Green synthesis of antimicrobial silver nanoparticles with Brassicaceae seeds

Rehana Perveen¹, Shahida Shujaat¹, Misbah Naz², Muhammad Zahid Qureshi¹,², Shaista Nawaz¹, Khurram Shahzad¹ and Muhammad Ikram⁵

¹ Department of Chemistry, Lahore College for Women University, Lahore, Pakistan
² Department of Chemistry, Government College University, Lahore 54000, Pakistan
³ Department of Biochemistry, Deanship of Educational Services, Qassim University, Buraidah, Saudi Arabia
⁴ Food & Biotechnology Research Centre, PCSIR Laboratories Complex, Lahore, Pakistan
⁵ Solar Cell Applications Research Lab, Department of Physics, Government College University Lahore, Lahore 54000, Pakistan

E-mail: dr.muhammadikram@gcu.edu.pk

Keywords: AgNPs, green synthesis, Brassicaceae family, antibacterial potential

Abstract
Herein, we demonstrate a facile and green route for the synthesis of silver nanoparticles (AgNPs) from silver nitrate and seed extracts of different vegetable seeds of Brassicaceae family. All the nanocomposites were fully characterized in the solid-state via various techniques such as UV–vis spectrophotometer (UV–Vis); x-ray diffraction (XRD), High-resolution transmission electron microscopy (HR-TEM), energy-dispersive x-ray spectroscopy (EDS), and Fourier transform infrared (FTIR) spectrometry. The experimental parameters such as variation in seeds extract concentration, temperature, stirring time and pH were noted and optimum condition of concentration (20 ml), temperature (80 °C) and pH 8.5 was selected for the synthesis of NPs. Optical absorbance of AgNPs at ≈425 nm indicated the formation of metallic silver through surface plasmon resonance. The successful capping of biological macromolecules was confirmed by FTIR spectroscopy. XRD pattern depicted the formation of face-centered cubic silver nano-composite with average crystal size ranges from ≈14–20 nm. Bio-synthesized Ag nanoparticles showed enhanced antibacterial potential against gram-positive (B. safensis, B. subtilis, B. pumilis and S. aureus) and negative gram (E. coli and S. typhi) strains by disc diffusion method. Highest antimicrobial activity was given by sample S3 (17 mm) against B. pumilis whereas, sample S2 and S5 also showed significant bactericidal potential against B. pumilis that is 15 mm. While highest zone of inhibition for sample S1 and S4 is 14 mm.

Abbreviations
(EDS) Energy dispersive x-ray spectroscopy,
(FTIR) fourier transform infrared spectroscopy,
(G–ve) gram-positive (G +ve) and gram negative,
(HR-TEM) high resolution transmission electron microscopy,
(JCPDS) joint committee on powder diffraction standards,
(Ag) Silver,
(UV–vis) ultra-violet visible spectroscopy,
(XRD) X-ray diffraction.

1. Introduction
Nanobiotechnology is a rapidly growing arena of modern research and deals with the fabrication of materials ranges from 1–100 nm [1–5]. Metal NPs are used in different fields as they have a high surface-to-volume ratio and unique

© 2021 The Author(s). Published by IOP Publishing Ltd
physical/chemical properties [4–9]. Nanomaterials have been applied in catalysis, water treatment [7, 8, 10],
medicine, pharmaceutical industry [11, 12], optics [7], cosmetics, bio-medical [13], edible products, drug delivery,
environment, mechanics, optics, chemical factories, space companies, electron transistors, optical, electrochemical
devices [14, 15], tumor analysis and treatment [16]. Silver nanomaterials are the particles of Ag with a variety of shapes
such as hexagonal plates, nanowires, pentagonal nano-rods, decahedral nanoparticles, nano-cubes, nano-flowers and
nano-spheres [17]. Silver nanoparticles can be found as nanorods, quantum dots, carbon nanotubes, nanocapsules,
fullerenes and nanoemulsion etc [18]. Silver nanoparticles have unique characteristics like conductivity, chemical
stability, catalysis, antimicrobial, anti-viral, anti-fungal and anti-inflammatory potential [8, 12, 19, 20]. These have
been incorporated into fibers, superconducting materials, cosmetic goods, food companies [10, 21], dresses,
catheters disinfectant sprays, food containers, paints, textile products [22], soaps, shampoos, detergents, shoes,
toothpaste and medicine [1, 23]. There is a dire need to develop eco-friendly protocols for NP synthesis that require
bio-compatible molecules instead of expensive and harmful chemicals [6].

Generally, NPs are produced in numerous ways such as physical and chemical that are time-consuming,
require toxic chemicals and disturb the natural environment. So, the development of a biologically-inspired
procedure for the fabrication of NPs is highly recommended [2, 14, 24, 25]. The physical method consists of laser
ablation, chemical reduction and production of metal clusters. Radiation methods involve ultraviolet/
microwave radiation, photo-chemical and sono-electrochemical approaches [6, 26]. Numerous other chemical
procedures include chemical reduction of metal salt precursors in solution, spray pyrolysis, sono-chemical,
microwave-assisted and micro-emulsions [22, 27, 28]. Silver nanoparticles have been synthesized by various phytoconstituents like alkaloids, flavonoids, and terpenoids for the Ag+ reduction [27].

Green chemistry is a unique process because it requires only plants for NP-synthesis, which offers a good
alternative to a chemical/physical method because they are cost-effective, environmentally sustainable and easily
expanded for large-scale processing. Green method is free from high pressure, temperature and lethal chemicals.
Recently plants, bacteria, fungi, hormones [29], proteins [30, 31] and enzymes (urease) [32] are also employed for the
synthesis of NPs. Bio-molecule functionalized NPs could be rapidly prepared at room temperature through a one-pot
reaction, for example protein-functionalized NPs were successfully synthesized for a variety of proteins with a wide
range of molecular weights and isoelectric points. The prepared NPs exhibited high quantum yield, high photostability,
colloidal stability and high functionalization efficiency. Although green plant-based synthesis does not only reduce
preparation costs but does not require specific techniques and plant preparations for the synthesis of nano-composites,
they use locally available plant seeds [4, 6]. We used plants for green synthesis in this study; however, the main
disadvantage of this method is that it is difficult to determine the reactive components present in extract because plants
contain a large number of organic compounds. The present study is conducted to synthesize and characterize silver
NPs by vegetable seeds belonging to the family Brassicaceae. Vegetables of Brassicaceae family widely used as a food spice
and medicine. They are good source of antioxidants, vitamins, minerals, chlorophylls, glucosinolates and polyphenols.
In addition, vegetable seeds possess several pharmacological activities for instance anti-inflammation, bacteriostatic
and antiviral potential. They also combat various illnesses including obesity, depression, cancer, cataracts and diabetes
[33–35]. The study aims to use green and cost benefit approach for the synthesis and characterization of
environmentally benign NPs and elucidating their interaction with G (+ve) and (−ve) bacterial strains.

2. Experimental section

2.1. Materials

Silver nitrate was obtained from Sigma-Aldrich and Nutrient Agar was procured from Oxoid. Glass apparatus was
cleaned with aqua regia and deionized water. Five different seeds of Brassicaceae family were collected Nursery. The seeds
were Raphanus sativus-GC.Herb.Bot.3296, Raphanus sativus-GC.Herb.Bot.3297, Brassica rapa-GC.Herb.
Bot.3298, Brassica campestris-GC.Herb.Bot.3299) and Brassica oleracea-GC.Herb.Bot.3300. These plants were
authenticated by Dr Zaheer-ul-din Khan, Government College University Lahore, Pakistan. The analytical chemicals
were used in current project. Bacterial strains were taken from PCSIR Laboratories Lahore, Pakistan.

2.2. Preparation of plant extract and synthesis of AgNPs

Seeds (10 g) of five different plants were soaked in 100 ml double distilled water for 12 h at 25 °C. Next day,
extracts were filtered and kept in refrigerator until further proceedings. The synthesis of AgNPs was performed
by varying different factors like concentration of seed extract, pH, stirring time and temperature. Seed extracts of
five different plants were used for the synthesis of AgNPs named S1, S2, S3, S4 and S5 (table 1). 20 ml of seeds extract
was recorded as the best conditions for the synthesis of NPs. So, 20 ml of seeds extract were mixed with
100 ml aqueous solution of silver nitrate for reduction of Ag+ into Ag0. The resultant solution was stirred for
about 1 h at pH 8.5. Formation of Ag- NPs was confirmed by color change [36]. A schematic illustration of
synthesis is illustrated in figure 1.
2.3. Characterizations samples

UV–vis spectrophotometer-UV-1700 Shimadzu was employed to record the absorption spectra at the wavelength of 200–800 nm for different AgNPs. Information about structure and mean crystal size of AgNPs were monitored by XRD (model: PANalytical X’Pert PRO) with the 2θ range of 10°–80°, equipped by Cu-Kα radiation with \( \lambda = 1.540 \, \text{Å} \). The morphology of nanomaterial was characterized by Philips-CM30 along with microscope (JEOL JEM 2100F) to record HR-TEM micrographs, coupled with EDS detector. The active functional groups involve in biosynthesized NPs were investigated by BRUKER ALPHA Platinum-ATR spectrometer.

2.4. Antimicrobial activity assay

The synthesized AgNPs using plant extracts were examined for antibacterial potential by disc diffusion process against different bacterial strains using a reported method [24, 37]. Standard culture media [CM145, CM271 and CM201] was used throughout the experiment and transferred to Petri plates aseptically. Sterile paper discs

Table 1. List of samples prepared from different seed extracts.

| Sr no. | Sample | Seeds of plant                                      |
|--------|--------|-----------------------------------------------------|
| 1      | S1     | *Raphanus sativus* Linn. var. *longipinnatus* Bailey (Red Radish) |
| 2      | S2     | *Raphanus sativus* Linn. (White Radish)              |
| 3      | S3     | *Brassica rapa* Linn. (Turnip)                       |
| 4      | S4     | *Brassica campestris* Linn. var. *sarson* Prain (locally called Saag) |
| 5      | S5     | *Brassica oleracea* var. *botrytis* Linn. (Cauliflower) |

Figure 1. (a) UV–vis absorption spectra of biosynthesized silver nanoparticles using different volume of seed extract (10, 20 and 30 ml); (b) pH of reaction mixture was varied for samples; (c) Different stirring times (0, 2, 4, 6, 8 and 10 min) were used at room temperature to evaluate the stirring effect; (d) The effect of temperature (20, 40, 60, and 80 °C) was monitored on the formation of AgNPs.
were impregnated with 20 \( \mu l \) freshly prepared silver nanoparticles. The discs were placed on freshly prepared Petri dishes with a control. Sterile water and streptomycin (1%, 20 \( \mu l \)) were employed as a negative control and positive control respectively. Antibacterial activity was performed in triplicate and microbes are grown in agar medium along with the preparation of nanoparticles impregnated disc. The Petri dishes were placed in incubator for 24 h, after incubation zones of inhibition were measured in millimeters.

3. Results and discussion

Various factors that affect the formation of AgNPs were analyzed by UV-Visible spectroscopy [2] such as concentration, pH, stirring time and temperature. The effect of concentration was studied by taking 10 ml, 20 ml and 30 ml seed extract in 100 ml AgNO\(_3\) (1.0 mM). The values of \( \lambda_{\text{max}} \) and absorbance depict that 20 ml concentration is most appropriate concentration for biosynthesis of NPs (figure 1(a)) [38]. The pH of reaction mixture was varied as acidic (4.5), neutral and alkaline (8.5) and recorded their effect on biosynthesized silver nanoparticles. The best pH for the synthesis of AgNPs was recorded to be 8.5 being alkaline or basic (figure 1(b)). Different stirring times (0, 2, 4, 6, 8 and 10 min) were used at room temperature to evaluate the stirring effect. These stirring times were not shown any significant effect on the formation of AgNPs (figure 1(c)). The effect of temperature (20, 40, 60, and 80 °C) was monitored on all five samples and it is confirmed from UV–vis absorption spectra that high temperature involves the formation of fine crystalline silver NPs (figure 1(d)) [39].

UV-Visible spectroscopic analysis of biosynthesized NPs has been depicted in figure 2. The absorption peaks that appeared at 410–450 nm reflected the surface plasmon resonance of silver NPs. There was no absorption in case of seed extracts while pristine samples showed a distinct peak at 425 nm as reported in literature [27]. However, higher and lower concentrations of seed extracts beyond the optimum value resulted in broader peaks with decreased absorption intensity and dark color reaction mixture indicates agglomeration between NPs. It was observed that biosynthesized AgNPs were stable in solution up to one month [40].

Green synthesis involves a variety of phytoconstituents that involve reduction of metal ions as well as stabilizing/capping metal NPs. So, it is not easy to propose the exact mechanism for reduction of silver ions. The plausible mechanism is shown in figure 3. The phyto-constituents involve tannins, polyphenols, and gallic acid contain high density of –OH groups. Hydroxyl group of the polyphenols oxidizes and releases two electrons [41]. These electrons are responsible for the reduction of 2Ag\(^+\) [42]. After the atomic silver-Ag\(^0\) formation, many reactions need to occur for silver NPs formation, since atomic silver-Ag\(^0\) is not considered a nanoparticle, its agglomeration forms NPs and these reactions are called nucleation. Complexation of polyphenol with metallic silver, and this bond with the biomolecules is responsible for the stabilization of the nanoparticles [43, 44]. The electrochemical potential difference is the main reason behind the interaction of ionic silver and phyto-constituents [2].

The functional groups of biosynthesized NPs S1, S2, S3, S4 and S5 were investigated by FTIR studies conducted in the range of 500–4000 cm\(^{-1}\) (figure 4(a)). The Significant absorbance peaks of Ag-NPs appeared at 3260, 2920, 1555, 1440, 1030 and 520 cm\(^{-1}\) correspond to mainly polyphenols and terpenoids, present in seed
extract. Absorption spectra at 3260 cm⁻¹ corresponds the stretching frequency of –OH and amine N–H [45]. While, peaks at 2920 cm⁻¹ are associated with C–H stretch of an alkane. However, vibrational band at C=C 1555 cm⁻¹ reveals the existence of C=C and 1440 cm⁻¹ depicted the stretching vibrations of –COO–. Peaks transmitted in the region 1030 cm⁻¹ reveals the presence of unsaturated ketone and ester. Variations in the FTIR spectra demonstrates that different biomolecules from plant extracts actively participate in the reduction of AgNO₃ and also contribute to the formation of specific size NPs either through cysteine residues or free amines.

Figure 3. Chemical mechanism proposed to synthesize green AgNPs.

Figure 4. (a) FTIR spectra of biosynthesized silver nanoparticles; (b) XRD diffraction pattern of silver nanoparticles prepared from five different seed extracts S1, S2, S3, S4 and S5.
by the surface-binding proteins [46]. This suggests that various functional groups (methyl, hydroxyl, carboxylate, and carbonyl) involve in the synthesis of AgNPs [47–49].

Figure 4(b) represents the XRD patterns of biosynthesized silver nanoparticles. A number of Bragg diffraction peaks indexed as 38° (111), 44° (200), 64° (220) and 76° (311) were ascribed to the crystallinity and the face-centered cubic Ag [JCPDS 04-0783] [50]. Sharpness of diffraction peaks reflects that several biomolecules from seed extracts involve in the formation of AgNPs. Broad peak in sample S2 at 38° represents an incomplete reduction of silver ions might be indicating inadequate phytochemicals in seed while a small peak at 26° shows the bio-organic phase on the surface of particles [51]. The average crystal size calculated from Scherrer equation ($d_{XRD}$) was 14.7, 20.1, 15, 14.3 and 18.9 nm for S1, S2, S3, S4 and S5 respectively.

HRTEM images demonstrate the morphology and crystal structure of biosynthesized NPs figures 5(a)–(e). The micrographs revealed agglomerated NPs with approximate size of less than 60 nm. HR-TEM presents Fast-Fourier Transform-FFT of particular area shown by bright Yellow Square in figures 5(a)–(b), describes high atomic resolution as well as structural information. Interlayer fringe spacing for sample S1 and S2 was measured to be 0.24 and 0.25 nm which corresponds to (111) facet of fcc silver crystal (JCPDS. No.01-087-0597) [52]. Which is well-matched with XRD results and reported data.

EDX examination was employed to investigate the elemental composition of phyto-synthesized AgNPs. Characteristic silver peaks were monitored at ∼3, 22 and 25 KeV (figure 6). However, a strong spectral signal at 3 KeV is a typical energy value for metallic Ag Nano crystallites [53]. Whereas, additional spectral signals (carbon-C and sulphur-S) reveals the presence of extracellular bio-moieties that were adsorbed on the surface of NPs. The bacteria are known to consist of cytoplasm, cell membrane and cell wall. The cell wall of gram-positive (G+ve) bacteria consists of one multilayer peptidoglycan polymer (20–80 nm) thickness while gram-negative (G–ve) bacteria consists of two cell membranes thickness 7–8 nm. The NPs stick to bacterial membrane due to opposite electrostatic charges on them causing cell shrinkage, perforation and ultimately cell death [54].

The five different samples of silver nanoparticles were screened for their antimicrobial potential, and the diagrams of zone inhibition were presented in figure 7. Streptomycin (1%) was employed as control. The prepared samples were found to be active against most bacterial strains taken into account. B. safensis and B. pumilis were found to be inhibited by three samples out of five. S. typhi was inhibited actively by the four samples. The least active inhibition was recorded against E. coli. The AgNPs from Raphanus sativus European (Red Radish, S1) were found to be potent against B. safensis, S. aureus and S. typhi. The AgNPs from Raphanus sativus East Asia (White Radish, S2) inhibited three bacterial strains and the potential was in comparison to the reference and showing slight activity against S. aureus and E. coli. The nanoparticles from Brassica rapa (Turnip, S3) were active against B. pumilis. The AgNPs from Brassica campestris (Saag, S4) exhibited excellent potential against two bacterial strains (B. safensis and S. aureus).
Figure 6. EDX of biosynthesized Ag-NPs.

Figure 7. Well diffusion assay (a)–(f) to assess the bactericidal potential of biosynthesized Ag-NPs prepared from five different seed extracts S1, S2, S3, S4 and S5 against various bacterial strains (a) Bacillus safensis, (b) Bacillus pumilis, (c) Staphylococcus aureus, (d) salmonella typhi, (e) Escherichia coli and (f) table representing antibacterial activity.
*typhi* in comparison to reference standard. *Brassicaoleracea* (Cauliflower, S5) presented the potential for three bacterial strains in each case ranging from excellent to moderate.

4. Conclusion

This work presents, green method for the synthesis of Ag-NPs using seed extracts and reveals the *Brassicaceae* family as an efficient biological reducing agent that can be easily scaled up as its economic, facile and environmentally benign features. Furthermore, the optimum reaction conditions for the preparation of Ag-NPs were determined by investigating different experimental parameters. Specifically, concentration of seed extract, pH, stirring time and temperature. The optimum conditions were found to be 20 ml of seed extract, 80 °C temperature, 30 min stirring time and 8.5 (alkaline) pH for nanoparticle synthesis. Active biological constituents of seed extract act as effective stabilizing and reducing agents that were investigated by FTIR studies. XRD and HRTEM provided information regarding the crystallite size and phase-purity, average crystalline size of the AgNPs was recorded in the range of 14–20 nm by Scherrer’s formula. The evidence of chemical composition was collected by EDS spectral signals. The synthesized material act as an efficient bactericidal agent against gram-positive and negative bacterial strains. This rapid synthesis of NPs by *Brassicaceae* family provides a good alternate for chemical reduction methods owing to its non-toxic nature. This environment-friendly synthesis of nanomaterial opens up new horizons in biomedical field. Further research is needed to evaluate their cytotoxicity and field potential.

Acknowledgments

Authors are thankful to HEC, Pakistan.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Competing interest

Authors confirm that this manuscript has no conflict of interest.

Funding

Authors are thankful to Higher Education Commission, HEC Pakistan for financial support.

Authors’ contributions

RP performed the whole experiments and MJ wrote the manuscript. SS provided the novel idea to carry out the experiment. ZQ and SQ participated in the data analysis of the results and discussion portion. KS and MI reviewed the manuscript, corrected the English, and carried out the FESEM and HRTEM analysis. All authors read and approved the final manuscript.

ORCID iDs

Muhammad Ikram [https://orcid.org/0000-0001-7741-789X](https://orcid.org/0000-0001-7741-789X)

References

[1] Varghese R A et al 2015 Satin leaf (*Chrysophyllum oliviforme*) extract mediated green synthesis of silver nanoparticles: antioxidant and anticancer activities *Journal of Pharmaceutical Sciences and Research* 7 266
[2] Rajeshkumar S et al 2016 Anticancer and enhanced antimicrobial activity of biosynthesized silver nanoparticles against clinical pathogens *J. Mol. Struct.* 1116 165–73
[3] Tarannum N and Gautam Y K 2019 Facile green synthesis and applications of silver nanoparticles: a state-of-the-art review *RSC Adv.* 9 34926–48
[4] Saxena A, Tripathi R and Singh R I D 1 N B 2010 Biological synthesis of silver nanoparticles by using onion (*Allium cepa*) extract and their antibacterial activity *Dig. J. Nanomater. Biostruct.* 5 427–32
Kumar A, Mazumdar RS and Dhewa T 2016 Biological synthesis of silver nanoparticles by using Viola serpenis extract Asian Pacific Journal of Tropical Disease 6 223–6

Khan A U et al 2015 Electrochemical and antioxidant properties of biogenic silver nanoparticles Int. J. Electrochem. 10 7905–16

Edison T N J et al 2016 Green synthesis of silver nanoparticles using Terminalia cuneata and its catalytic action in reduction of direct yellow-12 dye Spectrochim. Acta A 161 122–9

Rautela A et al 2019 Green synthesis of silver nanoparticles from Tectona grandis seeds extract: characterization and mechanism of antimicrobial action on different microorganisms Journal of Analytical Science and Technology 10 1–10

Artionang H F, Koleagung H and Wuntu A D 2019 Synthesis of silver nanoparticles using aqueous extract of medicinal plants’ (Impatiens balsamina and Lantana camara) fresh leaves and analysis of antimicrobial activity International Journal of Microbiology 2019 8642303

Gul S et al 2016 Novel synthesis of silver nanoparticles using melon aqueous extract and evaluation of their feeding deterrent activity against housefly Musca domestica Asian Pacific Journal of Tropical Disease 6 311–6

Deekonda K et al 2016 Electron beam radiation mediated green synthesis of silver nanoparticles using carboxymethyl sago pulp obtained from sago waste Polymer 86 147–56

Skiba M I et al 2020 Green synthesis of silver nanoparticles in the presence of polysaccharide: optimization and characterization J. Nanomater. 2020 3051308

Some S et al 2018 Biosynthesis of silver nanoparticles and their versatile antimicrobial properties Mater. Res. Express 6 012001

Ahmed S et al 2016 A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise J. Adv. Res. 7 17–28

Alagad K and Saleh T A 2016 Gold and silver nanoparticles: synthesis methods, characterization routes and applications towards drugs Journal of Environment & Analytical Toxicology 6 523–2161

Subhani M A et al 2019 Synthesis of silver nanoparticles from plant extracts and their antimicrobial application International Journal of Biosciences 14 243–57

Tranfarm M 2016 Chemiluminescence reactions enhanced by silver nanoparticles and silver alloy nanoparticles: applications in analytical chemistry TrAC, Trends Anal. Chem. 82 126–42

Castillo-Henríquez L et al 2020 Green synthesis of gold and silver nanoparticles from plant extracts and their possible applications as antimicrobial agents in the agricultural area Nanomaterials 10 1763

Some S et al 2020 Bio-molecule functionalized rapid one-pot green synthesis of silver nanoparticles and their efficacy toward the multidrug resistant (MDR) gut bacteria of silkworms (Bombyx mori) RSC Adv. 10 22742–57

Ni Z et al 2018 Synthesis of silver nanoparticle-decorated hydroxyapatite (HA@Ag) poriferous nanocomposites and the study of their antibacterial activities RSC Adv. 8 41722–30

Ajitha B et al 2016 Sesbania grandiflora leaf extract assisted green synthesis of silver nanoparticles: antimicrobial activity Mater. Today Proc. 3 1977–84

Thuc D T et al 2016 Green synthesis of colloidal silver nanoparticles through electrochemical method and their antibacterial activity Mater. Lett. 181 173–7

Rao P V et al 2016 Phytochemicals and biogenic metallic nanoparticles as anticancer agents Oxid. Med. Cell. Longevity 2016 3685671

Dhanda V et al 2016 Green synthesis of silver nanoparticles using Coffea arabica seed extract and its antibacterial activity Materials Science and Engineering: C 58 36–43

Masum M et al 2019 Biogenic synthesis of silver nanoparticles using Phyllanthus emblica fruit extract and its inhibitory action against the pathogen Acidovorax oryzae strain RS-2 of rice bacterial brown stripe Front. Microbiol. 10 820

Moldovan B et al 2016 A green approach to phytomediated synthesis of silver nanoparticles using Sambucus nigra L. fruits extract and their antioxidant activity J. Mol. Liq. 221 271–8

López-Miranda J L et al 2016 Biosynthesis of silver nanoparticles using a Tamarix gallica leaf extract and their antibacterial activity Mater. Lett. 176 285–9

Ravichandran V et al 2016 Green synthesis of silver nanoparticles using Atrocarpus altillus leaf extract and the study of their antimicrobial and antioxidant activity Mater. Lett. 180 264–7

Karagaz A et al 2020 Transfer of hydrophobic colloidal gold nanoparticles to aqueous phase using catecholamines J. Mol. Liq. 315 113796

Leng Y et al 2016 Protein-directed synthesis of highly monodisperse, spherical gold nanoparticles and their applications in multidimensional sensing Sci. Rep. 6 1–11

He X, Gao L and Ma N 2013 One-step instant synthesis of protein-conjugated quantum dots at room temperature Sci. Rep. 3 1–11

Shi H et al 2016 One-pot and one-step synthesis of bioactive uresce/ZnFe3O4 nanocomposites and their application in detection of urea Dalton Trans. 43 9016–21

Sanlier N and Guler S J H H R 2018 The benefits of Brassica vegetables on human health Journal of Human Research Health 1 1–13

Tian Y and Deng F 2020 Phytochemistry and biological activity of mustard (Brassica juncea): a review CyTA – Journal of Food 18 704–18

Nagahahdi P Y et al 2015 A mechanistic perspective on process-induced changes in glucosinolate content in Brassica vegetables: a review Crit. Rev. Food Sci. Nutr. 55 823–38

Du L et al 2016 Biosynthesis of Ag nanoparticles using liquefied cassava mash and its antibacterial activity against staphylococcus aureus and escherichia coli J. Nanosci. Nanotechnol. 16 8741–7

Siddique S et al 2015 Chemical composition and antimicrobial activities of essential oils of six species from family Myrtaceae Journal of Essential Oil Bearing Plants 18 950–6

Mehmood A and Murtaza G 2017 Impact of biosynthesized silver nanoparticles on protein and carbohydrate contents in seeds of Pismum sativum L. Crop Breeding and Applied Biotechnology 17 354–9

Artionang H F et al 2014 Green’ nanotechnologies: synthesis of metal nanoparticles using plants Acta Naturae 6 35–44

Nay M et al 2017 Green synthesis (A. indica seed extract) of silver nanoparticles (Ag-NPs), characterization, their catalytic and bactericidal action potential Nanoscientce and Nanotechnology Letters 9 1649–55

Aziz B et al 2019 Fabrication of interconnected plasmionic spherical silver nanoparticles with enhanced localized surface plasmon resonance (LSPR) peaks using quince leaf extract solution Nanomaterials 9 1557

Kim H S et al 2016 Concentration effect of reducing agents on green synthesis of gold nanoparticles: size, morphology, and growth mechanism Nanoscale Res. Lett. 11 230

Nunes M R et al 2018 Antioxidant and antimicrobial methylcellulose films containing Lippia alba extract and silver nanoparticles Carbohydrate Polym. 192 37–43
[44] Sganzerla W G et al 2020 Nanocomposite poly (ethylene oxide) films functionalized with silver nanoparticles synthesized with Acca sellowiana extracts Colloids Surf. A 602 125125
[45] Velmurugan P et al 2011 Crystallization of silver through reduction process using Elaeis guineensis biosolid extract Biotechnol. Prog. 27 273–9
[46] Gole A et al 2001 Pepsin—gold colloid conjugates: preparation, characterization, and enzymatic activity Langmuir 17 1674–9
[47] Naz M et al 2017 Eco-friendly biosynthesis, anticancer drug loading and cytotoxic effect of capped Ag-nanoparticles against breast cancer Applied Nanoscience 7 793–802
[48] Babu M G and Gunasekaran P 2009 Production and structural characterization of crystalline silver nanoparticles from Bacillus cereus isolate Colloids Surf., B 74 191–5
[49] Bar H et al 2009 Green synthesis of silver nanoparticles using seed extract of Jatropha curcas J. Mol. Liq. 348 212–6
[50] Priyadharshini R I et al 2014 Microwave-mediated extracellular synthesis of metallic silver and zinc oxide nanoparticles using Macro-Algae (Gracilaria edulis) extracts and its anticancer activity against human PC3 cell lines Appl. Biochem. Biotechnol. 174 2777–90
[51] SaiRam M et al 2000 Anti-microbial activity of a new vaginal contraceptive NIM-76 from neem oil (Azadirachta indica) Journal of Ethnopharmacology 71 377–82
[52] Singh V, Shrivastava A and Wahi N 2015 Biosynthesis of silver nanoparticles by plants crude extracts and their characterization using UV, XRD, TEM and EDX African Journal of Biotechnology 14 2554–67
[53] Bilal M et al 2019 Biosynthesized silver supported catalysts for disinfection of Escherichia coli and organic pollutant from drinking water Colloids Surf. A 281 295–306
[54] Sirelkhatim A et al 2015 Review on zinc oxide nanoparticles: antibacterial activity and toxicity mechanism Nano-Micro Letters 7 219–42