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Antimicrobial Efficacy of Green Silver Nanoparticles and Potential Implications for Human Health and the Environment

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Abstract: The beginnings of the applications of nanotechnology in the field of health sciences took place in early 2000s. There is a wide range of application of nanoparticles and its uses are emerging rapidly. Nanoparticle synthesis is usually carried out by various physical and chemical methods using various hazardous and toxic chemicals which may have adverse effect in the medical applications. Nevertheless, green synthesis approaches of producing silver nanoparticles are an alternative source of conventional method and is cost effective, environment friendly, easily scaled up for large scale synthesis and in this method there is no need to exploit high pressure, energy, temperature and toxic chemicals as in case of chemical and physical method. In this review, we report, some of the major applications of green synthesis of silver nanoparticles.

Keywords: Nanotechnology, nanoparticles, medical applications, environment friendly, green synthesis

1. INTRODUCTION

Nanotechnology refers broadly to a field of applied science and technology whose unifying theme is the control of matter on the atomic and molecular scale. Nanoparticles have properties which are based on the characteristics such as size and shape. The application of nanoscale materials and structures, usually ranging from 1 to 100 nm, is an emerging area of nanoscience and nanotechnology. Nanoparticles exhibit completely new or improved properties

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based on specific characteristics such as size, distribution and morphology, if compared with larger particles of the bulk material they are made of. Nanoparticles present a higher surface to volume ratio with decreasing size of nanoparticles. Specific surface area is germane for catalytic reactivity and other related properties such as antimicrobial activity in silver nanoparticles.

As specific surface area of nanoparticles is increased, their biological effectiveness can increase due to the increase in surface energy (Willems and Wildenberg, 2005). Metal nanoparticles are hugely studied due to their unique optical, electrical and catalytic properties. To utilize and optimize chemical or physical properties of nano-sized metal particles, a large spectrum of research have been focused to control the size and shape, which is crucial in tuning their physical, chemical and optical properties (Alivastos, 1996; Coe et al., 2002; Bruchez, 1998). Various techniques, including chemical and physical means have been developed to prepare metal nanoparticles, such as chemical reduction (Yu, 2007; Jiang et al., 2002; Pileni et al., 1993; Sobal et al., 1999), electrochemical reduction (Liu, 2004; Sandmann et al., 2000), photochemical reduction (Mallick et al., 2005; Deak et al., 2000), heat evaporation (Park et al., 2002; Sorensen et al., 2005) and so on. In most cases, the surface passivator reagents are needed to prevent nanoparticles from aggregation. Unfortunately many organic passivators such as thiophenol (Mehta et al., 1999), thiourea (Pattabi and Uchil, 2000), mercapto acetate, etc. are toxic enough to pollute the environment if large scale nanoparticles are produced.

Monodispersity of size and selectivity of shape are two key issues that are the focus of nanoparticle synthesis research. Nonetheless, monodispersity is very critical for device applications (Fendler and Meldrum, 1995), the fascinating properties exhibited by anisotropic nanoparticles (El-Sayed, 2001) makes shape-selective synthesis exciting. Catalytic properties exhibited by nano cubes of palladium (Shi and Masel, 1989) and the remarkably different optical properties of gold and silver nanotriangles and nano rods are some examples of exciting shape-dependent properties (El-Sayed and Kelly et al., 2003). Gold and silver nanotriangles in particular are promising as they could find potential applications in cancer hyperthermia (Shankar et al., 2004), as wave guides for electromagnetic radiation (Maier et al., 2001), surface enhanced Raman spectroscopy (SERS) substrates (Dick et al., 2002), and infrared radiation absorbing optical coatings (Sastry et al., 2005) to state a few. Consequently, a variety of synthetic procedures leading to planar gold and silver nanostructures have been reported. Methods offering reasonable control over silver nanotriangle edge lengths (Jin et al., 2001 and Jin et al., 2003) and more recently thickness (Metraux and Mirkin, 2005) have been reported. These include photochemical transformation of spherical nanoparticles or wet chemical synthesis with (Hao et al., 2002) or without templates (Metraux and Mirkin, 2005; Marzon, 2002). Similar reports for gold, however, are relatively few and more recent. Procedures employing liquid crystal (Wang et al., 2005) and polymer templates (Kim et al., 2004) leading to high yields of planar and triangular gold nanostructures have been reported recently. Solution-based methodologies such as aspartate reduction (Dong et al., 2004) and starch-mediated reduction (Sarma and Chattopadhyay, 2004) among others (Sau and Murphy, 2004) lead to the production of planar gold nanostructures with reasonable control over their optical properties.

There is a wide range of application of nanoparticles and its uses are emerging rapidly. Silver nanoparticles has significant role in the field of diagnostic (Schultz et al., 2000), food industries (Chaudhry and Castle, 2011), agriculture (Nair et al., 2010), textile industries (Kelly and Johnston, 2011), water treatment (Dankovich and Gray, 2011), as an antioxidant (Brindha et al., 2013), antimicrobial (Ravikumar et al., 2013), anti-cancer (Boca et al., 2011), cosmetics (Jain et al., 2009), ointments (Murphy, 2008), larvicides (Roopan et al., 2013), catalysis and electronics (Crooks et al., 2001; Gittins et al., 2000). Synthesis and characterization of nanoparticles is an important area of research as selection of size and shape of nanoparticles provide an efficient control over many of the physical and chemical properties (Steven et al., 1998; Alivastos, 1996). Nanoparticle synthesis is usually carried out by various physical and chemical methods using various hazardous and toxic chemicals which may have adverse effect in the medical applications. However, green synthesis approaches of producing Ag NPs are an alternative source of conventional method and possess excellent antimicrobial activity (Sharma et al., 2009). Biological materials like plant leaf extract (Pandey et al., 2009), bacteria (Saifuddin, 2009), fungi (Bhainsa and D’Souza, 2006) and enzymes (Willner et al., 2007) are used for the green synthesis of silver nanoparticles. Green synthesis process offers numerous benefits of eco-friendliness and compatibility for pharmaceutical and other biomedical applications as they do not use toxic chemicals for the synthesis protocol.

2. GREEN SYNTHESIS APPROACH

Indian greeneries are the chief and cheap source of medicinal plants and plant products. From centuries till date, these medicinal plants have been extensively utilized in Ayurveda. Recently, many such plants have been gaining importance due to their unique constituents and their versatile applicability in various developing fields of research and development. Nanobiotechnology is currently one of the most dynamic disciplines of research in contemporary material science whereby plants and different plant products are finding an imperative use in the synthesis of nanoparticles (NPs). Earlier, the antifungal properties of silver and silver nitrate were well incorporated in the field of medical science. Also, the medicinal importance of innumerable plants and plant parts were known. But the plant-mediated silver nano product is a relatively newer concept. Nanobiotechnology and their derived products are unique not only in their treatment methodology but also due to their uniqueness in particle size, physical, chemical, biochemical properties and broad range of application as well. This current emerging field of nano biotechnology is at the primary stage of development due to lack of implementation of innovative techniques in large industrial scale and yet has to be improved with the modern technologies. Hence, there is a need to design an economic, commercially feasible as well environmentally sustainable route of synthesis of Ag NPs in order to meet its growing demand in diverse sectors. Various approaches available for the synthesis of silver NPs include chemical (Sun et al., 2002), electrochemical (Chen et al., 2003), radiation (Rajh et al., 2001), photochemical methods (Callegari et al., 2003) and Langmuir-Blodgett (Zhang et al., 2006) and biological techniques (Sastry et al., 2004). In this race of Ag NP preparation, plant-mediated green biomimetic synthesis of silver nanoparticle is considered a widely acceptable technology for rapid production of silver nanoparticles for successfully meeting the excessive need and current market demand and resulting in a reduction in the employment or generation of hazardous substances to human health and the environment. Green synthesis is cost effective, environment friendly, easily scaled up for large scale synthesis and in this method there is no need to use high pressure, energy, temperature and toxic chemicals as in case of chemical and physical method. Some examples of green synthesis are synthesis of gold nano triangles by using Lemmon grass extract and tamarind leaf extract (Sastry et al., 2004; Balaprasad, 2005), geranium leaf assisted biosynthesis of silver nanoparticles (Sastry et al., 2003), synthesis of silver nanoparticles using Fungus (Mukherjee et al., 2001; Sastry et al., 2003), synthesis of silver nanoparticles by using soluble starch (Varadarajan et al., 2006), extra cellular synthesis of silver nanoparticles by a silver tolerant yeast strain MKY3 (Paknikar et al., 2003), synthesis of Au, Ag and bimetallic Au core-Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth (Rai et al., 2004), biosynthesis of silver based crystalline nanoparticles of well-defined composition and shapes (such as equilateral triangles and hexagons) within the periplasmic space of bacteria *Pseudomonas stutzery* AG259 isolated from silver mines (Klaus et al., 1999; Klaus et al., 2001).

Recently, the green synthesis of Ag NPs has been reported using the extract of plants such as *Artocarpus heterophyllus* (Jagtap and Bapa, 2013), *Sesbania grandiflora* (Velusamy et al., 2013), *Punica granatum* (Edison and Sethuraman, 2013), *Pithecellobium dulce* (Raman et al., 2012), *Malva parviflora* (Zayed et al., 2012), *Iresine herbstii* (Dipankar and Murugan, 2012), *Hibiscus cannabinus* (Bindhu and Umadevi, 2013), *Hevea brasiliensis* (Baffa et al., 2011), *Euphorbia prostrata* (Zahir and Rahuman, 2012), *Cissus quadrangularis* (Valli and Vaseeharan, 2012; Rao et al., 2012; Vanaja et al., 2013), *Catharanthus roseus* (Gopal et al., 2013), *Coccinia grandis* (Mandal et al., 2012), *Ixora coccinea* (Karuppiah and Rajmohan, 2013), *Lippia citriodora* (Cruz et al., 2010), *Manilkara zapota* (Rajakumar and Rahuman, 2012), *Piper pedicellatum* (Boruah et al., 2013) and *Prosopis juliflora* (Raja et al., 2012). Studies have also shown that Alfalfa roots can absorb Ag from agar medium and are able to transport it to the plant shoot in the same state of oxidation (Gardea-Torresdey, 2003). Existing literature also report successful synthesis of silver nanoparticles through a green route where the reducing and capping agent selected was the latex obtained from *Jatropha curcas* (Bar et al., 2009). Ag NPs were also obtained using *Aloe vera* (Chandran et al., 2006), *Acalypha indica* (Krishnaraj et al., 2010), *Garcinia mangostana* (Dhanraj et al., 2010) leaf extracts. *Crataegus douglasii* fruit extract (Ghaffari-Moghaddam and Hadi-Dabanlou, 2014) as well as various other plant extracts (Shameli et al., 2014) as reducing agent. Silver toxicity towards wide range of micro-organisms has long been known. Among all the well-known activity of silver ions and silver-based compounds is that they kill microbes effectively (Chopra, 2007). Silver nanoparticles interact with the bacterial membrane proteins and DNA as they possess sulphur and phosphorus compounds and silver have higher affinity to react with these compounds (Kim et al., 2000).

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