp, *Oscillatoria willei, Nannochloropsis oculata*, and *Pithophora oedogonia* (4, 33, 34, 37-39). Synthesis can be done in two different approaches; (a) using microalgal cell extract as a natural source of reducing and capping agent or (b) applying the whole cell. For instance, de-oiled biomass of thermotolerant oleaginous microalgae *Acutodesmus dimorphus* have been used for extracellular biosynthesis of AgNPs (40). On the other hand, extract of *Caulerpa racemosa, Chaetomorpha linum*, and *Cystophora moniliformis* were reported to be effective for biosynthesis of AgNPs (41-43). Unfortunately, microalgae mediated biosynthesis required an elaborated process of culturing and maintaining cells and beyond that the rate of cell growth and biomass preparation is

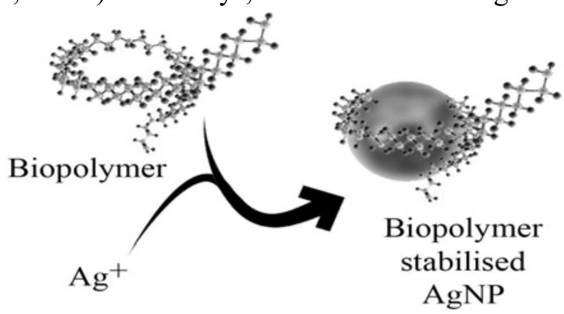

Figure 2. Biopolymers can wrap around AgNPs and stabilise them.

very slow (4, 36).

Plant mediated synthesis of AgNPs is another choice for biosynthesis of AgNPs. In this approach plant extract is used as a natural source of reducing and capping agents. Preparing of plant extract even in the large scale is very cheap and fast. Also, scientists try to use plants which are abundant and have not food value to reduce the cost of the raw materials. Plant mediated synthesis is also more effective than microbial synthesis since that plant extract is more potent in reducing power than microbial culture filtrates (44-47). A lot of literature has been reported to facilitate the production of AgNPs by plant mediated synthesis approach. AgNPs were successfully synthesised by using leaf extract of maple, eucalyptus, black tea, *Lippia citriodora, Matricaria chamomilla, Lantana camara, Zataria multiflora, Mediterranean cypress* (*Cupressus sempervirens*), and *Artemisia annua* (8, 19, 20, 48-52). Also other parts of plants such as have reported to be effective such as *Alcea rosea* flower extract, *Crataegus douglasii* fruit extract, orange peel extract, coffee extract, *Chrysanthemum morifolium* Ramat. extract, *Medicago sativa* and *Sterculia foetida* seed exudate, and *Cinnamon zeylanicum* bark extract (5, 53-56). Very little work has been performed to understand the exact mechanism behind the plant mediated synthesis and it remains to be elucidated. Various biomolecules including enzymes, proteins, sugars, vitamins, alkaloids, phenolic acids, terpenoids, and polyphenols are the main phytochemiclas that play an important role in the bioreduction of silver ions to AgNPs (4, 47, 57-61).

4. Conclusion

AgNPs emerged as a novel form of silver in modern medical and pharmaceutical sciences to fight against multidrug-resistant organisms. Increasing demand for AgNPs in various sciences and technologies resulted in development of techniques for synthesis of AgNPs. Chemical synthesis is one of the most first approaches in this regards and biosynthesis is a novel approach to eliminate disadvantages of chemical synthesis.

Conflict of Interest

None declared.

5. References

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