Journal of Molecular Liquids 262 (2018) 318–321

Contents lists available at ScienceDirect

Journal of Molecular Liquids

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

Short Communication

Biogenic synthesis, characterization and antibacterial activity of gold nanoparticles synthesised from vegetable waste

R. Mythili [a], T. Selvankumar [a], P. Srinivasan [a], A. Sengottaiyan [a], J. Sabastinraj [b], Fuad Ameen [c], Ahmed Al-Sabri [c], S. Kamala-Kannan [d], M. Govarthanan [a,e,*], H. Kim [e,**]

[a] PG & Research Department of Biotechnology, Mahendra Arts and Science College (Autonomous), Kalippatti, Namakkal 637501, Tamil Nadu, India
[b] Department of Biotechnology, Jamal Mohamed College (Autonomous), Tiruchirapalli 620020, Tamil Nadu, India
[c] Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
[d] Division of Biotechnology, Advanced Institute of Environment and Bioscience, College of Environmental and Bioresource Sciences, Chonbuk National University, Iksan 570 752, Republic of Korea
[e] Department of Environmental Engineering, University of Seoul, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 26 February 2018
Received in revised form 13 April 2018
Accepted 16 April 2018
Available online 17 April 2018

Keywords:
Antibacterial
Characterization
Gold nanoparticles
Green synthesis
Vegetable waste

ABSTRACT

In this study, we report the potential use of market vegetable waste for the synthesis of gold nanoparticles (AuNPs). The AuNPs were synthesised using a green method without using any harmful chemical. The AuNPs obtained from vegetable wastes were characterised by UV– vis spectroscopy, transmission electron microscopy, scanning electron microscopy energy dispersive spectroscopy, X-ray diffraction, and Fourier transform-infrared spectroscopic (FT-IR) analysis. The particles size for the green synthesised AuNPs from vegetable waste were ranged from 10 to 70 nm. The AuNPs showed significant antibacterial activity against clinical pathogens. Hence, this attempt has shown a great potential for utilizing market vegetable waste as a bio-reductant for the synthesis of AuNPs.

1. Introduction

Gold nanoparticles (AuNPs) are some of the most extensively studied nanomaterial in the field of nano biotechnology. AuNPs have attracted wide attention due to their potential applications in catalysis [1], antimicrobial [2], anticancer [3], drug delivery [4], and agriculture [5]. The AuNPs can be easily synthesised and show high chemical as well as thermal stability [6]. The conventional physico-chemical methods attempted over the past several years for AuNPs synthesis are electrochemical [7], photochemical [8], sono-chemical [9] and microwave assisted processes [10]. However, all these physico-chemical methods are complex, cost-intensive, and pressure-required and use toxic chemicals that can harm the human and the eco-system [11]. Currently, the use of biological materials for the synthesis of AuNPs has become a popular alternative. In particular, plants and plant based wastes have been successfully used for the production of AuNPs. Several studies have reported on the synthesis of AuNPs using plants [12–14]. To the best of our knowledge, the use of market vegetable waste has not been reported so far, for AuNPs synthesis.

In recent years, waste management represents an important challenge in agricultural industries and markets. It demands an integrated approach in the context of reuse for the production of value-added products. India is the largest consumer of vegetable and produces tons of vegetables wastes annually. Such estimates for the worldwide consumption of vegetable are several folds higher. The vegetable wastes were usually discarded in vegetable markets. The vegetables are mainly composed of phytochemicals and many natural polysaccharides. Thus, the use of market vegetable waste attracted for the synthesis of AuNPs.

In the present study, market vegetable wastes were used for the production of AuNPs. The synthesised AuNPs structures have been characterised by using standard spectrochemical methods. In addition, antibacterial activity of the AuNPs has also been investigated.

2. Materials and methods

2.1. Chemicals

Gold (III) chloride hydrate ($HAuCl_4$) was purchased from Sigma-Aldrich (St Louis, MO, USA). All other chemicals were analytical grade and purchased from Hi-Media Laboratories, Mumbai, India.

* Correspondence to: M. Govarthanan, Department of Energy and Environmental System Engineering, University of Seoul, Republic of Korea.
** Corresponding author.
E-mail addresses: gova.muthu@gmail.com (M. Govarthanan), h_kim@uos.ac.kr (H. Kim).

https://doi.org/10.1016/j.molliq.2018.04.087
0167-7322/

2.2. Vegetable waste collection

Vegetable waste was collected from a waste disposal yard of a vegetable market (Wednesday Market), Mallasamudram (11.4939° latitude and 78.0295° longitude), India. The trading of vegetables in this city was approximately 2–5 tons/week. The 1–2 tons quantity of vegetables trading produces a huge quantity of wastes in the form of discarded vegetables, fresh skins of vegetables, fresh/damaged leaves etc. The fresh vegetable waste was collected in plastic bags and brought to the laboratory.

2.3. AuNPs synthesis

The vegetable waste was washed thoroughly with tap water and double-distilled water until no impurities remained. The mixed vegetable waste (200 g) were separated and added to 1000 mL of sterile double-distilled water and crushed using a mortar and pestle. The extract was filtered through Whatman No.1 filter paper and stored at 4 °C for further experiments. The vegetable waste extract (4 mL) was added to 96 mL of 1 mM $HAuCl_4$ solution and incubated in an orbital shaker for 12–24 h. The production of AuNPs was visually observed by a colour change from yellow to dark red.

2.4. Characterization of AuNPs

The optical absorption spectra of the synthesised AuNPs were observed using UV–vis spectrophotometer (Elico-SL 164). The surface morphology and size of the AuNPs were measured using transmission electron microscopy (TEM, FEI Tecnai TF 20 high resolution). The elemental composition of the AuNPs was confirmed by scanning electron micrograph-energy dispersive spectroscopy (SEM–EDS; Jeol JSM 6390). Fourier transform-infrared spectra (FT-IR) of AuNPs were obtained with a Perkin-Elmer FT-IR spectrophotometer (IRAffinity-1S) in the diffuse reflectance mode at a resolution of 4 particles cm^{-1} in KBr pellets. X-ray powder diffraction was used to determine the crystalline nature of the samples (XPERT-Pro diffractometer using Cu-Ka radiation). Scanning was done in the region of 2θ from 10° to 80° at 0.04°/min with a time constant of 2 s.

2.5. Antibacterial activity

The antibacterial activity of the AuNPs was assessed by the well diffusion method using two different clinical pathogenic bacteria, namely, *Klebsiella* sp. (Accession Number: KC899845), and *Staphylococcus* sp. (Accession Number: KC688883). The pure cultures of the bacteria were grown in nutrient agar media. Briefly, four different concentrations of (25, 50, 75 and 100 μg/mL) AuNPs were loaded on to the wells of the petridishes inoculated with *Klebsiella* sp. and *Staphylococcus* sp., individually. The antibiotic ampicillin (1mg/mL), was used as a positive control. The plates were incubated at 37 °C for 12–24 h and the zones of inhibition around the wells were measured manually.

3. Results and discussion

Recently, several studies have reported on the synthesis of AuNPs using environment friendly and renewable sources. In these adopted methodologies, abundant of plants and its products were utilized to generate AuNPs. In the present study, a simple and facile method was developed to synthesize AuNPs using market vegetable waste extract and chloroauric acid solution. The vegetable waste extract was mixed with chloroauric acid metal salt solution and the bio reduction of the Au^+ into AuNPs was observed at 37 °C for 12–24 h. The colour change was monitored from yellow to dark red indicating production of AuNPs.

The AuNPs synthesised from vegetable waste was examined by UV–Vis spectroscopy in the range of 200–800 nm. Expectedly, a characteristic absorption peak was observed around 530 nm, which is attributed to the surface plasmon resonance of AuNPs. The excitation of the surface plasmon resonance of AuNPs could be responsible for the colour change in the reaction mixture. The observed results are consistent with a previous study which reported similar colour change in the reaction mixture [15]. The morphological structure and size of the AuNPs were shown in Fig. 1. The TEM image of AuNPs obtained from vegetable waste extract exhibit spherical and triangle shapes and particles size was found in the average range of 10–70 nm. Noruzi et al. [16] reported the spherical and triangle nature of the AuNPs obtained from *Rosa hybrid* petal extract with an average size of 10 nm. The particles were present mostly in aggregates. The size of the AuNPs was mainly depending on the physico-chemical properties of the reaction mixture such as, pH, temperature and reactant concentration [17].

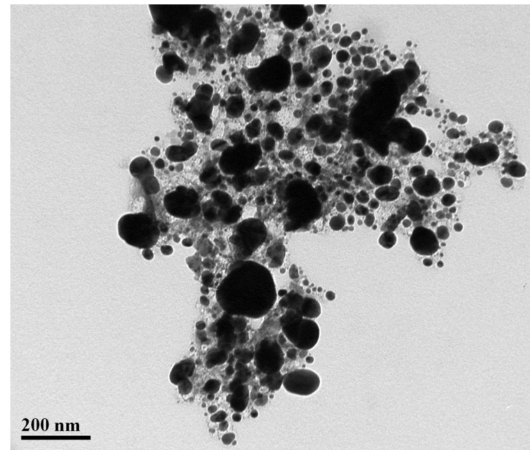

Fig. 1. (a) TEM image of AuNPs synthesised from vegetable waste extract.

Fig. 2 shows the EDS spectrum of the vegetable waste extract mediated synthesized AuNPs. The strongest peak at ~2 keV confirmed the presence of elemental gold in its pure form. Furthermore, the EDS pattern of AuNPs also consists of O and C with small amounts. The O and C peaks may be developed from the phytochemicals of the vegetable waste. The crystalline character of the synthesised AuNPs was determined by the XRD analysis. Fig. 3 shows the XRD pattern of AuNPs obtained from vegetable waste extract. The XRD pattern exhibited four different diffraction peaks (111, 200, 220 and 311) at 2θ. The reflection peak (111) is more intense than other reflection peaks (200), (220), and (311). These results are in agreement with the previous studies reported that the cubic nature of AuNPs [14,17,18].

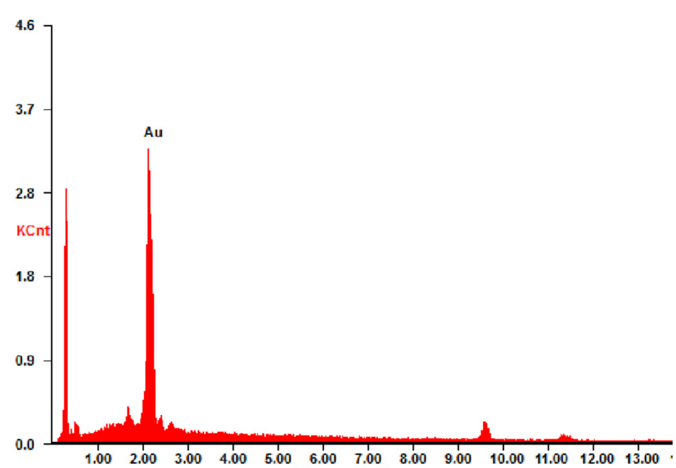

Fig. 2. SEM-EDX spectrum of AuNPs.

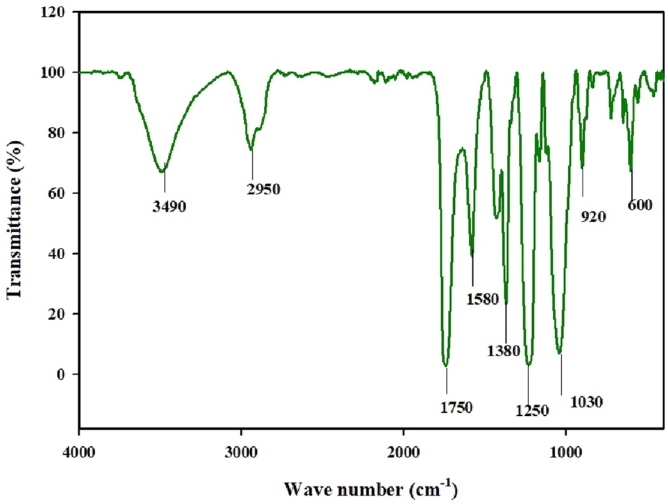

Fig. 3. FTIR spectrum of AuNPs obtained from vegetable waste extract.

The potential phytochemicals responsible for the bio-reduction and the stabilization of AuNPs can be determined by the FT-IR analysis. Fig. 4 shows the FTIR spectra of AuNPs synthesised from vegetable waste extract. The AuNPs show prominent peaks at 3490, 2950, 1780, 1580, 1380, 1250, 1030, 920, and 600 cm^{-1}, respectively. The peak at 1380 cm^{-1} was assigned to the symmetrical stretch of the carboxyl group. The peak at 1250 cm^{-1} indicated acetyl group of molecules present in the AuNPs. The peaks at 1030 and 920 cm^{-1} were due to the C—O stretching vibrations of ether and alcohol groups respectively. The peak at 600 cm^{-1} in the spectra of AuNPs corresponds to C—C groups of aromatic rings and C—O stretching of carboxyl groups of proteins. The strong adsorption bands at 3490 and 2950 cm^{-1} are characteristic stretching vibrations of O—H and C—H groups respectively [17,19]. The FT-IR results indicate the possible role of phytochemicals in capping and stabilizing the AuNPs.

Gold nanoparticles are extensively used in various value-added products as antibacterial agent to fight against the infectious microorganisms. Antibacterial activity of AuNPs was observed against *Klebsiella* sp. (Accession Number: KC899845), and *Staphylococcus* sp. (Accession Number: KC688883) and the results are shown in Fig. 5. The antibacterial activity of four different concentrations of AuNPs (25, 50, 75 and 100 μg/mL) and its representative zones of inhibition around the wells were observed respectively. The antibacterial activity of AuNPs is consistent with previous reports on that of AuNPs synthesised from plant extracts

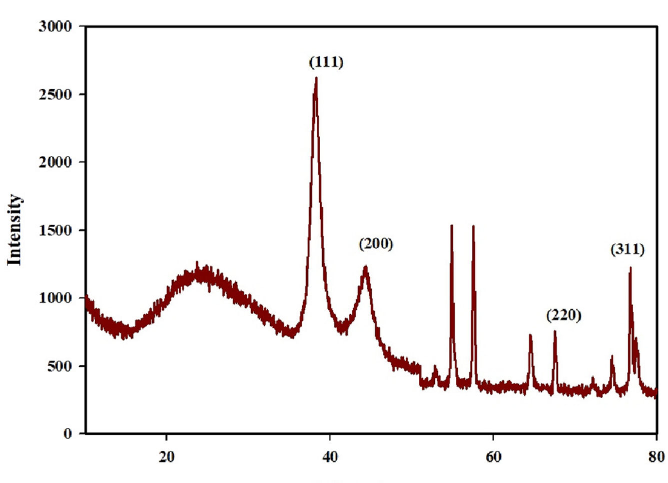

Fig. 4. XRD spectrum of AuNPs obtained from vegetable waste extract.

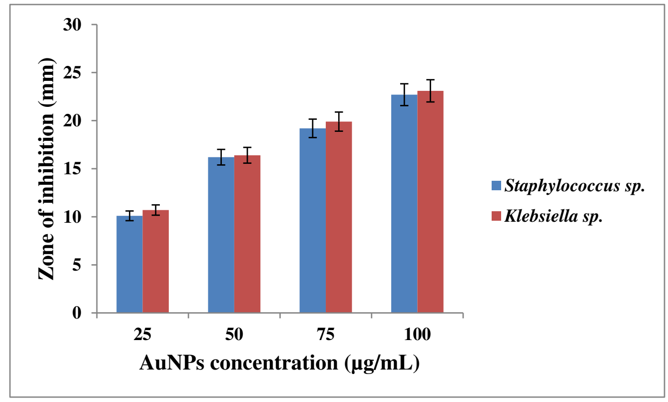

Fig. 5. Bactericidal activity of AuNPs.

[20]. The obtained results indicated that the AuNPs synthesised using market vegetable waste effectively inhibited the growth of tested pathogens. This ideal characteristics of the AuNPs makes them as a potential candidate for developing both narrow-spectrum and broad-spectrum antibacterial agent.

4. Conclusion

In conclusion, market vegetable waste could be used as an efficient biological substrate for the rapid and consistent synthesis of AuNPs. This simple, low cost, non-toxic, and abundantly available market vegetable waste could be used as an efficient alternative to the other biological materials. Such waste materials for synthesising AuNPs will be an advantage since the biological waste materials can be potentially converted into value-added nanomaterials. This study might open ways to explore utilization of other naturally available biological wastes for the synthesis of nanoparticles.

Conflict of interest

The authors declare that they don't have any conflict of interest.

Acknowledgement

The authors (Fuad Ameen and Ahmed Al-Sabri) extended their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group NO (RGP-1438-029). H. Kim is financially supported by the Korea Environmental Industry and Technology Institute (Project no. 2015001790002), which is greatly appreciated.

References

[1] S.A. Aromal, D. Philip, Green synthesis of gold nanoparticles using *Trigonella foenum-graecum* and its size-dependent catalytic activity, Spectrochim. Acta A 97 (2012) 1–5.
[2] N. Dorosti, F. Jamshidi, Plant-mediated gold nanoparticles by *Dracocephalum kotschyi* as anticholin esterase agent: synthesis, characterization, and evaluation of anticancer and antibacterial activity, J. Appl. Biomed. 14 (2016) 235–245.
[3] S. Rajeshkumar, Anticancer activity of eco-friendly gold nanoparticles against lung and liver cancer cells, J. Eng. Biotech. 14 (2016) 195–202.
[4] M. Ghorbani, H. Hamishehkar, Redox and pH-responsive gold nanoparticles as a new platform for simultaneous triple anti-cancer drugs targeting, Int. J. Pharm. 520 (2017) 126–138.
[5] W. Mahakham, P. Theerakulpisut, S. Maensiri, S. Phumying, A.K. Sarmah, Environmentally benign synthesis of phytochemicals-capped gold nanoparticles as nanopriming agent for promoting maize seed germination, Sci. Total Environ. 573 (2016) 1089–1102.
[6] M. Noruzi, Biosynthesis of gold nanoparticles using plant extracts, Bioprocess Biosyst. Eng. 38 (2015) 1–14.
[7] Y. Hu, Y. Song, Y. Wang, J. Di, Electrochemical synthesis of gold nanoparticles onto indium tin oxide glass and application in biosensors, Thin Solid Films 519 (2011) 6605–6609.

[8] P.R. Teixeira, M.S. Santos, A.L.G. Silva, S.N. Báo, R.B. Azevedo, M.J.A. Sales, L.G. Paterno, Photochemically-assisted synthesis of non-toxic and biocompatible gold nanoparticles, Colloids Surf., B 148 (2016) 317–323.
[9] N.S.M. Yusof, M. Ashok kumar, Sonochemical synthesis of gold nanoparticles by using high intensity focused ultrasound, ChemPhysChem 16 (2015) 775–781.
[10] S.K. Seol, D. Kim, S. Jung, Y. Hwu, Microwave synthesis of gold nanoparticles: effect of applied microwave power and solution pH, Mater. Chem. Phys. 131 (2011) 331–335.
[11] C. Balalakshmi, K. Gopinath, M. Govindarajan, R. Lokesh, A. Arumugam, N.S. Alharbi, S. Kadaikunnan, J.M. Khaled, G. Benelli, Green synthesis of gold nanoparticles using a cheap *Sphaeranthus indicus* extract: impact on plant cells and the aquatic crustacean *Artemia nauplii*, J. Photochem. Photobiol. B 173 (2017) 598–605.
[12] K. Gopinath, K.S. Venkatesh, R. Ilangovan, K. Sankaranarayanan, A. Arumugam, Green synthesis of gold nanoparticles from leaf extract of *Terminalia arjuna*, for the enhanced mitotic cell division and pollen germination activity, Ind. Crop. Prod. 50 (2013) (2013) 737–742.
[13] P. Balashanmugam, P. Durai, M.D. Balakumaran, P.V. Kalaichelvan, Phytosynthesized gold nanoparticles from *C. roxburghii* DC. leaf and their toxic effects on normal and cancer cell lines, J. Photochem. Photobiol. B 165 (2016) 163–173.
[14] A. Aravinthan, S. Kamala-Kannan, M. Govarthanan, J.H. Kim, Accumulation of biosynthesized gold nanoparticles and its impact on various organs of Sprague Dawley rats: a systematic study, Toxicol. Res. 5 (2016) 1530.
[15] V.P.N. Sanna, G. Dessì, P. Manconi, A. Mariani, S. Dedola, M. Rassu, C. Crosio, C. Iaccarino, M. Sechi, Single-step green synthesis and characterization of gold conjugated polyphenol nanoparticles with antioxidant and biological activities, Int. J. Nanomedicine 9 (2014) 17.
[16] M. Noruzi, D. Zare, K. Khoshnevisan, D. Davoodi, Rapid green synthesis of gold nanoparticles using *Rosa hybrida* petal extract at room temperature, Spectrochim. Acta A 79 (2011) 1461–1465.
[17] P. Velmurugan, M. Cho, S.M. Lee, J.H. Park, K.J. Lee, H. Myung, B.T. Oh, Phytocrystallization of silver and gold by *Erigeron annuus* (L.) Pers flower extract and catalytic potential of synthesized and commercial nano silver immobilized on sodium alginate hydrogel, J. Saudi Chem. Soc. 20 (2016) 313–320.
[18] J. Zha, C. Dong, X. Wang, X. Zhang, X. Xiao, X. Yang, Green synthesis and characterization of monodisperse gold nanoparticles using *Ginkgo Biloba* leaf extract, Optik 144 (2017) 511–521.
[19] J. Yu, D. Xu, H.N. Guan, C. Wang, L.K. Huang, D.F. Chi, Facile one-step green synthesis of gold nanoparticles using *Citrus maxima* aqueous extracts and its catalytic activity, Mater. Lett. 166 (2016) 110–112.
[20] A. Bankar, B. Joshi, A. Ravi Kumar, S. Zinjarde, Banana peel extract mediated synthesis of gold nanoparticles, Colloids Surf., B 80 (2010) 45–50.