Antimicrobial Potential of *Andrographis paniculata* Conjugated Gold Nanoparticle

Nurulshima Razalli¹, Subash C. B. Gopinath¹,²*, Farizul Hafiz Kasim¹,³, Ahmad Radi Wan Yaakub¹, Periasamy Anbu⁴

¹School of Bioprocess Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia  
²Institute of Nano Electronic Engineering, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia  
³Centre of Excellence for Biomass Utilization, School of Bioprocess Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia  
⁴Department of Biological Engineering, College of Engineering, Inha University, Incheon 402-751, Republic of Korea  
*Correspondence to: Subash C. B. Gopinath, email: subash@unimap.edu.my

Received: May 23, 2019 Accepted: July 4, 2019 Published: July 17, 2019 DOI: doi.org/10.26689/itps.v2i1.744
Copyright: Razalli et al. This is an open-access article distributed under the terms of the Attribution-Non-Commercial 4.0 International 4.0 (CC BY-NC 4.0), which permits all non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract: Background: Herbal extracts have been traditionally used as antibacterial agents, and different strategies have been proposed to enhance their antimicrobial activities. This research aimed to assess the antimicrobial potential of *Andrographis paniculata* conjugated gold nanoparticle (GNP) compounds against *Escherichia coli* and *Bacillus subtilis*.

Methods: Herbal extract was conjugated with GNP through electrostatic interaction, and characterization was carried out by Fourier-transmission infrared spectroscopy, screening electron microscopy, and transmission electron microscopy and supported by energy-dispersive X-ray spectroscopy. Antibacterial activity of the herbal extract and GNP conjugation was evaluated by disc diffusion assay.

Results: Chemical and morphological characterizations of the GNP and herbal extract conjugate revealed intactness of the GNP. In disc diffusion assay, the inhibition zone formed by these compounds was measured for both microorganisms, and they were in the range of 0.6-0.9 cm for the herbal extract. When the herbal extract conjugated with GNP, the zone was between 0.8 and 1.1 cm.

Conclusion: This study demonstrated the potentiality of GNP to carry the antibacterial compounds from the herbal extract.

Keywords: *Andrographis paniculata*; Gold nanoparticle; Antimicrobial potential; Herbal extract

1. INTRODUCTION

Before the existence of microbes was discovered, humans believed that plants have healing properties, reflecting the current antimicrobial characterization principles [1,2]. Formerly, humans utilized plants to treat infectious diseases, and the so-called “traditional medicines” are still being used for the treatment of various illnesses [3-5]. The original plants are the sources of natural compounds which have the antimicrobial potential and are likely to become the new anti-infection agents. In the previous studies, it was said that the search on novel anti-infection or antimicrobial agents has been underway in various fields including ethnopharmacology. Different studies have focused on investigating the antimicrobial activity of plant extract. With these developments, many assays are generated involving the extracts from different parts of plant such as stem, leave, or root of the plant [6-8].

*Hempedu bumi* (*Andrographis paniculata*) is a Ayurveda Herb shrub that belongs to the Acanthaceae family [9,10]. *A. paniculata* grows predominantly in Taiwan, Sri Lanka, China, and India. In China, this plant is used as the herbal medicine for various illnesses. Recently, *A. paniculata* herb is widely used to treat different diseases [11-14].

Nanotechnology is an emerging area of study that gains increasing interest, and it focuses on the development of biological and synthetic methods in nanoparticle
arepowder was weighed, added Bacillus subtilis) and Gram-

7 herbal extract, GNP, and used were nutrient agar, nutrient broth, and ampicillin which conjugated GNP were used in this experiment. Other materials samples namely, compounds was purchased from Sigma Aldrich, USA. Two in Selangor, Malaysia. GNP which was used to capture the herbal evaluate the inhibitory effects of compounds in Malaysia Perlis. The main material used in the experiment to negative (Escherichia coli) bacteria. These bacterial species were provided by the School of Bioprocess Engineering, Universiti Malaysia Perlis. The main material used in the experiment to evaluate the inhibitory effects of compounds in A. paniculata leaves which were purchased from Ethno Resources Sdn. Bhd. in Selangor, Malaysia. GNP which was used to capture the herbal compounds was purchased from Sigma Aldrich, USA. Two samples namely, A. paniculata herbal extract and A. paniculata conjugated GNP were used in this experiment. Other materials used were nutrient agar, nutrient broth, and ampicillin which were purchased from Sigma-Aldrich, USA.

2. MATERIALS AND METHODS

2.1. Reagents and Biomolecules

GNP was selected to study the effectiveness of bactericidal agent against Gram-positive (Bacillus subtilis) and Gram-negative (Escherichia coli) bacteria. These bacterial species were provided by the School of Bioprocess Engineering, Universiti Malaysia Perlis. The main material used in the experiment to evaluate the inhibitory effects of compounds in A. paniculata leaves which were purchased from Ethno Resources Sdn. Bhd. in Selangor, Malaysia. GNP which was used to capture the herbal compounds was purchased from Sigma Aldrich, USA. Two samples namely, A. paniculata herbal extract and A. paniculata conjugated GNP were used in this experiment. Other materials used were nutrient agar, nutrient broth, and ampicillin which were purchased from Sigma-Aldrich, USA.

2.2. Extraction of A. paniculata and Conjugation of Herbal Extract with GNP

Five grams of A. paniculata powder was weighed, added to 50 mL of sterile distilled water, and allowed to suspend overnight. The collected pure herbal extract was then heated on a hot plate at 55°C for 10 min. The extracted solution was cooled and filtered using the filter paper. The extracted solution was also subject to fine contamination removal by filtration using syringe filter. Finally, sterile Falcon tube was used to store the herbal extract solution and it was kept at 4°C for further use [10].

To conjugate, the obtained herbal extract was mixed with the purchased GNP. After incubation for 30 min, the herbal extract conjugated GNP was centrifuged. Collected pellet was washed thrice with plenty of water and used for further characterization [10].

2.3. Characterization of A. paniculata Conjugated GNP

2.3.1. Morphological Observation

Scanning electron microscopy (SEM) (Hitachi, S-4300 SE, Japan) and transmission electron microscopy (TEM) were used for characterizing the morphology of the nanoparticles. Experiments were conducted with different magnifications to determine the shape, size, and distribution of the particles. In this experiment, herbal extract conjugated GNP was characterized by TEM (JEM-2100F; JEOL Ltd., Japan). The presence of GNP was confirmed using energy-dispersive X-ray (EDX) spectroscopy. Sample preparation for TEM was done by depositing on a copper grid, and the samples were analyzed after evaporating the liquid portion [2,10].

2.3.2. Fourier-Transform Infrared (FTIR) Spectroscopy

The FTIR spectroscopy was performed to analyze both dissolved leaf sample and the conjugated GNP. The analyzed samples include A. paniculata herbal extract, GNP, and A. paniculata herbal extract conjugated GNP. The samples were analyzed using Shimadzu 8400 s within a spectral range of 400-4000 cm⁻¹. The purpose of this method was to predict the chemical functional groups of the samples [2,10].

2.4. Evaluation of Antimicrobial Activity

2.4.1. Preparation of Bacillus Spp. And E. Coli

First, a pinpoint of inoculum of each microorganism was taken from the basic culture, and they were grown independently in the sterile culture tube containing 3 mL of sterilized broth. The bacterium inoculated broth was grown overnight, and then, the number of colonies with 10⁷ cells was used for the disc diffusion assay in nutrient agar plate. All the materials used were sterile and have been autoclaved at 121°C for 15 min [10].

2.4.2. Preparation of Nutrient Agar Plate

A 14 g of nutrient agar powder was weighed and suspended in 1 L of distilled water. The solution was sterilized in autoclave, and the nutrient agar solution was left to cool until reaching 50°C. It was then transferred into the sterile Petri dishes
under the sterile condition to prevent contamination. The Petri dishes were sealed and covered using Parafilm™ and stored in refrigerator until the next usage to avoid contamination.

2.4.3. Disc Diffusion Assay

Disc diffusion assay is one of the methods that can be used to evaluate antimicrobial activity. Filter paper was used to absorb the solution on the surface of nutrient agar plate [10]. The filter paper was punched into small circles and sterilized by autoclaving. The sterilized filter paper discs were kept in a sealed container for further use. Experiments were performed in triplicates.

2.4.4. Preparation of Dilutions

Dilutions were made and tested to get the minimum inhibition concentration by the microbial activity using disc diffusion method. The ratio of the sterile distilled water: A. paniculata herbal extract solution was 1:1. Initially, 500 μL of A. paniculata herbal extract solution was transferred into the first test tube (1) using micropipette. Then, 250 μL of A. paniculata herbal extract solution from test tube (1) was transferred into test tube (2), and 250 μL of the sterile distilled water was added. These steps were repeated for following test tubes (3-5). The dilutions were made using micropipette with sterile tip to prevent contamination.

2.4.5. Disc Diffusion Method and Determination of Minimum Inhibitory Concentration (MIC)

Initially, 100 μL of B. subtilis. (10^7 cells) was pipetted onto the agar plate then spread well. Using forceps, sterile filter paper discs were transferred onto the surface of the agar plate carefully. The filter paper discs were labeled properly, and each filter paper disc was loaded with different amounts of solutions (20, 25, 30, 35, 40, and 45 μL) from the dilutions made. Then, the agar plates were placed in the incubator set at 37°C overnight and monitored on the next day. Different dilutions containing 20, 25, 30, 35, 40, and 45 μg of compounds from the plant extract were tested to determine the MIC. These steps for the disc diffusion method were repeated for E. coli as well to find the MIC. A clear zone of inhibition formed at the end of the incubation and diameter was measured using a ruler [10]. The experiment was repeated using conjugated GNP sample. Experiments were performed in triplicates.

3. RESULTS AND DISCUSSION

In this study, compounds of A. paniculata leaf extract were collected and conjugated with GNP. The complex compounds were characterized morphologically and chemically by SEM, TEM, and FTIR. Furthermore, the antimicrobial potential of the conjugated GNP and herbal extract was tested separately (Fig. 1).

3.1. SEM

SEM analysis was performed to determine the size of the particles consisted in the complex of herbal extract and GNPs (Fig. 2A and B). This study confirmed the intactness and sizes of GNPs, indicating that the GNP nanoparticles can be used for this study. The mechanism of the properly sized GNP entry into the cell wall is unclear. However, a few hypotheses have been proposed to give some ideas on the antimicrobial effect of GNPs at nanolevel. The bactericidal activity of GNP greatly relies on the particle size. Thus, these SEM results clearly indicated that GNPs were intact with the compounds from the herbal extract.

3.2. TEM

TEM was utilized to determine the size and shape of the purchased GNPs. It has been found that used particles were polydispersed and spherical in shape. The size of molecules of the purchased GNPs with herbal extract conjugate was approximately 20 nm as shown in Fig. 3. In addition, EDX spectrum clearly confirmed the presence of gold elements.

3.3. FTIR Spectroscopy

Measurement using FTIR spectroscopy was carried out to identify the possible molecules from A. paniculata herbal extract conjugated gold nanoparticle. Extract of Andrographis paniculata is conjugated with gold nanoparticle for the assessment of antibacterial activity.
extract and *A. paniculata* herbal extract conjugated GNP that exhibit efficient antimicrobial properties. FTIR has been performed with three samples such as the herbal extract, GNP, and herbal extract conjugated GNP. The spectrum of *A. paniculata* herbal extract displayed a broadband at 3364.99 cm\(^{-1}\), which represented the stretching of O-H functional group while the weak band at 1640.12 cm\(^{-1}\) was corresponding to the asymmetric stretching of C=O group (Fig. 4A). The spectrum with a broadband of GNP molecule was at 3372.44 cm\(^{-1}\), and the weak band was at 1638.60 cm\(^{-1}\) (Fig. 4B). FTIR spectrum confirmed the presence of hydroxyl and carbonyl group in *A. paniculata* herbal extract. In addition, the broadband and weak band stretching for GNP indicated the presence of C=O stretching. Different reports have revealed the role of hydroxyl and carbonyl groups in the preparation of herbal extract including their phytochemical and phenolic compounds that can act as a reducing and stabilizing agent. The sample of herbal extract conjugated with GNP molecule showed the highest broadband as compared to the spectrum of herbal extract and GNP. The herbal extract conjugated GNP showed the strong broadband at 3374.53 cm\(^{-1}\) and the weak broadband at 1639.55 cm\(^{-1}\) (Fig. 4C). This result proved that *A. paniculata* herbal extract can be combined with GNP to make bioreductant and capping agent.

3.4. Antimicrobial Activity of Herbal Extract and GNP Conjugate

Antimicrobial activity of herbal extract and *A. paniculata* herbal extract conjugated GNP against two different microorganisms, namely *E. coli* and *B. subtilis* was studied (Figs. 5 and 6). The conjugated GNPs and herbal extract exhibited an inhibitory activity against the bacterial growth. Zone of inhibition was recorded, and the inhibition zone for herbal extract was in the range from 0.6±0.05 to 0.9±0.08 cm. For the herbal extract conjugated GNP, the zone was between 0.8±0.06 and 1.1±0.1 cm. The antibacterial effect was noticed in both Gram-negative and Gram-positive bacteria. However, this finding was not consistent with the antimicrobial activity.
of GNP and herbal extract conjugates as stated in other studies although applications of gold (Au) are claimed to be better. It is widely accepted that metal nanoparticles are harmful to fungi and bacteria [40], and this characteristic allows them to adhere with cell wall of microorganisms, resulting in the destruction and death of the cell. In this study, different concentrations (20, 25, 30, 35, 40, and 45 µg) of herbal extracts were tested. The MIC was determined at 45 µg and it was compared with the conjugation with GNPs (Figs. 5 and 6). Further, there is no significant difference in the antimicrobial activity against B. subtilis and E. coli. This study is well supported by and can be correlated with the previous findings which were demonstrated using graphene and silver nanoparticle conjugating the herbal extract for microbial inhibitions [2,10].

4. CONCLUSION

The herbal extract from A. paniculata conjugated GNP was analyzed using TEM, SEM, and FTIR spectroscopy. The characterization experiment determined the morphology, size, shape, and chemical nature of the herbal extract conjugated GNP. Furthermore, the antimicrobial potential of A. paniculata conjugated GNP was assessed. Disc diffusion method was used to evaluate the antimicrobial activity. From this study, the zones of inhibition found for both B. subtilis and E. coli by herbal extract conjugated GNP were in the range between 0.8±0.06 and 1.1±0.1 cm. The inhibition zone for herbal extract was slightly smaller than the conjugated GNP, ranging from 0.6±0.05 to 0.9±0.08 cm. The obtained results clearly indicate better antimicrobial potential of herbal extract conjugated GNP than the herbal extract alone, and a larger zone of inhibition is probably due to the better dispersion of the compound in aqueous solution. Validation with additional inhibition studies should be performed for more insights.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Ramanathan, S.; Gopinath, S.C.B. Potentials in Synthesizing Nanostructured Silver Particles. Microsyst. Technol., 2017, 10, 1-13.
[2] Gopinath, S.C.B.; Ramanathan, S.; Suk, K.H.; Ee Foo, M.; Anbu, P.; Uda, M.N.A. Engineered Nanostructures to Carry the Biological Ligands. MATEC Web Conf., 2018, 150, 6002.
[3] Cowan, M.M. Plant Products as Antimicrobial Agents. Clin. Microbiol. Rev., 1999, 12(4), 564-82.
[4] Krishnaiah, D.; Sarbatly, R.; Nithyanandam, R. A Review of the Antioxidant Potential of Medicinal Plant Species. Food Bioprod. Process., 2011, 89(3), 217-33.
[5] Bono, D. R. S.; Krishnaiah, D.; Sarbatly, R.; Bono, A. Phytochemical Antioxidants for Health and Medicine a Move Towards Nature. Biotechnol. Mol. Biol. Rev., 2007, 1, 97-104.
[6] Williams, G.C.; Nesse, R.M. The Dawn of Darwinian Medicine. Q. Rev. Biol., 2004, 66(1), 1-22.
[7] Pandey, K.B.; Rizvi, S.I. Plant Polyphenols as Dietary Antioxidants in Human Health and Disease. Oxid. Med. Cell. Longev., 2009, 2(5), 270-8.
[8] Daszak, P.; Tabor, G.M.; Kilpatrick, A.M.; Epstein, J.; Plewriiwt, R. Conservation Medicine and a New Agenda for Emerging Diseases. Ann. N. Y. Acad. Sci., 2004, 1026, 1-11.
[9] Wasman, S.Q.; Mahmood, A.A.; Chua, L.S.; Alshawsh, M.A.; Hamdan, S. Antioxidant and Gastroprotective Activities of Andrographis paniculata (Hempedu bumi) in Sprague Dawley rats. Indian J. Exp. Biol., 2011, 49(10), 767-72.
[10] Foo, M.E.; Anbu, P.; Gopinath, S.C.B.; Lakshmipriya, T.; Lee, C.G.; Yun, H. S.; Uda, M.N.A.; Yaukob, A.R.W. Antimicrobial Activity of Functionalized Single-walled Carbon Nanotube with Herbal Extract of Hempedu bumi. Surf. Interface Anal., 2018, 50(3), 354-61.
[11] Kumar, R.A.; Kudalay, V.; Kumar, N.V.; Nanduri, S.; Rajagopal, S. Anticancer and Immunostimulatory Compounds from Andrographis Paniculata. J. Ethnopharmacol., 2004, 29(2-3), 291-5.
[12] Zaidan, M.R.; Rain, A.N.; Badrul, A.R.; Adlin, A.; Norazah, A.; Zakiah, I. In Vitro Screening of Five Local Medicinal Plants for Antibacterial Activity Using Disc Diffusion Method. Trop. Biomed., 2005, 22(2), 165-70.
[13] Roy, S.; Rao, K.; Bhuvaneswari, C.; Giri, A.; Mangamooori, L.N. Phytochemical Analysis of Andrographis Paniculata Extract and its Antimicrobial Activity. World J. Microbiol. Biotechnol., 2010, 26(1), 85-91.
[14] Subramanian, R.; Asmawi, M.Z.; Sadikun, A. In Vitro α-Glucosidase and α-Amylase Enzyme Inhibitory Effects of Andrographis Paniculata Extract and Andrographide. Acta Biochim. Pol., 2008, 55(2), 391-8.
[15] Gopinath, S.C.B.; Kumar, P.K.R.; Tominaga, J. A BioDVDA Media with Multilayered Structure is Suitable for Analyzing Biomolecular Interactions. J. Nanosci. Nanotechnol., 2011, 11(7), 1-7.
[16] Gopinath, S.C.B.; Kumaresan, R.; Awazu, K.; Fujimaki, M.; Mizuhata, M.; Tominaga, J.; Kumar, P.K.R. Evaluation of Nucleic Acid Duplex Formation on Gold over Layers in Biosensor Fabricated Using Czochralski-Grown Single-Crystal Silicon Substrate. Anal. Bioanal. Chem., 2010, 398(2), 751-8.
[17] Tanisell, S.; Md Arshad, M.K.; Gopinath, S.C.B. Current State of Green Reduction Strategies: Solution-Processed Reduced Graphene Oxide for Healthcare Biodetection. Mater. Sci. Eng. C, 2018, 96, 904-14.
[18] Anasdass, J.R.; Kannaiyan, P.; Raghavachary, R.; Gopinath, S.C.B.; Chen, Y. Palladium Nanoparticle-Decorated Reduced Graphene Oxide Sheets Synthesized Using Ficus Carica Fruit Extract: A Catalyst for Suzuki Cross-Coupling Reactions. PLoS One, 2018, 13(2), 1-13.
[19] Lakshmipriya, T.; Fujimaki, M.; Gopinath, S.C.B.; Awazu, K.; Horiguchi, Y.; Nagasaki, Y. A High-Performance Waveguide-Mode Biosensor for Detection of Factor IX Using PEG-Based Blocking Agents to Suppress Non-Specific Binding and Improve Sensitivity. Analyst, 2013, 138(10), 2863.
[20] Lakshmipriya, T.; Horiguchi, Y.; Nagasaki, Y. Co-Immobilized Poly(Ethylene Glycol)-Block-Polyamines Promote Sensitivity and Restrict Biofouling on Gold Sensor Surface for Detecting Factor IX in Human Plasma. Analyst, 2014, 139(16), 3977-85.
[21] Lakshmipriya, T.; Gopinath, S.C.B.; Citartan, M.; Hashim, U.; Tang, T.H. Gold Nanoparticle-Mediated High-Performance Enzyme-Linked Immunosorbent Assay for Detection of Tuberculosis ESAT-6 Protein. Micro Nanosyst., 2016, 8(2), 92-8.
[22] Lakshmipriya, T.; Gopinath, S.C.B.; Tang, T.H. Biotin-Streptavidin Competition Mediates Sensitive Detection of Biomolecules in Enzyme Linked Immunosorbent Assay. PLoS One, 2016, 11(3), e0151153.
[23] Gopinath, S.C.B.; Awazu, K.; Fujimaki, M.; Shimizu, K.; Shima, T. Observations of Immuno-Gold Conjugates on Influenza Viruses Using Waveguide-Mode Sensors. PLoS One, 2013, 8(7), 1-10.
[24] Gopinath, S.C.B.; Awazu, K.; Fujimaki, M.; Shimizu, K.; Mizutani, W.; Tsukagoshi, K. Surface Functionalization Chemistries on Highly Sensitive Silica-Based Biosensor for Analyzing Biomolecular Interactions. J. Nanosci. Nanotechnol., 2014, 14, 3985-91.
[25] Fujimaki, M.; Norum, K.; Sato, K.; Kato, T.; Gopinath, S.C.B.; Wang, X.; Awazu, K.; Okhi, Y. Detection of Colored Nanomaterials Using Evanescent Field-Based Waveguide Sensors. Opt. Express, 2010, 18(15), 15732-40.
Md Nor, M.N.M. Field-Effect Transistor-Integration with TiO2 Nanoparticles for Sensing of Cardiac Troponin I Biomarker. J. Nanosci. Nanotechnol., 2018, 18(8), 5283-91.

Perumal, V.; Hashim, U.; Gopinath, S.C.B.; Haarindraprasad, R.; Poopalan, P.; Liu, W.W.; Ravichandran, M.; Balakrishnan, S.R.; Ruslinda, A.R. A New Nano-Worm Structure from Gold-Nanoparticle Mediated Random Curving of Zinc Oxide Nanorods. Biosens. Bioelectron., 2016, 78, 14-22.

Letchumanan, I.; Md Arshad, M.K.; Balakrishnan, S.R.; Gopinath, S.C.B. Gold-Nanorod Enhances Dielectric Voltammetry Detection of c-Reactive Protein: A Predictive Strategy for Cardiac Failure. Biosens. Bioelectron., 2019, 130, 40-7.

Letchumanan, I.; Gopinath, S.C.B.; Md Arshad, M.K.; Anbu, P.; Lakshmipriya, T. Gold Nano-Urchin Integrated Label-Free Amperometric AptaSensing Human Blood Clotting Factor IX: A Prognosticative Approach for “Royal Disease.” Biosens. Bioelectron., 2019, 131, 128-35.

Liu, J.; Qin, G.; Raveendran, P.; Ikushima, Y.; Ikushima, Y. Facile “Green” Synthesis, Characterization, and Catalytic Function of Beta-D-Glucose-Stabilized Au Nanocrystals. Chemistry, 2006, 12(8), 2131-8.

Kuppusamy, P.; Yusoff, M.M.; Govindan, N. Biosynthesis of Metallic Nanoparticles Using Plant Derivatives and Their New Avenues in Pharmaceutical Applications an Updated Report. Saudi Pharm. J., 2014, 24(4), 473-84.

Khan, M.; Al-Marr, A.H.; Khan, M.; Shaik, M.R.; Mohri, N.; Adil, S.F.; Kuniyil, M.; Alkhalifan, H.Z.; Al-Warthan, A.; Tremel, W.; Tahir, M.N.; Siddiqui, M.R.H. Green Approach for the Effective Reduction of Graphene Oxide Using Salvadora Persica L. Root (Miswak) Extract. Nanoscale Res. Lett., 2015, 10(1), 281.

Iravani, S. Green Synthesis of Metal Nanoparticles Using Plants. Green Chem., 2011, 13, 2638-50.

Kasthuri, J.; Kathiravan, K.; Rajendiran, N. Phyllanthin-Assisted Biosynthesis of Silver and Gold Nanoparticles: A Novel Biological Approach. J. Nanopart. Res., 2009, 11(5), 1075-85.

Bankura, K.; Maity, D.; Mollick, M.M.R.; Mondal, D.; Bhowmick, B.; Roy, I.; Mdy, T.; Sarkar, J.; Rana, D.; Acharya, K.; Chattopadhyay, D. Antibacterial Activity of Ag-Au Alloy NPs and Chemical Sensor Property of Au NPs Synthesized by Dextran. Carbohydr. Polym., 2014, 107(1), 151-7.

Rónavári, A.; Igaz, N.; Gopisetty, M.K.; Szerenész, B.; Kovács, D.; Papp, C.; Vágvölgyi, C.; Boros, I.M.; Könya, Z.; Kiricsi, M.; Pfeiffer, I. Biosynthesized Silver and Gold Nanoparticles Are Potent Antimycotics against Opportunistic Pathogenic Yeasts and Dermatophytes. Int. J. Nanomed., 2018, 13, 695-703.

Gopinath, S.C.B.; Perumal, V.; Kumaresan, R.; Lakshmipriya, T.; Rajintraprasad, H.; Rao, B.S.; Arshad, M.K.M.; Chen, Y.; Kotani, N.; Hashim, U. Nanogapped Impedimetric Immunosensor for the Detection of 16Â KDa Heat Shock Protein against Mycobacterium tuberculosis. Microchim. Acta, 2016, 183(10), 2697-703.

Perumal, V.; Saheed, M.S.M.; Mohamed, N.M.; Saheed, M.S.M.; Murthe, S. S.; Gopinath, S.C.B.; Chiu, J.M. Gold Nanorod Embedded Novel 3D Graphene Nanocomposite for Selective Bio-Capture in Rapid Detection of Mycobacterium tuberculosis. Biosens. Bioelectron., 2018, 116, 116-22.

Anniebell, S.; Gopinath, S.C.B. Polymer Conjugated Gold Nanoparticles in Biomedical Applications. Curr. Med. Chem., 2018, 25(12), 1433-45.

Ramanathan, S.; Gopinath, S.C.B.; Anbu, P.; Lakshmipriya, T.; Kasim, F.H.; Lee, C.G. Eco-friendly Synthesis of Solanum trilobatum Extract-Capped Silver Nanoparticles is Compatible with Good Antimicrobial Activities. J. Mole. Struct., 2018, 1160, 80-91. 20 and 100 nm scales are shown. Energy-dispersive X-ray spectrum clearly indicates the presence of gold.