Colloids and Surfaces A: Physicochem. Eng. Aspects 497 (2016) 280–285

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

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

Biogenic synthesis of gold nanoparticles by yeast *Magnusiomyces ingens* LH-F1 for catalytic reduction of nitrophenols

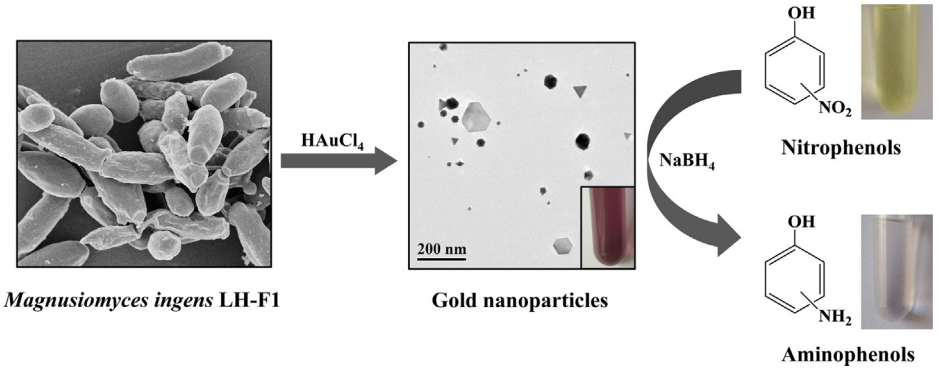
Xuwang Zhang, Yuanyuan Qu*, Wenli Shen, Jingwei Wang, Huijie Li, Zhaojing Zhang, Shuzhen Li, Jiti Zhou

State Key Laboratory of Fine Chemicals, Key Laboratory of Industrial Ecology and Environmental Engineering (Ministry of Education), School of Environmental Science and Technology, Dalian University of Technology, Dalian 116024, China

HIGHLIGHTS

- This is the first report on AuNPs biosynthesis by *Magnusiomyces ingens*.
- Various shaped AuNPs were synthesized by strain LH-F1.
- Some biomolecules were found to be absorbed on the surface of AuNPs.
- AuNPs showed excellent catalytic activities for the reduction of nitrophenols.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form 17 February 2016
Accepted 24 February 2016
Available online 18 March 2016

Keywords:
Gold nanoparticles
Magnusiomyces ingens
Nitrophenols
Biosynthesis

ABSTRACT

In the present study, the biogenic synthesis of gold nanoparticles (AuNPs) was achieved using the yeast cells of *Magnusiomyces ingens* LH-F1. Based on UV–vis spectral analysis, 2.2 mg/mL biomass (OD_{600} = 2.0) and 1.0 mM $HAuCl_4$ were preferable for AuNPs synthesis by strain LH-F1. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) images revealed that various shaped nanoparticles were obtained, including sphere, triangle and hexagon. Based on the analyses of Fourier transform infrared spectroscopy (FTIR) and sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), some biomolecules were absorbed on the surface of AuNPs, which could be involved in the formation of AuNPs. The as-synthesized AuNPs exhibited excellent catalytic activities for the reduction of nitrophenols (i.e. 4-nitrophenol, 3-nitrophenol and 2-nitrophenol) to aminophenols in the presence $NaBH_4$. This is the first report on AuNPs biosynthesis by *Magnusiomyces ingens*, which may serve as an efficient candidate for green synthesis of metal nanoparticles.

1. Introduction

Gold nanoparticles (AuNPs) have attracted enormous attention in recent decades due to their unique photophysical, electronic and catalytic properties. They have broad applications in the fields of electronics, environmental sensing, biomedicine and fine chemical synthesis [1,2]. Various physical and chemical methods have been successfully used to produce AuNPs, but most of them are either of high-cost or involved with the usage of hazardous chemicals [3,4]. The biological methods are considered to be the green and eco-friendly alternatives for the synthesis of nanoparticles owing to their nature of rich diversity, cost-effective, and mild condition [5].

* Corresponding author.
E-mail address: qyy@dlut.edu.cn (Y. Qu).

http://dx.doi.org/10.1016/j.colsurfa.2016.02.033
0927-7757/

Biological systems, such as bacteria, fungi and plants, have been shown to possess the ability of producing AuNPs via intra- and/or extra-cellular ways [4]. Among them, fungi are gaining more interests for the green synthesis of nanoparticles due to their practical advantages of easy handling, large amounts of secreted proteins and high yields of biomass, which make them more promising for industrial AuNPs production [3,6]. Up to now, a few fungal species have been reported for biogenic synthesis of AuNPs, and these nanoparticles are found to be multi-shaped, e.g. sphere, triangle, hexagon, cube and rod [3,4]. Some proteins or biomolecules secreted by fungi may act as reducing, capping and stabilizing agents responsible for the synthesis of AuNPs, while NAD(P)H-dependent reductases are considered to be the most common type [3,4,7]. Yeasts such as *Candida albicans* [8], *Hansenula anomala* [9], *Pichia jadinii* [10] and *Yarrowia lipolytica* [11] have also been reported to produce AuNPs, which have a good potential for the bulk production of nanoparticles [4]. However, other yeast species for AuNPs synthesis are less investigated.

The reduction of nitrophenols to aminophenols in the presence of $NaBH_4$ has been generally reported to examine the catalytic behaviors of AuNPs [12,13] Nitrophenols, like 4-nitrophenol (4-NP), are widely used in the manufacture of dyes, pharmaceuticals and pesticides, and they pose a great threat to human and the environment due to the carcinogenic and mutagenic properties [14]. Previous studies have already indicated that AuNPs can efficiently catalyze the hydrogenation of nitroarene to anilinem at ambient temperature [2,12]. The reduction product of nitrophenols, like 4-aminophenol (4-AP), have a broad application in various industries, including photographic developer, corrosion inhibitor, drying agent and the manufacture of analgesic and antipyretic drugs [15]. The catalytic activity of AuNPs is generally related to the particle size, and the functional groups on the surface of AuNPs may also affect the catalytic behavior [15]. Therefore, developing a facile and green approach to synthesize AuNPs with high catalytic activities for nitrophenols reduction is of environmental and industrial importance.

Magnusiomyces ingens (synonym of *Dipodascus ingens*) is a non-conventional yeast, but the green synthesis of metal nanoparticles by *Magnusiomyces ingens* has been rarely described. In previous study, a yeast strain *Magnusiomyces ingens* LH-F1 was isolated from sea mud, which exhibited a good capability in decolorizing various azo dyes under aerobic condition [16]. Herein, the biogenic synthesis of AuNPs from $HAuCl_4$ was investigated using the yeast cells of *Magnusiomyces ingens* LH-F1. The effects of reaction conditions on AuNPs synthesis were investigated, and the resulting nanoparticles were characterized by UV–vis spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), Fourier transform infrared spectroscopy (FTIR) and sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). In addition, the catalytic activities of the as-synthesized AuNPs were also determined for the reduction of nitrophenols to aminophenols. To the best of our knowledge, this is the first study regarding the biogenic synthesis of AuNPs by yeast *Magnusiomyces ingens*.

2. Experimental

2.1. Materials

Hydrogen tetrachloroaurate (III) hydrate ($HAuCl_4{\cdot}3H_2O$) was purchased from J&K Scientific Ltd. (China). Nitrophenols and aminophenols were obtained from Sinopharm Chemical Regent Beijing Co., Ltd. (China), including 4-nitrophenol (4-NP), 3-nitrophenol (3-NP), 2-nitrophenol (2-NP), 4-aminophenol (4-AP), 3-aminophenol (3-AP), 2-aminophenol (2-AP). All other chemicals were of analytical grade.

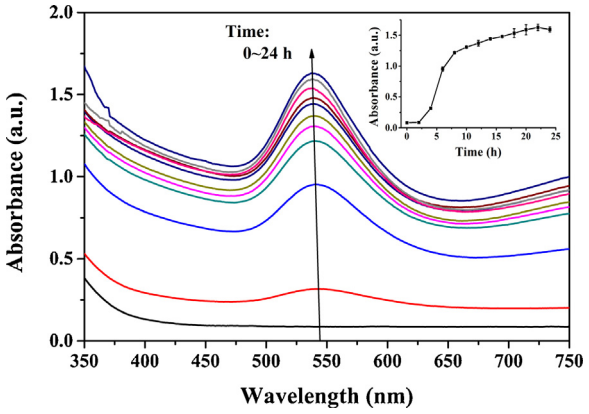


Fig. 1. Time evolution of UV–vis spectra during the formation of AuNPs by the cells of *Magnusiomyces ingens* LH-F1. The insert shows the intensity change of SPR peak during the formation of AuNPs. Strain LH-F1 cells (OD_{600} 2.0) were incubated with 1.0 mM $HAuCl_4$ at 30 °C for 24 h under continuous shaking.

The yeast strain, *Magnusiomyces ingens* LH-F1 (CGMCC No. 10367), was isolated previously from the sea mud of a harbor industrial zone in Dalian, China, which was routinely cultivated in the culture medium containing KH_2PO_4 1.0 g/L, $(NH_4)_2SO_4$ 1.0 g/L, $MgSO_4{\cdot}7H_2O$ 0.5 g/L and glucose 4.0 g/L [16].

2.2. Biosynthesis of AuNPs by yeast Magnusiomyces ingens LH-F1

Strain LH-F1 was grown aerobically at 30 °C in the culture medium until it reached the late log-phase. Cells were harvested by centrifugation (10,000*g* for 10 min at 4 °C), washed twice with double distilled water (ddH_2O), and stored at −80 °C prior to use. Then, cells were re-suspended in the same ddH_2O to the optical density at 600 nm (OD_{600}) of 2.0 (corresponding to the dry cell weight of 2.2 mg/mL). For AuNPs synthesis, the $HAuCl_4$ stock solution (50 mM) was added to the cell suspension with a final concentration of 1.0 mM, and the reaction mixture was incubated at 30 °C for 24 h under continuous shaking. Subsequently, the mixture was centrifuged at 3000*g* for 5 min, and the supernatant was collected, which was then filtered through 0.45 μm syringe Millipore filters to remove the cell debris before further characterization.

Effects of different parameters on AuNPs synthesis by strain LH-F1 were investigated, including the concentrations of biomass and initial gold ion. To check the influences of biomass concentration, strain LH-F1 cells were re-suspended to OD_{600} 1.0, 1.5, 2.0, 2.5 and 3.0, which were then mixed with 1.0 mM $HAuCl_4$. As for the effects of initial gold ion, strain LH-F1 cells (OD_{600} 2.0) were mixed with 0.1, 0.5, 1.0, 2.0 and 5.0 mM $HAuCl_4$. The mixtures were incubated at 30 °C for 24 h under continuous shaking, and UV–vis spectra were monitored to evaluate the formation of AuNPs.

2.3. Characterization of AuNPs

Spectral analysis of AuNPs was performed using a UV–vis spectrophotometer (Metash UV-9000, China). Gold concentrations were determined using inductively coupled plasma optical emission spectrometer (ICP-OES, Perkin-Elmer Optima 2000 DV, USA). SEM (Hitachi SU8020, Japan) and TEM (FEI Tecnai G220 S-Twin, USA) were used to evaluate morphology of AuNPs. DLS measurement was carried out by Zetasizer Nano ZS (Marvin Instruments, UK) to analyze the average particle size of AuNPs. FTIR spectra of AuNPs and strain LH-F1 cells were obtained using a Shimadzu