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ORIGINAL ARTICLE

Exploitation of de-oiled jatropha waste for gold nanoparticles synthesis: A green approach

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Abstract A novel single step green-synthesis route has been developed for the synthesis of gold nanoparticles using aqueous extract of *de-oiled jatropha waste* (*DJW*). *DJW*, a second stage waste, was adopted as a reducing agent to reduce $HAuCl_4$. Different optimal parameters such as ratio of $HAuCl_{4(aq)}/DJW_{(aq)}$, reaction temperature and pH effects were also studied to fine-tune the shape of the gold nanoparticles (AuNPs). The resultant AuNPs were characterized by UV–visible spectrometry, Transmission electron microscopy, Selected area electron diffraction, Powder X-ray diffraction and Fourier transform infrared spectroscopy. Triangle, hexagonal and spherical shaped AuNPs were obtained with the average particle size of ~14 nm. Furthermore, the AuNPs were capped and efficiently stabilized by protein molecules present in the *DJW*. In short, this novel synthesis route provides an environmental friendly and low cost option, as compared to currently available expensive chemical and/or physical methods.

1. Introduction

With the world's growing demand for energy, alternative green energy technologies were getting much attraction recently. Biodiesel is one of the major alternative fuels adopted worldwide. Undoubtedly, abundant amount of solid wastes generated accompanies biodiesel extraction. Therefore, recycle or utilization of such waste materials becomes a crucial research topic. Recently, gold nanoparticle (AuNP) synthesis has been considered as a significant area in the field of material science due to their distinctive and tunable surface plasmon resonance, which

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plays an vital role in biomedical applications such as tissue imaging, photo-thermal therapy and drug delivery (Huang, 2006). An environmental-friendly protocol was proposed for the synthesis of AuNPs, without the usage of hazardous chemicals, to avoid adverse effects in medical applications. Subsequently, techniques such as lithography, ultrasonics, photochemical reduction and UV–irradiations have gained much attention to synthesize AuNPs (Raveendran et al., 2003). However, these techniques are expensive (Sau et al., 2001; Magnusson et al., 1999; Narayanan and Sakthivel, 2008). Fortunately, growing knowledge toward green chemistry has led the aspiration in nano-research for the synthesis of nanoparticles mediated by waste materials.

The control of composition, size, shape and dispersity is an important factor for the development of novel, facile and economically viable protocols. Among all the synthesis routes, plant-mediated and biological ways are especially suitable due to their effortlessness and eco-friendliness. For instance, plants, such as Alfalfa (Gardea-Torresdey et al., 2002, 2003), Aloe-vera (Chandran et al., 2006), Cinnamomum camphora (Huang et al., 2007) (see Table 2) have been well studied as prospective reductants for the synthesis of AuNPs.

Even though many economical reductants have been reported for the green synthesis of AuNPs, *de-oiled jatropha waste* (*DJW*) as an economical and eco-friendly material, has not yet been studied and entered in the scientific literature. Utilization of this second stage, *DJW,* as a reductant for the bio-synthesis of AuNPs is a win–win strategy because it not only converts the waste into a useful material but also prevents on-site burning of the waste and saves on disposal costs.

Here is a report on a "greener" synthesis method for the preparation of AuNPs using *DJW*. The term "greener" is used since naturally renewable energy waste material, 1 a second stage waste is used not only as reducing but also as protecting agent. Last but not the least, the proposed synthesis route is carried out at a negligible energy input.

2. Experimental

2.1. Procurement of *DJW* raw material

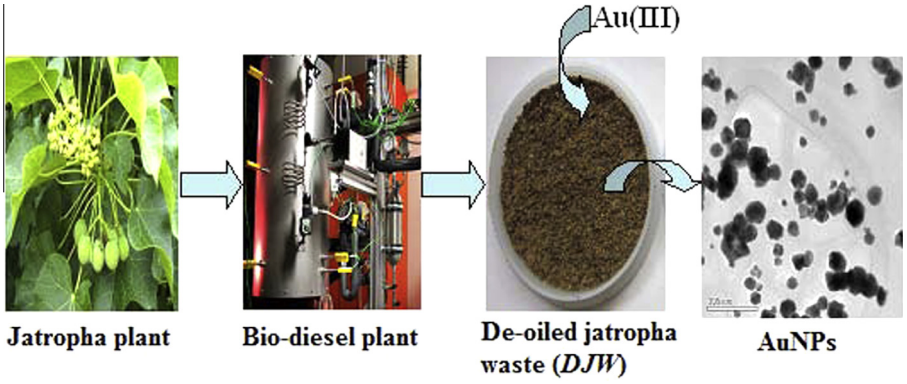
Lin et al. has been working on the production of bio-hydrogen from *de-oiled jatropha waste*, (Kumar et al., 2012; Kumar and Lin, 2013), which is obtained from a biodiesel company (Hua Neng Pvt. Ltd, Central Taiwan) after the extraction of vegetable oil from the abovementioned biomass (Aromal et al., 2012). *DJW;* a second stage waste material was used in this study. The exploration of this waste for energy (hydrogen) production has been reported in the literature (Kumar et al., 2012; Kumar and Lin, 2013). In this study, *DJW* procured from the Green Energy Development Centre, Feng Chia University, Taiwan was used for the synthesis of AuNPs as shown in Scheme 1, where detailed qualitative and quantitative composition was illustrated in earlier reports (Kumar et al., 2012; Kumar and Lin, 2013) as depicted in Table 1. 20 g of *DJW* was diluted in 70 mL of water and heated to 45 °C for 30 min and the extract was collected, filtered and ready for use.

2.2. Synthesis of AuNPs

In the present investigation, a facile, cost effective and single step green synthesis of AuNPs with $DJW_{(aq)}$, at room temperature was explored. First, 50 mg of $HAuCl_4 \bullet 3H_2O$ (Chloroauric acid; Sigma–Aldrich Chemicals) was dissolved in 120 mL of doubly distilled deionized water. For each experiments, 25 mL of $HAuCl_{4(aq)}$ was added into a beaker of 100 mL and stirred for 10 min prior to the addition of $DJW_{(aq)}$. After one hour, the color of mixture solution became orange from pale yellow, which represents the reduction of Au(III) to Au(0), indicating the formation of AuNPs. The experiment was repeated with a series of different conditions. By which, effects of $DJW_{(aq)}$ quantity (7–20 mL), which is later expressed in terms of the ratio $HAuCl_{4(aq)}/DJW_{(aq)}$, reaction temperature [RT (30–60 °C)], and pH value (3.0–6.0), were investigated.

2.3. Characterization methods

The specimens of AuNPs were ultrasonically agitated in acetone to disperse and then dried on a copper grid prior to the high-resolution transmission electron microscopy (HR-TEM) and selected area electron diffraction (SAED) examination (JEOL JEM-2100F) operated at 200 keV. The UV–visible spectra were recorded on a V-550 UV–visible spectrophotometer with samples in quartz cuvette in the range of 200–800 nm. Powder X-ray diffraction (XRD) measurements were carried out (Philips X'Pert PRO) using CuKα (0.154 nm) radiation (45 kV, 40 mA), operating at 40 kV and 40 mA. The FT-IR spectra were also recorded using a Perkin–Elmer FT-IR spectrophotometer.



Scheme 1 Schematic drawing of green synthesis flow chart.