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Microbial synthesis of gold nanoparticles: Current status and future prospects

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ABSTRACT

Gold nanoparticles have been employed in biomedicine since the last decade because of their unique optical, electrical and photothermal properties. Present review discusses the microbial synthesis, properties and biomedical applications of gold nanoparticles. Different microbial synthesis strategies used so far for obtaining better yield and stability have been described. It also includes different methods used for the characterization and analysis of gold nanoparticles, viz. UV–visible spectroscopy, Fourier transform infrared spectroscopy, X ray diffraction spectroscopy, scanning electron microscopy, ransmission electron microscopy, atomic force microscopy, electron dispersive X ray, X ray photoelectron spectroscopy and cyclic voltametry. The different mechanisms involved in microbial synthesis of gold nanoparticles have been discussed. The information related to applications of microbially synthesized gold nanoparticles and patents on microbial synthesis of gold nanoparticles has been summarized.

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1. Introduction

Gold is one of the well known noble metals. It is used as heat insulator in automobiles and reflective layer on some high-end CDs. It produces an intense red color when used as a coloring agent in cranberry glass [1–3]. Gold, in variety of forms, has been used in medicine throughout the history of civilization [4,5]. Gold and gold compounds have been used in treatment of rheumatic diseases and discoid lupus erythematosus [6,7], restorative dentistry [8–10] and various inflammatory skin disorders such as pemphigus, urticaria and psoriasis [11]. Gold eyelid implants are used in lagopthalmos patients and in patients suffering from facial nerve palsy [12–15].

Nanomaterials are believed to display different properties than that of bulk materials, and so is true in the case of gold nanoparticles

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(AuNPs) [16–18]. In last few years, AuNPs have received importance in research because of their unique optical, electrical and photothermal properties [19–21]. Moreover, they are highly stable to oxidation [22,23]. The phase and morphology variations in AuNPs can alter their physical and chemical properties [24]. The first review on the medical applications of gold and gold compounds was published by Fricker (1996) [5]. Since then, 33 reviews have been published till to date on gold, gold compounds, nanostructures and their importance in various fields. However, up till now there has been no review on microbial synthesis of AuNPs, this is the first review specifically about the microbial synthesis of AuNPs, its mechanism of synthesis, characterization, patents and applications.

2. Synthesis methods

Synthesis of nanoscale gold with controlled phase and morphology is one of the fundamental and technological interests. The synthesis of gold colloids, recently named as AuNPs, was reported about 150 years ago by Michael Faraday using phosphorous to reduce $AuCl_4^-$ ions [25]. In recent years, a wide range of AuNPs have been developed for applications in biotechnology, industries, and electrical, pharmaceutical, medical and agricultural fields [26–28] by variety of physical, chemical and biological methods. Gold nanostructures of well defined compositions are synthesized in the form of clusters, colloids, wires, rods, tubes, powders, thin films, etc., by using these techniques [18,29–31].

2.1. Gold nanoparticles

Traditionally, AuNPs have been synthesized by physical and chemical methods summarized in Fig. 1. AuNPs of size ranging from 1 to 100 nm and different shapes have been obtained by using these techniques. Though these synthesis methods have been extensively studied, they have certain drawbacks such as use of harsh chemicals, stringent synthesis conditions, energy and capital intensive [32–34] and less productivity [35,36]. Current synthetic methods result in mixed shape nanoparticles (NPs) that require expensive and low-yield purification procedures such as differential centrifugation [37]. Moreover, these methods impose environmental hazards due to toxic solvents or additives and produce more sludge. Hence, there is an increasing need to develop clean, nontoxic, environmentally benign and sustainable synthesis procedures. Development of high yield and low cost methods for NPs production is an important challenge [34]. Consequently, researchers in nanoparticle synthesis have turned to biological systems due to their rich diversity [38,39].

Biosynthesis can be successfully used for the production of smaller particles in large scale [40,41]. It is important to note that biologically synthesized NPs exhibit enhanced stability [42] and better control over morphology [43]. Biological systems like bacteria, fungi, actinomycetes and plants have the ability to produce NPs [44–48]. NPs are produced by microbes, intra and/or extracellularly, due to their innate potential [46,49–51]. However, the extraction of NPs formed by intracellular biosynthesis is generally difficult because of additional processing steps such as ultrasonication and treatment with suitable detergents [52]. Thus, microorganisms giving extracellular biosynthesis of NPs must be extensively screened [53–55]. Use of microorganisms as potential biofactories for synthesis of AuNPs is a relatively new area of research with considerable prospects. Further, it is environmentally acceptable, economic, time saving and can be easily scaled up for large scale synthesis [41,56–59]. Subsequent sections give the detailed information about the various microbial synthetic strategies used for AuNPs.

2.1.1. Bacteria

Among microorganisms, prokaryotes have received the most attention in the area of AuNP synthesis [60]. For the first time microbial synthesis of AuNPs was reported in *Bacillus subtilis* 168 which revealed the presence of 5–25 nm octahedral NPs inside the cell wall [61]. In *Rhodopseudomonas capsulata*, spherical AuNPs with 10–20 nm range have been observed [62] at lower concentration and nanowires with network at higher concentration [63]. Six cyanobacteria have been reported for production of AuNPs. *Plectonema* sp. [64,65], *Anabaena* sp., *Calothrix* sp., and *Leptolyngbya* sp. have been exploited for the AuNP synthesis [66]. Single-cell protein of *Spirulina platensis* was also shown to produce AuNPs and Au core–Ag shell NPs [67]. An overview on bacterial synthesis of AuNPs is given in Table 1. If one tries to group the AuNP producing bacteria according to 9th edition of Bergey's Manual of Systematic Bacteriology (2005) [68], the members belonging to groups glidobacteria, and beta, epsilon and zeta proteobacteria have not been reported so far.

2.1.2. Fungi

Fungi appear to be more promising for large scale production of NPs as they are simpler to grow both in the laboratory and at an industrial scale as well as secrete large amount of proteins [34,89,90]. Besides this, fungi synthesize NPs of defined dimensions with good monodispersity [34,89]. Different fungal species, e.g., *Fusarium oxysporum*, *Verticillium* sp. have been reported [89,91,92] to synthesize NPs either intra or extracellularly. Shankar et al. (2004) [44] demonstrated that gold nanoplates can be synthesized by using fungal extracts. Yeasts like *Pichia jadinii* and *Yarrowia lipolytica* were also shown to have a good potential for synthesis of AuNPs [93,114] and they are now under the specialized exploration to engineer AuNPs. The yeast strains are having many advantages over bacteria for the bulk production of NPs as yeasts are easy to handle in laboratory conditions, synthesize high amount of

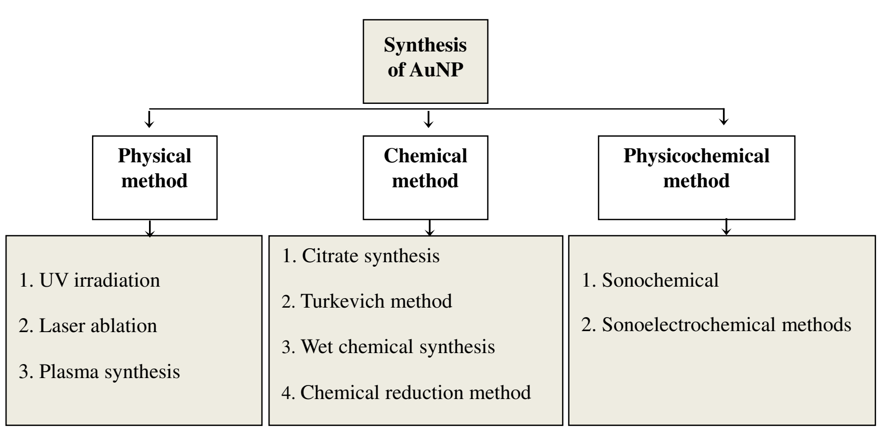

Fig. 1. Physicochemical methods for synthesis of AuNPs.