Industrial Crops and Products 70 (2015) 356–373

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Review

Plant extract synthesized silver nanoparticles: An ongoing source of novel biocompatible materials

Ramachandran Rajan[a], Krishnaraj Chandran[b], Stacey L. Harper[c], Soon-Il Yun[b,*], P. Thangavel Kalaichelvan[a,*]

[a] Centre for Advanced Studies in Botany, School of Life Sciences, University of Madras, Guindy Campus, Chennai 600 025, Tamil Nadu, India
[b] Department of Food Science & Technology, College of Agriculture & Life Sciences, Chonbuk National University, Jeonju 561-756, Republic of Korea
[c] Environmental and Molecular Toxicology, Oregon State University, Corvallis, 97331 OR, United States

ARTICLE INFO

Article history:
Received 26 November 2014
Received in revised form 2 March 2015
Accepted 7 March 2015
Available online 29 March 2015

Keywords:
Plant extracts
Phytosynthesis
Silver nanoparticles
Bioreduction
Biomedical applications

ABSTRACT

In view of its simplicity, low cost involvement, higher reducing potential, zero contamination and reduced or less environmental impact, the plant extract based green chemistry process has recently been emerged as one of the active areas of current nanobiotechnological research. According to the Pubmed data, more than half of the research articles published during 2009–2013 have focused the phytosynthesis of silver nanoparticles. The reaction parameters employed in the plant mediated synthesis protocol have been optimized to achieve better yield, controlled size, shape, and greater particle stability. With the aid of FT-IR spectral data, a few plant metabolites such as apiin, ascorbic acid, citric acid, cyclic peptide, ellagic acid, epicatechin gallate, euphol, galangin, gallic acid, phyllanthin, pinocembrin, retinoic acid, sorbic acid, and theaflavin have been identified as responsible compounds for the biogenic synthesis of silver nanoparticles. Due to their greater biocompatibility, scalability, and applicability, the plant extract derived silver nanoparticles have shown superior antioxidant and anticancer properties besides having pinnacle antimicrobial activities against clinically isolated pathogens including multi drug resistant and yeast pathogens. Thus, phytonanotechnology has opened up new avenues in treating and/or controlling various dreadful diseases of humans such as cancer. The present review gives an updated knowledge on plant extract synthesized silver nanoparticles with particular emphasis to their applications such as antimicrobial, antioxidant, and anticancer activities.

Contents

* Corresponding authors. Tel.: +82 063 270 2566.
E-mail addresses: siyun@jbnu.ac.kr (S.-I. Yun), ptkalai2003@yahoo.com (P.T. Kalaichelvan).

http://dx.doi.org/10.1016/j.indcrop.2015.03.015
0926-6690/

1. Introduction

Owing to the smaller particle size, various shapes and increased surface area, nanoparticles display very different properties than their parent materials and are found to be interesting candidates for various applications, particularly in biomedical science (Iravani, 2011). Efforts have made to synthesize these tiny particles employing physical, chemical, and biological methods. In case of physical processes, there is always a need to maintain high temperature, pressure, and energy (Thakkar et al., 2010) while most of the chemicals such as reactants, starting materials, and solvents used in the chemical synthetic routes are found to be toxic and potentially hazardous not only to the environment but also to the biological systems (Begum et al., 2009; Li et al., 2011; Roy et al., 2010). Another problem associated with this method is the formation of toxic by-products (Shankar et al., 2004). Additionally, there has been serious concern about their stability and safety in living systems. All these inherent drawbacks have limited the use of as-synthesized nanoparticles in the biomedical field and demanded the need of safer alternative methods (Li et al., 2011; Narayanan and Sakthivel, 2010). In fact, biological systems have long been known to produce nanoparticles utilizing microorganisms (Samadi et al., 2009; Sastry et al., 2003) and plants (Haverkamp and Marshall, 2009; Namrata et al., 2009).

Currently, an exhaustive study on biological synthesis of nanoparticles has been carried out using a wide range of microorganisms such as bacteria, fungi, actinomycetes, and algae as well as plant extracts (Mittal et al., 2013; Narayanan and Sakthivel, 2010, 2011). The microbe mediated synthesis methods have several disadvantages like identification of potent strain, maintenance of aseptic conditions for the profuse growth of microorganisms, chances of infection and contamination (Kumar and Yadav, 2009; Njagi et al., 2011). Biological synthesis of nanoparticles using microorganisms is relatively expensive than using plant extracts (Dhillon et al., 2012; Luangpipat et al., 2011; Narayanan and Sakthivel, 2011). Above all, the microbial synthesis method is quite time consuming (Narayanan and Sakthivel, 2010) and requires about 2–3 days for the growth of a potent strain and another 1–2 days for synthesis and purification of nanoparticles. As a result, scientists switched over their interest toward plant systems for fabricating biocompatible nanomaterials. Using this green chemistry approach, approximately 200 plants belonging to different families have been screened for their ability to synthesize various metal nanoparticles including silver (Bar et al., 2009; Krishnaraj et al., 2010; Kumar et al., 2010; Sathishkumar et al., 2009), gold (Ghodake et al., 2010; Song et al., 2009), iron (Njagi et al., 2011), palladium (Petla et al., 2012; Roopan et al., 2012; Yang et al., 2010), lead (Joglekar et al., 2011), and copper (Lee et al., 2013; Valodkar et al., 2011).

Among the various metal nanoparticles, silver nanoparticles have been gaining increasing momentum throughout the world and the number of publications on plant extract synthesized silver nanoparticles is gradually being increased since 2009. The bactericidal activity of silver is a well-established fact and it has a long traditional record. Similar to the bulk silver, nanoparticulated silver also inhibits the growth of microbes. Silver in nano form performs relatively much higher antimicrobial activity compared to its macroscopic counterpart. Furthermore, silver nanoparticles have been shown to possess better antioxidant and anticancer properties and have the potential to be developed as novel therapeutic agents (Iravani, 2011; Song and Kim, 2009). Many excellent reviews describing various methods for metal nanoparticles preparation, their characterization techniques and biological applications have appeared over the last few years. However, fewer reviews have described the biological synthesis of silver and gold nanoparticles using plants, their probable synthesis mechanisms and antimicrobial properties to some extent (Gan and Li, 2012; Mittal et al., 2013; Narayanan and Sakthivel, 2011). The goal of the present review is to summarize particularly the plant extract synthesized silver nanoparticles and discusses the phytochemicals responsible for this biogenesis, also to discuss their potential applications such as antimicrobial, antioxidant, and anticancer activities.

2. Advantages of plant extract mediated nanoparticles synthesis

An important reason for researching the plants for nanoparticles synthesis is their easy availability. Metal nanoparticles can be produced using whole plant or extract of a particular plant part or powder made from plants; however, the availability of reducing agents is quite large in the extract than the whole plant or powder and most of the reported studies have utilized plant extracts. Until now, all the phytosynthesis methods have primarily used aqueous (water) extract for nanoparticles production. Moreover, the biological synthesis procedure is very simple as it requires no specific conditions unlike the physical and chemical methods. The bioreduction potential of plant extracts is comparatively higher than the microbial culture filtrate and many researchers have supported this hypothesis (Iravani, 2011; Kannan et al., 2011; Narayanan and Sakthivel, 2010). For instance, *Rosa rugosa* leaves extract synthesized both silver and gold nanoparticles within 10 min (Dubey et al., 2010b). Recently, Gangula et al. (2011) have reported that *Breynia rhamnoides* extract rapidly synthesized both silver and gold nanoparticles within 7 min and this is the much faster reduction process reported for the first time. In addition to these, the waste products generated from the plant mediated synthesis processes are usually compatible with the environment since these particles are resulted from natural plant extracts. On the contrary, the waste products of microbial synthesis methods are likely to be dangerous to the environment depending on the type of microbe used for the synthesis. As far as the safety of biological synthesis procedures is concerned, the plant mediated approach has less or almost zero contamination and thus it has much reduced impact on the environment (Dahl et al., 2007). Apart from mediating the phytosynthesis or reducing the metal ions, the phytochemicals present in the plant extracts are known to stabilize the synthesized nanoparticles (Iravani, 2011; Kumar and Yadav, 2009). Besides, this biogenic method of nanoparticles synthesis appears to be reproducible and the particles, produced through this environmentally friendly approach, are found highly stable (Iravani, 2011; Kalaiarasi et al., 2010). Thus, the plant extract based protocol fulfills all the criteria for greener synthesis (Fig. 1) and is suitable for large scale production as it seems to be facile, low cost involvement, eco-friendly and safe for human therapeutic use (Gan and Li, 2012; Iravani, 2011; Kumar and Yadav, 2009; Mittal et al., 2013). Because of these advances over other methods, this single step procedure has now turned as viable alternative to conventional physical,