Nanotechnol Rev 2016; 5(6): 529–536

## Research highlight

Kaushik Roy\*, Chandan K. Sarkar and Chandan K. Ghosh

**Antibacterial mechanism of biogenic copper nanoparticles synthesized using *Heliconia psittacorum* leaf extract**

DOI 10.1515/ntrev-2016-0040

Received May 29, 2016; accepted June 22, 2016; previously published

online September 15, 2016

**Abstract:** Here, we report on the novel green synthesis of metallic copper nanoparticles from copper sulfate solu- tion by using the leaf extract of *Heliconia psittacorum*. The stability and gradual formation of copper nanoparti- cles during interaction with the extract were investigated using ultraviolet-visible spectroscopy. The pattern of X-ray diffraction revealed the crystallinity and different phases of the nanoparticles. High-resolution transmission elec- tron microscopy was done to obtain information about the morphology and microstructure of the green nano- particles. The infrared spectra detected organic bioactive molecules associated with capping and stabilization of the particle surface. The antibacterial properties of these bioengineered Cu nanoparticles were tested toward a Gram-positive bacteria – *Staphylococcus aureus* – and two strains of Gram-negative bacteria – *Escherichia coli* and *Pseudomonas putida*. The antibacterial study showed that these biogenic copper nanoparticles have potent bacteri- cidal property toward the examined bacterial species.

**Keywords:** antibacterial study; biogenic copper nanopar- ticles; *Heliconia psittacorum* extract; HRTEM; UV-Vis spec- troscope; XRD.

**\*Corresponding author: Kaushik Roy,** Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata 700 032, India, e-mail: [lordkaushikroy@gmail.com;](mailto:lordkaushikroy@gmail.com) and School of Materials Science and Nanotechnology, Jadavpur University, Kolkata 700 032, India

**Chandan K. Sarkar:** Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata 700 032, India

**Chandan K. Ghosh:** School of Materials Science and Nanotechnology, Jadavpur University, Kolkata 700 032, India

# 1 Introduction

Metal nanoparticles have already been investigated for diverse applications in the field of optoelectronics, sensors, catalysis, nanomedicine, purification technolo- gies, and so on [1, 2]. In particular, the nanoparticles of coinage metals (e.g. silver, gold and copper) are drawing attention these days for their surprising optical, catalytic, sensing, and antimicrobial properties [3, 4]. Therefore, considerable effort has been dedicated to the development of novel synthetic routes for the preparation of metallic nanoparticles [5]. In contrary to gold and silver nanopar- ticles, synthesis of stable copper nanoparticles remains as a huge challenge to researchers because copper is very prone to oxidation during exposure to aqueous medium or air [6]. In spite of this adversity, some previous studies reported synthesis of copper nanoparticles by reduction of copper salts under an inert condition [7]. However, very few reports were found on preparing metallic copper nan- oparticles without inert ambience [8]. Furthermore, green synthetic routes for nanoparticles are always preferable due to their simplicity, ease, and eco-friendliness [9]. The green synthesis of copper nanoparticles is still at an early stage of development compared to the development of green synthesis methods for silver or gold [10]. Copper is an easily available, low-cost metal compared to silver and gold; hence, production of copper nanoparticles through a simple and eco-friendly method can be an easy and more economic choice for future commercial applications of nanotechnology [11].

For preparing copper nanoparticles by clean and green methods, a few studies promoted the use of bio- molecules like proteins and biopolymers [12, 13]. Jia et al. synthesized cellulose-coated Cu nanoparticles for bacte- ricidal applications [14]. Usman et al. prepared chitosan- stabilized copper nanoparticles having a mean size of 40–70 nm [15]. Nasrollazadeh et al. prepared Cu nano- particles featuring *Euphorbia esula* extract to study the catalytic activity of nanoparticles [16]. In spite of these

reports, it still remains a challenge to researchers to syn- thesize copper nanoparticles with stability, proper shape, and desired quality through green procedures. Here, for the first time, we report a novel green synthesis process for the production of surface-stabilized copper nanopar- ticles from copper salt using *Heliconia psittacorum* leaf extract under ambient conditions. The functional organic molecules present in the leaves of *H. psittacorum* can play the role of a reducing and stabilizing agent without the requirement for an inert atmosphere. This is a green, single-step process that yielded stable, biogenic copper nanoparticles with prominent antibacterial potential for all tested bacterial strains.

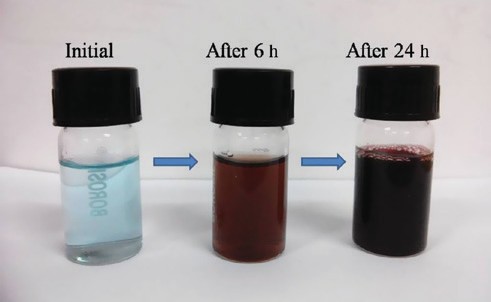
# Materials and experimental methods

## Materials

Fresh leaves of *Heliconia psittacorum* plants (shown in Figure 1) were collected from a local farm and authenti- cated before preparing the leaf extract. Analytical-grade copper sulfate was purchased from Merck India Ltd (Mumbai, India). The culture medium (nutrient agar) required for the antibacterial study was procured from



**Figure 1:** Heliconia psittacorum plants.



**Figure 2:** Color change of the reacting solution.

Himedia (Mumbai, India). Deionized (DI) water was used for performing all experiments. Glassware was cleaned with DI water and dried in the air.

## Methods

### Biosynthesis of copper nanoparticles

Around 100 g of *Heliconia psittacorum* leaves was cleaned, chopped, and then ground with 50 ml DI water inside a grinder for 10 min. The supernatant was filtered out, and the obtained soup was further used as the standard aqueous leaf extract of *H. psittacorum*. A 20 mm stock solu- tion of copper sulfate was prepared by dissolving 0.49 g of CuSO4 in 100 ml of DI water. The biological synthesis of copper nanoparticles was carried out by adding 100 ml of leaf extract of *H. psittacorum* to 100 ml stock solution of CuSO4 (conc. 20 mm), keeping the resulting concentration of the reacting solution as 10 mm. The solution was incu- bated at ambient temperature (25C) for the next 24 h. The color of the reacting solution began to change from sky blue to reddish brown after almost 6 h of observation (refer to Figure 2), indicating generation of copper nanoparticles inside the medium. The solution color darkened with the time of incubation and finally turned into dark red after 24

h. The bioreduction of copper sulfate to Cu nanoparticles

was examined periodically with an ultraviolet-visible (UV- Vis) spectrometer. The biosynthesized nanoparticles were separated out from the reacting solution by centrifugation at 5590 *g* for 20 min. The formed precipitate was redis- persed in DI water (small amount) and again centrifuged at 894 *g* for nearly 10 min for better removal of extract resi- dues. Then, the pellet deposited at the bottom of centrifu- gation tubes after repeated centrifugation was carefully collected and dried overnight in a desiccator to make the

dried powder of biosynthesized copper nanoparticles for further experiments.

### Characterization techniques to analyze Cu nanoparticles

The production of copper nanoparticles during interaction in the reacting medium was verified at certain periodic inter- vals by recording the UV-Vis spectra of the mixture under a double-beam UV-Vis spectrometer (Perkin Elmer, USA) at 400–800 nm wavelengths. The X-ray diffraction (XRD) pattern of dry particles was obtained using an X-ray diffrac- tometer (Rigaku Ultima-III; CuK radiation   0.154 nm; operating volt  −40 kV) at 2  20–80. Fourier transform infrared (FTIR) spectroscopy of the biosynthesized nano- copper was done on the KBr pellet by using a Shimadzu FTIR spectroscope (model name – IR-Prestige, Japan) in order to detect the organic molecules that contributed to the stabilization of colloidal particles. The sample for high- resolution transmission electron microscopy (HRTEM) was methodically prepared by suspending the dry powder of Cu nanoparticles in DI water, maintaining a specific con- centration, i.e. 50 g/ml. The suspension was sonicated for 15 min, and a few drops were spread evenly on copper grids before drying inside a desiccator overnight. The grid was finally scanned using HRTEM (model name – JEOL-2010; operating volt  −200 kV) to study the microstructure and lattice images of the copper nanoparticles.

### Procedure for antibacterial study

The antibacterial activities of biogenic copper nanopar- ticles were evaluated through an agar disc diffusion pro- cedure. Inoculates of bacterial species (*Staphylococcus aureus*, *Pseudomonas putida*, and *Escherichia coli*) were prepared by allowing to grow a single bacterial colony in the favorable medium (nutrient broth) overnight. The medium turbidity was set to standard McFarland scale value 0.5. The bacterial species were spread on nutrient agar plates before creating the wells of equal diameter. The suspension of Cu nanoparticles with concentration 50 g/ml was taken as S1, while its half-diluted part (i.e. concentration 25 g/ml) was taken as S2 for carrying out the concentration-dependent antibacterial study. Pure leaf extract of *Heliconia psittacorum* was used as a nega- tive control and marked as S3 in this experiment. Finally, the three samples – S1, S2, and S3 – were added in three separate wells made on each agar plate impregnated with specific bacterial strain. These agar plates were then

incubated in darkness overnight at 37C, and the inhibi- tion zone formed around cups or wells were measured to analyze the antibacterial property of these copper nano- particles. The antibacterial study was performed in tripli- cates for accuracy of obtained results.

# Results and discussion

## Preparation of biogenic Cu nanoparticles

*Heliconia psittacorum* or parrot’s flower is a perennial herbaceous plant extensively found in South Asia and South America. The green leaves and stem of this plant contain strong bioactive molecules that can reduce copper cations in the reacting medium [17]. When leaf extract of

*H. psittacorum* was added dropwise to the light blue solu- tion of CuSO4, the color of the mixture remained light blue initially. After observation for 6 h at ambient tempera- ture, expectedly the color of the reacting solution began to change from light blue to reddish brown, as shown in Figure 2. This may be owing to the reduction of Cu2 by biomolecules present in *H. psittacorum* leaf extract and further stabilization of the colloidal particles in the solu- tion [18]. Gradual change in the solution color was noticed over a period of 24 h as the color intensified with time and turned into dark red, denoting the saturation point of nanoparticle production [19]. The reacting solution was scanned at regular intervals (every 3 h) under a UV-Vis spectrophotometer to investigate the production of Cu nanoparticles and further kinetic study of this green syn- thetic route. The absorbance spectra (shown in Figure 3A) feature maximum absorbance near 550 nm wavelength, confirming the synthesis of copper nanoparticles and spectral recordings at different time intervals provide an insight to the rate of nanoparticle formation in the react- ing solution. Figure 3B shows the variance of peak absorb- ance with time, where it is clear that initially maximum absorbance increases with time almost linearly because of higher colloidal particle production during exposure to bioactive molecules [20]. However, after 12 h of incuba- tion, the formation rate began to saturate and finally satu- rated after 24 h, as shown in Figure 3B.

## Structural analysis using XRD and HRTEM

The XRD curve of biogenic copper nanoparticles (refer to Figure 4) shows three distinct peaks at 2  43.34,

**A**

0.7

0.6

0.5

0.4

Absorbance

0.3

0.2

0.1

0.0

400 500 600 700 800

Wavelength (nm)

50.48, and 74.26 that may be attributed to the (111), (200), and (220) crystal planes of metallic copper as per JCPDS card file no.-04-0836 [21]. Thus, the XRD result verified that the green synthesized Cu nanoparticles have a crystalline nature with fcc (face centered cubic) structure.

The HRTEM images of copper nanoparticles show the shape, size, and surface morphology of the particles as depicted in Figure 5. It may be observed from the images that the leaf extract-derived copper nanoparticles have a near spherical shape and average diameter between 8 and 12 nm. The fringes of the lattice structure suggest high crystallinity, and spacing between the planes was meas- ured to be around 0.21 nm, which may correspond to the

24 h

12 h

9 h

6 h

**B** 0.45

0.40

0.35

0.30

Peak absorbance

0.25

0.20

0.15

0.10

0.05

0.00

5 10 15 20 25

Incubation time (h)

(111) crystal planes of copper.

## FTIR analysis: role of capping agent

Another prospect of green synthesis is the importance of bioactive organic molecules (found in the extract) that contribute to capping and stability of biogenic nano- particles. Figure 6 demonstrates the infrared spectra (in mode of absorbance) of the leaf extract and green-syn- thesized copper nanoparticles. The infrared spectrum of the leaf extract consists of eight notable absorb- ance peaks throughout the entire range of wavenum- ber, i.e. 500–4000 cm−1. Two distinct peaks at 1618 and

**Figure 3:** (A) UV-Vis absorption spectra of Cu nanoparticles recorded at regular intervals. (B) Variation of peak absorbance with incubation time.

160

140

(111)

120

(200)

100

Intensity

80

(220)

60

40

20

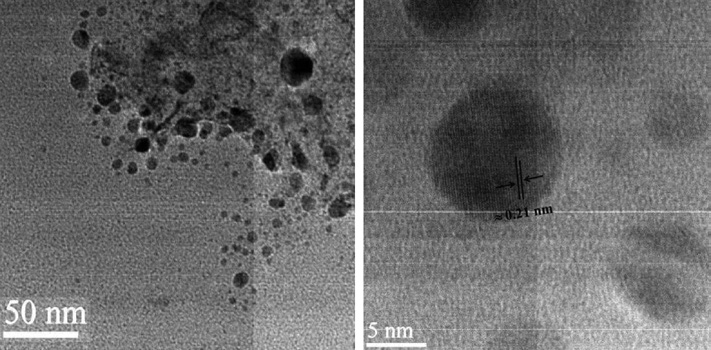
0

20 30 40 50 60 70 80

2 (°)

**Figure 4:** XRD pattern of biogenic copper nanoparticles.

3096 cm−1 may be attributed to the stretching vibration of CO and O-H bonds present in amides and aromatic organic compounds, respectively [22]. Bands at 977 and 1419 cm−1 may refer to bending of C-H bonds present in alkenes and alkanes, respectively [23]. The band noticed at 1097 cm−1 may indicate the stretching vibration of C-N bonds present in amines, and a band at 1147 cm−1 points to the stretching of the C-O bonds found in phenolic compounds [24]. Two other bands at 619 and 777 cm−1 may be attributed to the stretching vibrations arising from haloalkanes [25]. As observed in Figure 6, the FTIR spectrum of green-synthesized copper nanoparticles appears less intensified and broadened. In addition, the absence of impurity peaks in the recorded spectrum denotes the purity of the bioengineered nanoparticles, though small peaks of C-O and C-N bonds are shifted, suggesting the capping of copper nanoparticles by amine groups [26]. From the FTIR study, it may be con- cluded that the amine groups along with the aromatic compounds (like phenol, etc.) probably capped and sta- bilized the copper nanoparticles during production in the reacting medium [27].



**Figure 5:** HRTEM images of green copper nanoparticles.

3096

0.50

0.45

1097

1147

0.40

619

977

0.35

777

1419

1618

0.30

Absorbance

0.25

0.20

0.15

0.10

0.05

0.00

1000 2000 3000 4000

Wavenumber (cm–1)

showed zero inhibition, suggesting no role in the antibac- terial mechanism.

The zone of inhibition observed here against *Staph- ylococcus aureus* is greater than that of different leaf extract-mediated silver nanoparticles as reported by earlier studies. For example, Abdel-Aziz et al. studied the antibacterial efficacy of plant-mediated Ag nanoparti- cles toward *S. aureus* and observed the zone of inhibition around 12.63 mm [28]. Roy et al. reported that the inhi- bition zones caused by parsley leaf extract-mediated Ag nanoparticles toward *S. aureus* and *Escherichia coli* were

12.50 and 14.15 mm, respectively [29]. Recently, Gupta et al. showed that the green silver nanoparticles curbed the bacterial growth of *S. aureus* as well as *E. coli* efficiently,

**A**

**B**

**Figure 6:** FTIR spectra of (A) *Heliconia psittacorum* leaf extract and

(B) biosynthesized copper nanoparticles.

## Analysis of antibacterial activity

The antibacterial efficacy of the bioengineered copper nanoparticles was determined toward a few pathogenic bacteria – *Staphylococcus aureus*, *Pseudomonas putida*, and *Escherichia coli*. *Staphylococcus aureus* is a Gram-pos- itive bacteria, whereas *P. putida* and *E. coli* are Gram-neg- ative types. As seen from Figure 7, the largest inhibition zone was noticed against *S. aureus* irrespective of the concentration of Cu nanoparticles added. *Pseudomonas putida* and *E. coli* showed comparatively lower levels of inhibition. Quantitative analysis of the inhibitory effect of the copper nanoparticles toward the tested pathogenic strains has been demonstrated in Figure 8, where a sharp rise in the inhibitory effect may be observed depending on higher concentrations of biosynthesized copper nano-

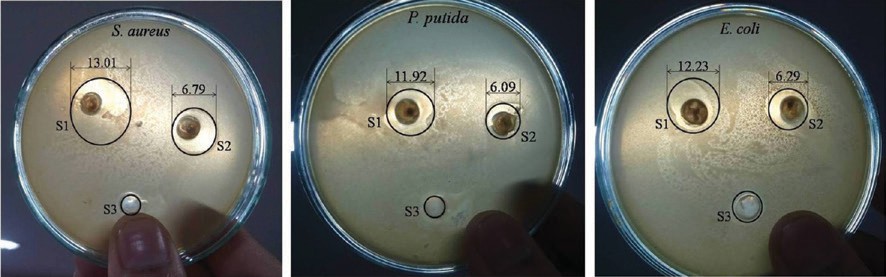
and the inhibition zones were found to be nearly 12 and 14 mm, respectively [30]. The inhibition zones obtained in this study were around 13.01, 11.92, and 12.23 mm for

*S. aureus*, *P. putida*, and *E. coli*, respectively. It is clear from these reports that copper nanoparticles show more activ- ity in preventing the growth of Gram-positive *S. aureus*, whereas Ag nanoparticles are more efficient to curb the growth of Gram-negative strains like *E. coli* and *P. putida*. The probable reason for the higher activity of Cu nan- oparticles toward Gram-positive *Staphylococcus aureus* may be the cell wall components of Gram-positive bacte- ria that contain different amines and carboxyl group com- pounds. Chemically, amines can couple with aryls in the presence of copper, leading to copper-catalyzed amina- tion, as shown below [31]. Here, the aromatic compounds, like phenol, involved in the capping of colloidal particles may act as aryls and couple with amines, resulting into the alteration of composition and permeability of bacte-

rial cell walls [32].

particles. The *Heliconia psittacorum* extract (taken as S3)

C6H5OH+RO-NH2 CuRO-NH-C6H5 +H2 O



**Figure 7:** Zone of inhibition observed after 24 h.

16

14

Diameter of inhibition zone (mm)

12

10

8

6

4

2

0

Control S2 S1 -- Control S2 S1 -- Control S2 S1

of cytoplasmic fluid. As a result, cellular transport is interrupted and the cells expire gradually [36]. Another reason for cell death may be that the metal ions released from nanoparticles during interaction with bacterial cells affect the cellular respiratory chain by inhibiting respiratory enzymes, leading to reactive oxygen species (ROS) generation. Then, ROS imparts oxidative stress to the cells, causing significant cellular damage [37]. In addition, metal nanoparticles may react with soft bases like phosphorous and sulfur present in the cellular DNA, preventing its replication and protein binding. Conse- quently, bacterial cells stop all functions and eventually die [38, 39].

*S. aureus*

Control (S3) - Extract S2 – 25 g/ml

S1 – 50 g/ml

*P. putida*

*E. coli*

**Figure 8:** Quantitative antibacterial study of biosynthesized copper nanoparticles.

Accordingly, carboxyl group compounds may decompose in the presence of copper [33].

CH3CH2COOH CuCH3 -CH3 +CO2

This catalytic reactivity of copper toward carboxyl groups and amines found in the cell wall of Gram-positive bacteria is possibly responsible for the better antibacterial efficacy of copper nanoparticles against Gram-positive *Staphylococcus aureus* than Gram-negative strains [34].

Although true mechanism for the antibacterial action of copper nanoparticles is not fully understood, there are few theories to realize the action of metallic nanoparticles on bacterial cells. Earlier studies claim that the metal nanoparticles like silver and copper have the capability to get attached on the microbial cell walls due to electrostatic attraction and further penetrate it [35]. “Pits” formation on cell membrane degrades the selective permeability of the membrane, causing leakage

# Conclusion

The green route for nanoparticle production has flour- ished in the field of nanotechnology as a fascinating alternative to common procedures for its low cost, envi- ronmental friendliness, and simplicity. Here, we reported a novel green procedure for the production of copper nanoparticles by employing the leaf extract of *Heliconia psittacorum*. The characterization techniques not only showed the crystallinity and size distribution of bio- genic copper nanoparticles but also showed the involve- ment of intrinsic bioactive moieties engaged in capping and surface stabilization of nanoparticles in the reacting solution. These green-synthesized copper nanoparticles exhibited considerable antibacterial efficacy toward the tested pathogens – *Staphylococcus aureus*, *Pseudomonas putida*, and *Escherichia coli*. Future research may be focused on finding possible ways to employ the antimi- crobial potential of biogenic copper nanoparticles to mini- mize the impact of various bacterial pathogens on human health.

**Acknowledgments:** A Senior Research Fellowship under CSIR-Direct (India) scheme is gratefully acknowledged by Kaushik Roy.

# References

1. Bogue R. Nanosensors: a review of recent research. *Sensor Rev.* 2009, 29, 310–315.
2. El-Nour KMMA, Eftaiha A, Al-Warthan A, Ammar RAA. Synthesis and applications of silver nanoparticles. *Arab. J. Chem.* 2010, 3, 135–140.
3. Kumbhakar P, Ray SS, Stepanov AL. Optical properties of nano- particles and nanocomposites. *J. Nanomat.* 2014, 2014, Article ID 181365, 1–2.
4. Roy K, Sarkar CK, Ghosh CK. Photocatalytic activity of biogenic silver nanoparticles synthesized using potato (*Solanum tuberosum*) infusion. *Spectrochim. Acta Pt. A* 2015, 146, 286–291.
5. Serizawa T, Hirai Y, Aizawa M. Novel synthetic route to peptide-capped gold nanoparticles. *Langmuir* 2009, 25, 12229–12234.
6. Singh BP, Jena BK, Bhattacharjee S, Besra L. Development of oxidation and corrosion resistance hydrophobic graphene oxide-polymer composite coating on copper. *Surf. Coatings Technol.* 2013, 232, 475–481.
7. Benavente E, Lozano H, Gonzalez G. Fabrication of copper nanoparticles: advances in synthesis, morphology control, and chemical stability. *Rec. Pat. Nanotechnol*. 2013, 7, 108–132.
8. Harne S, Sharma A, Dhaygude M, Joglekar S, Kodam K, Hudlikar M. Novel route for rapid biosynthesis of copper nano- particles using aqueous extract of *Calotropis procera* L. latex and their cytotoxicity on tumor cells. *Colloids Surf. B Biointer- faces* 2012, 95, 284–288.
9. Iravani S. Green synthesis of metal nanoparticles using plants.

*Green Chem.* 2011, 13, 2638–2650.

1. Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, Taliansky ME, Kalinina NO. “Green” nanotechnologies:

synthesis of metal nanoparticles using plants. *Acta Nat.* 2014, 6, 35–44.

1. Athanassiou EK, Grass RN, Stark WJ. Large-scale production of carbon-coated copper nanoparticles for sensor applications. *Nanotechnology* 2006, 17, 1668–1673.
2. Morioka T, Takesue M, Hayashi H, Watanabe M, Smith RL,

Jr. Antioxidation properties and surface interactions of polyvinylpyrrolidone-capped zerovalent copper nanoparticles synthesized in supercritical water. *ACS Appl. Mater. Interfaces* 2016, 8, 1627–1634.

1. Valodkar M, Jadeja RN, Thounaojam MC, Devkar RV, Thakore S. Biocompatible synthesis of peptide capped copper nanopar- ticles and their biological effect on tumor cells. *Mater. Chem. Phys.* 2011, 128, 83–89.
2. Jia B, Mei Y, Cheng L, Zhou J, Zhang L. Preparation of copper nanoparticles coated cellulose films with antibacterial proper- ties through one-step reduction. *ACS Appl. Mater. Interfaces* 2012, 4, 2897–2902.
3. Usman MS, El Zowalaty ME, Shameli K, Zainuddin N, Salama M, Ibrahim NA. Synthesis, characterization, and antimicrobial

properties of copper nanoparticles. *Int. J. Nanomed.* 2013, 8, 4467–4479.

1. Nasrollazadeh M, Sajadi SM, Khalaj M. Green synthesis of copper nanoparticles using aqueous extract of the leaves of *Euphorbia esula* L and their catalytic activity for ligand-free Ullmann-coupling reaction and reduction of 4-nitrophenol. *RSC Adv.* 2014, 4, 47313–47318.
2. Castro ACR, Aragão FAS, Loges V, Costa AS, Willadino LG, Castro MFA. Macronutrients contents in two development phases of *Heliconia psittacorum. Acta Hort.* 2011, 886, 285–288.
3. Susman MD, Feldman Y, Vaskevich A, Rubinstein I. Chemical deposition and stabilization of plasmonic copper nanoparti- cle films on transparent substrates. *Chem. Mater.* 2012, 24, 2501–2508.
4. Salvadori MR, Lepre LF, Ando RA, do Nascimento CAO, Correa

B. Extra and intracellular synthesis of nickel oxide nanopar- ticles mediated by dead fungal biomass. *PLoS One* 2013, 8, 1–8.

1. Roy K, Sarkar CK, Ghosh CK. Rapid colorimetric detection of Hg2 ion by green silver nanoparticles synthesized using *Dahlia pinnata* leaf extract. *Green Process. Synth.* 2015, 4, 455–461.
2. Rahman K, Khan A, Muhammad NM, Jo J, Choi K. Fine-reso- lution patterning of copper nanoparticles through electrohy- drodynamic jet printing. *J. Micromech. Microeng.* 2012, 22, 065012.
3. Smith BC. *Infrared Spectral Interpretation: A System- atic Approach*. CRC Press: Boca Raton, FL, 1998. ISBN: 9780849324635.
4. Isaac RSS, Sakthivel G, Murthy C. Green synthesis of gold and silver nanoparticles using *Averrhoa bilimbi* fruit extract. *J. Nanotechnol.* 2013, 906592, 6.
5. Roy K, Sarkar CK, Ghosh CK. Green synthesis of silver nano- particles using fruit extract of *Malus domestica* and study of its antimicrobial activity. *Dig. J. Nanomater. Bios.* 2014, 9, 1137–1147.
6. Cavallo G, Metrangolo P, Terraneo G. The halogen bond. *Chem. Rev.* 2016, 116, 2478–2601.
7. Duchaniya RK. Optical studies of chemically synthesis CdS nanoparticles. *Int. J. Min. Metal. Mech. Eng.* 2014, 2, 54–56.
8. Cheirmadurai K, Biswas S, Murali R, Thanikaivelan P. Green synthesis of copper nanoparticles and conducting nanobio- composites using plant and animal sources. *RSC Adv.* 2014, 4, 19507–19511.
9. Abdel-Aziz MS, Shaheen MS, El-Nekeety A, Abdel-Wahhab MA. Antioxidant and antibacterial activity of silver nanoparticles biosynthesized using *Chenopodium murale* leaf extract. *J. Saudi Chem. Soc.* 2013, 18, 356–363.
10. Roy K, Sarkar CK, Ghosh CK. Plant-mediated synthesis of silver nanoparticles using parsley (*Petroselinum crispum*) leaf extract: spectral analysis of the particles and antibacterial study. *Appl. Nanosci.* 2015, 5, 945–951.
11. Gupta K, Barua S, Hazarika SN, Manhar AK, Nath D, Karak N, Namsa ND, Mukhopadhyay R, Kalia VC, Mandal M. Green silver nanoparticles: enhanced antimicrobial and antibiofilm activity with effects on DNA replication and cell cytotoxicity. *RSC Adv.* 2014, 4, 52845–52855.
12. Baiker A, Monti D, Fan YS. Deactivation of copper, nickel and cobalt catalysts by interaction with aliphatic amines. *J. Catal.* 1984, 88, 81–88.
13. Guo Z, Chen G, Liu L, Zeng G, Huang Z, Chen A, Hu L. Activity variation of *Phanerochaete chrysosporium* under nanosilver exposure by controlling of different sulfide sources. *Sci. Rep.* 2016, 6, 20813–20818.
14. Hortin GL, Meilinger B. Cross-reactivity of amino acids and other compounds in the biuret reaction: interference with uri- nary peptide measurements. *Clin. Chem.* 2005, 51, 1411–1419.
15. Ruparelia JP, Chatterjee AK, Duttagupta SP, Mukherji S. Strain specificity in antimicrobial activity of silver and copper nano- particles. *Acta Biomater.* 2008, 4, 707–716.
16. Chakrapani V, Ahmed KBA, Kumar VV, Ganapathy V, Anthony SP, Anbazhagan V. A facile route to synthesize casein capped copper nanoparticles: an effective antibacterial agent and selective colorimetric sensor for mercury and tryptophan. *RSC Adv.* 2014, 4, 33215–33221.
17. Kruk T, Szczepanowicz K, Stefanska J, Socha RP, Warszynski P. Synthesis and antimicrobial activity of monodisperse copper nanoparticles. *Colloids Surf. B Biointerfaces* 2015, 128, 17–22.
18. Aziz N, Faraz M, Pandey R, Shakir M, Fatma T, Varma A, Barman I, Prasad R. Facile algae-derived route to biogenic silver nano- particles: synthesis, antibacterial and photocatalytic proper- ties. *Langmuir* 2015, 31, 11605–11612.
19. Hatchett DW, Henry S. Electrochemistry of sulfur adlayers on the low-index faces of silver. *J. Phys. Chem.* 1996, 100, 9854–9859.
20. Völker C, Oetken M, Oehlmann J. The biological effects and possible modes of action of nanosilver. *Rev. Environ. Contam. Toxicol.* 2013, 223, 81–106.

**Chandan K. Sarkar**

Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata 700 032, India

Chandan K. Sarkar received his DPhil degree from University of Oxford, UK, in 1983. He joined Jadavpur University, India, in 1987 and is currently working as a professor in the Department of Elec- tronics and Telecommunication Engineering, Jadavpur University, India.

**Chandan K. Ghosh**

School of Materials Science and Nanotechnology, Jadavpur University, Kolkata 700 032, India

Chandan K. Ghosh received his PhD in science from Jadavpur University, India. He is currently working as an assistant professor in the School of Materials Science and Nanotechnology, Jadavpur University, India.

# Bionotes

**Kaushik Roy**

Department of Electronics and Telecommunication Engineering, Jadavpur University, Kolkata 700 032, India;

and School of Materials Science and Nanotechnology, Jadavpur University, Kolkata 700 032, India [**lordkaushikroy@gmail.com**](mailto:lordkaushikroy@gmail.com)

Kaushik Roy completed MTech in nanoscience and technology in 2012 at Jadavpur University, India. He is currently working as a senior research fellow in Jadavpur University, India, and his field of interest lies on different applications of noble metal nanoparticles.