Green synthesis of silver nickel bimetallic nanoparticles using plant extract of Salvadora persica and evaluation of their various biological activities

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Abstract
Metallic nanoparticles play vital role in the field of science, medicine, food and technology. Various strategies have been used for the synthesis of bimetallic nanoparticles to improve the physical and chemical properties of monometallic nanoparticles. The present study describes synthesis of Ag-Ni bimetallic nanoparticles, using aqueous extract of Salvadora persica. Silver and nickel ions were reduced by secondary metabolites within the extract which act as reducing as well as capping agents. UV–visible spectrum produced an absorbance band in the range of 400 nm to 450 nm due to electronic transitions associated with resonance of surface electrons that was an indication of the formation of nanoparticles. Scanning Electron Microscopy (SEM) and x-ray diffraction spectroscopy (XRD) were used for the determination of morphology and dimension of nanoparticles. Particle dimension of synthesized nanoparticles was 23.67 nm. Energy dispersive x-ray spectroscopy (EDX) was used for the elemental analysis that showed the presence of silver and nickel in elemental form. Fourier Transform Infrared Microscopy (FTIR) was used for the functional group analysis. Synthesized Ag–Ni bimetallic nanoparticles were assessed for the estimation of their antioxidant potential by three methods i.e. DPPH free radical scavenging mechanism, phosphomolybdenum complex method and determination of phenolic contents. Percent scavenging activity of synthesized Ag-Ni bimetallic nanoparticles was observed as 70.5% at 1500 μg ml⁻¹ concentration. Total antioxidant activity calculated for synthesized nanoparticles was 0.6479 against BHT as a reference. Total phenolic contents of green synthesized nanoparticles were calculated to be 74.5 mg g⁻¹ GAE. Different parameters like temperature, pH, effect of adsorbent concentration, time of contact, and concentration of adsorbate, were optimized for the utmost removal of congo red dye and chromium (VI).

1. Introduction

Synthesis of nanoparticles using biological method has become an area of great interest because it is inexpensive method and does not produce toxic chemicals. In this method micro-organisms or plants are used for reduction reaction, for the synthesis of nanoparticles [1–3]. Micro-organisms used in biosynthesis require a culture media and aseptic conditions for their growth [4]. Due to the ease of development and availability, the use of plant extract is considered more beneficial than the use of micro-organisms. Therefore, synthesis of nanoparticles using plant extracts is preferred over other reported methods [5–7]. Biomolecules, for example alkaloids, polysaccharides, phenolics, tannins, saponins, terpenoids, proteins, amino acids and vitamins are present abundantly in plants that act as reducing as well as capping agents for the production of nanoparticles. These
biomolecules having chemically complex structures exhibit various medicinal applications and are responsible for the reduction of metallic ions along with stabilization of resulting metallic nanoparticles [8].

Silver nanoparticles exhibit significant antibacterial activity along with various pharmaceutical, industrial, environmental, and biomedical applications [9]. Therefore, a lot of work has been reported on synthesis as well as characterization of metallic silver nanoparticles using different plant extracts along with their antibacterial, antifungal and antioxidant potential [10–13]. Recently, biosynthesized bimetallic nanoparticles has also been reported which have applications in imaging, labeling, drug delivery and in a medical field owing to their compatibility in biological systems [14]. Bimetallic nanoparticles show enhanced activity compared to monometallic nanoparticles. Various types of bimetallic nanoparticles have been investigated based on their different shapes [15].

Salvadora persica is a large evergreen bush or small tree with extensive twigs, in some cases, developing as the thickest shrubs and on sand hillock, related to Salvadoraceae family, usually named as 'Pili', 'Jal' and 'Tooth brush tree' and is broadly scattered in Pakistan, Saudi Arabia Iran, India and Africa. The blooms are greenish yellow and fruits are pale green to red brown when ripened. The fruits are sweet, and suitable for eating. Leaves and flowers are used for the treatment of gum problems, skin syndromes, kidney stones and as anti-helminthic. The plant has also been integrated into commercially accessible toothpaste. Salvadora persica contain abundance of bioactive compounds, such as flavonoids, terpenoids, alkaloids (salvadorine), steroids and saponins [16].

In literature, various chemical methods have been used for the synthesis of bimetallic nanoparticles. Previously no work has been done on the green synthesis of silver-nickel bimetallic nanoparticles using Salvadora persica plant extract.

The present report is related to the synthesis and characterization of silver-nickel bimetallic nanoparticles by using Salvadora persica plant extract along with the evaluation of their antioxidant potential. Moreover, synthesized bimetallic nanoparticles were used to study their effect on percentage removal of chromium (VI) and congo red dye.

2. Experimental methods

2.1. Preparation of plant extract

The collected plant of Salvadora persica was washed, dried in shade and crushed to fine powder. At a preliminary stage, the extract was prepared by adding 5 grams of powdered plant material in 100 ml distilled water in the flask. The mixture was boiled at 100 °C for 15 min with continuous stirring. After that mixture was filtered [17].

2.2. Synthesis of silver–nickel bimetallic nanoparticles

Silver–nickel bimetallic nanoparticles were synthesized by adding 20 ml of plant extract to the equal molar concentration (2 mM) mixture of 100 ml of silver nitrate and 100 ml nickel nitrate in a beaker. The resulting mixture was stirred continuously and heated at 70 °C on hotplate until a notable change in the color of reaction mixture was appeared that showed the formation of silver–nickel bimetallic nanoparticles. Resulting solution was centrifuged at 3500 rpm for 20 min for the collection of solid nanoparticles [18].

2.3. Characterization of synthesized nanoparticles

UV-visible spectroscopy was primarily used technique that indicated the formation of nanoparticles with the help of spectra produced as a result of surface plasmon resonance. FTIR analysis was used to identify the functional groups responsible for the formation of nanoparticles. Morphology and dimension of resulting silver–nickel bimetallic nanoparticles was studied using scanning electron microscopic and x-ray diffraction analysis. Presence of elemental sliver and nickel in synthesized nanoparticles was determined using electron diffraction x-ray spectroscopy.

2.4. Antioxidant potential

2.4.1. DPPH Free Radical Scavenging Method

Assessment of antioxidant potential of resulting Silver–nickel bimetallic nanoparticles using 2,2-diphenyl-1-picrylhydrazyl hydrate (DPPH) was carried out by Lee and Shibamoto, (2001) method. In short, different concentrations of the Ag–Ni bimetallic nanoparticles (1500 μg, 1000 μg, 500 μg, 250 μg) were reacted with 3 ml of 0.1 mM DPPH methanolic solutions. The mixture was kept at room temperature for 30 min, and absorbance of upper layer was calculated at the wavelength value of 517 nm using UV-Vis spectrophotometer. Decrease in the value of absorbance indicated an increase in antioxidant activity [19]. Percentage scavenging activity of all the samples was calculated by following formula:
Butylated hydroxytoluene value was calculated at 695 nm by UV-Visible spectrophotometer using 4 ml of reagent solution as blank.

Where D is the average diameter of particles in nm, which indicated the existence of hydroxyl group. An additional peak appeared at 1075.49 cm\(^{-1}\) within the range of 1050–1200 cm\(^{-1}\) of C–O stretching present in nitro compounds and bending of N–H bond present in amines respectively. Other peak appeared within the range of 1050–1200 cm\(^{-1}\) indicated the existence of C–O group [24–26]. The peaks indicated the existence of many functional groups in the aqueous extract of Salvadora persica liable for the formation of stable Ag-Ni bimetallic nanoparticles.

SEM images of silver-nickel bimetallic nanoparticles have been shown in figures 2(a), (b). The average diameter 24 nm [27, 28].

EDX spectrum figure 2(c) was carried out at 0–14 kev with distinct peaks in the region of silver and nickel. Other signals in the spectrum showed the presence of elemental Ag and Ni in the sample. Silver produced a prominent peak around 3 kev while the peak of nickel was appeared around 0.9 kev and 8 kev [29, 30]. XRD spectrum showed a pattern of four prominent peaks at 2θ values 28.0°, 32.5°, 38.0° and 46.50°. The average particle size was calculated by using Debye–Scherrer’s formula:

\[
D = \frac{K\lambda}{\beta \cos \theta}
\]

Where D is the average diameter of particles in nm, \(\lambda\) (0.154 06 nm) is the wavelength of the x-ray used \(\beta\) is FWHM of the peaks appeared at 2\(\theta\), K is the Scherrer constant having value of (0.9–1) and \(\theta\) is Bragg angle \((\theta = 2\theta/2)\). Average diameter of bimetallic silver-nickel nanoparticles calculated was 23.67 nm.

2.4.2. Total phenolic contents
Total Phenolic contents present in the synthesized silver-nickel bimetallic nanoparticles were estimated by method of Makkar et al (1993). Reaction mixture was prepared using 0.1 ml of Folin–Ciocalteu’s phenol reagent (2 N) and 2.8 ml of 10% sodium carbonate. 500 \(\mu\)g ml\(^{-1}\) of silver-nickel bimetallic nanoparticles were added in the prepared mixture and left for 40 min. Absorbance values were recorded at 725 nm using UV-visible spectrophotometer. Total phenolic contents were calculated as milligram of gallic acid equivalents per gram of the sample by plotting graph of different concentrations of gallic acid [20].

2.4.3. Total antioxidant activity
Phosphomolybdenenum Complex formation method, by Prieto et al (1999) was used for the evaluation of total antioxidant activity. In this method 500 \(\mu\)g ml\(^{-1}\) of Ag-Ni bimetallic nanoparticles were added to 4 ml of reagent solution in test tubes, and then covered with aluminum foil. The reagent solution was prepared by using 28 mM sodium phosphate, 4 mM ammonium molybdate and 0.6 molar sulphuric acid. Covered test tubes were heated at 95 °C in the water bath for 90 min. After that, the mixture was left at room temperature to cool and absorbance value was calculated at 695 nm by UV-Visible spectrophotometer using 4 ml of reagent solution as blank. Butylated hydroxytoluene (BHT) was taken as standard [21].

2.4.4. Removal of chromium (VI) and congo red dye
Effect of Ag-Ni bimetallic nanoparticles was studied on percentage removal of chromium (VI) and congo red dye using 1000ppm stock solution. 2.835 g of K\(_2\)Cr\(_2\)O\(_7\) was dissolved in distilled water using 1000 ml measuring flask and make the volume upto the mark to prepare 1000ppm solution of chromium (VI).

The effect of pH, temperature, adsorbent concentration, concentration of solution, and contact time on the process of adsorption was studied. Several graphical and statistical analyses were carried out to explore the process of adsorption.

3. Results and discussion

3.1. Characterization of Synthesized Bimetallic Nanoparticles:
Exclusive optical properties of nanoparticles are responsible for the formation of UV-Visible spectrum. Optical properties of the nanoparticles are affected by their shape and size. Spectra of plant extract and solution of nanoparticles at the different time interval were obtained shown in figure 1(a). Peak intensity due to surface plasmon resonance resulted from electronic transitions within the nanoclusters confirmed the formation of silver-nickel bimetallic nanoparticles [22, 23]. A broad absorption band within the wavelength range 400 nm and 450 nm was observed.

FTIR spectrum of Salvadora persica plant extract figure 1(b) showed a prominent peak at 3206.28 cm\(^{-1}\) which indicated the existence of hydroxyl group. An additional peak appeared at 1075.49 cm\(^{-1}\) due to stretching of C–O–C which corresponds to ketonic group while peaks appeared at 1575.59 cm\(^{-1}\) and 1537.82 cm\(^{-1}\) owing to N–O stretching present in nitro compounds and bending of N–H bond present in amines respectively. XRD showed the formation of stable Ag-Ni bimetallic nanoparticles.

%Scavanging \(= \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100\)
3.2. Antioxidant potential

Antioxidants inhibit the oxidation of biological molecules by blocking the oxidative free radical chain reactions which have an adverse effect on tissues of living organisms. Oxidative stress leads to cancer, cardiovascular and cerebrovascular diseases. Many synthetic antioxidants have been used to block the oxidative reactions, but they are not applicable to biological systems. Therefore, natural antioxidants obtained from plants are being used to control the harmful effects caused by oxidants [31].

3.2.1. DPPH Free radical scavenging activity

DPPH free radical scavenging method was used for the assessment of antioxidant activity of Ag-Ni bimetallic nanoparticles. DPPH is a stable compound that accepts hydrogen radical or electrons from biosynthesized Ag-Ni bimetallic nanoparticles. Antioxidant activity of synthesized nanoparticles is directly linked to their reducing potential. Decrease in absorbance of DPPH was observed due to its reaction with nanoparticles and color of solution changes from purple to light yellow. The results have been presented in figure 3 which showed the effect of different concentrations of Ag-Ni bimetallic nanoparticles on free radical inhibition.

The highest percent inhibition i.e. 70.50% was observed at 1500 μg ml⁻¹. To control the effects of oxidative free radical chain reactions, an innovative variety of natural antioxidants have been proved effective. Biosynthesized Ag-Ni bimetallic nanoparticles acted as reducing agent which terminated the free radical chain reaction by converting them into stable product [32].

Figure 1. (a) UV visible spectrum of plant extract and synthesized nanoparticles. (b) FTIR spectrum of plant extract of Salvadora persica.
3.2.2. Total phenolic contents
Among the groups of biologically active compounds, the significant one found in plants are flavonoids and phenolic compounds. Polyphenols play vital role in prevention of many diseases and show high antioxidant potential. Polyphenols prevent the formation of hydroperoxides due to highly reactive free radical species. They also deactivate the lipid free radicals [33]. Total Phenolic contents of synthesized bimetallic nanoparticles displayed good value i.e. 74.5 mg g⁻¹ GAE as compared to blank (5.23 mg g⁻¹).

Figure 2. (a), (b) SEM images of green synthesized Ag-Ni bimetallic nanoparticles. (c) EDX spectrum of synthesized Ag-Ni bimetallic nanoparticles. (d) XRD spectrum of synthesized Ag–Ni bimetallic nanoparticles.
3.2.3. Total antioxidant activity
Antioxidants are capable of inhibiting oxidative chain reactions that occur in the presence of atmospheric oxygen or reactive oxygen species. Antioxidants inhibit the oxidative chain reactions and stabilize the polymeric products such as petrochemicals, pharmaceuticals, cosmetics and foodstuffs. Antioxidants prevent organisms from the attack of free radicals and involved in the defense mechanism. Method of formation of phosphomolylybdenum complex was applied for the determination of total antioxidant activity of the silver-nickel bimetallic nanoparticles. This method involves the reduction of molybdenum (VI) with the help of antioxidants to molybdenum (V). Transfer of electron in this method, is affected by the configuration of the antioxidant. This method is used to detect the presence of antioxidants for example, ascorbic acid, tocopherol, carotenoid and phenolic compounds. Total antioxidant activity of silver-nickel nanoparticles was found good i.e. 0.6203 as compared to BHT (Butylated hydroxytoulene) as a reference standard having value 0.818.

3.3. Removal of chromium (VI)
3.3.1. Effect of temperature
Influence of temperature on removal of chromium (VI) through the process of adsorption was studied at different temperatures (25 °C, 35 °C, 45 °C, 55 °C, 65 °C) using 20 ml solution of initial concentration 10 mg l⁻¹ and 10 mg of Ag-Ni bimetallic nanoparticles as adsorbent. The effect of temperature on removal has been displayed in figure 4(a). The figure showed increase in adsorption of chromium (VI) per gram of nanoparticles with the increase in temperature up to certain limit. Maximum removal was observed at 45 °C. With the increase in temperature of solution, mobility of ions towards the active sites was also increased that increase the rate of adsorption at higher temperature. Therefore, higher temperature enhances the removal of metal ions.

3.3.2. Effect of pH
The pH value is an important parameter for controlling the process of adsorption. It affects charge density on the surface of the adsorbents, behavior of adsorbate molecules and their ionization potential. The experiment was carried out using 25 ml metal solution of 10 mg l⁻¹ concentration. The pH values 2–10 were selected to estimate the influence of pH on rate of adsorption by adding 10 mg of adsorbent. Influence of pH on the removal of chromium (VI) has been shown in figure 4(b). As, pH value changed from 4 to 10, a decrease in concentration adsorbed per gram of nanoparticles M (mg g⁻¹), was observed. Maximum removal of the metal was observed at pH value of 2. Electrostatic interaction is the principle driving force between adsorbent and adsorbate molecules. Higher the interaction, the greater the rate of adsorption of heavy metal was observed.

The removal of Cr (VI) was reduced as the value of pH increased from 4–10, correspondingly. Depending on the concentration of chromium and pH value, Cr (VI) may occur in these forms (Cr₂O₇²⁻, HCrO₄⁻ or CrO₄²⁻). Cr (VI) ion is mainly introduced in H₂CrO₄ form. At 2 °pH 6 there exist an equilibrium between two forms Cr₂O₇²⁻ and HCrO₄⁻. In alkaline conditions, Cr (VI) prevalently exists as chromate anion. In acidic conditions positive charge is induced on the adsorbent surface due to the higher rate of protonation which improved the removal rate of Cr metal anions.
3.3.3. Effect of adsorbate concentration

Influence of varying concentration of the adsorbate molecule on the concentration adsorbed by nanoparticles $M(\text{mg g}^{-1})$ is a significant factor in adsorption process. Adsorbent-adsorbate solution is prepared with different...
amount of adsorbate and fixed adsorbent concentration. The influence of different concentrations of adsorbate (10 mg l\(^{-1}\), 20 mg l\(^{-1}\), 30 mg l\(^{-1}\), 40 mg l\(^{-1}\) and 50 mg l\(^{-1}\), \(V = 25\) ml) was studied. Adsorbed concentration of metal on nanoparticles M(mg g\(^{-1}\)) is directly related to available number of sites for adsorption of adsorbate material. Concentration of adsorbate, adsorbed on Ag-Ni bimetallic nanoparticles M(mg g\(^{-1}\)) have been represented graphically in figure 4(c). It was noted that increase in concentration of metal ion solution, increased the adsorbed concentration of Cr(VI) on adsorbent surface of Ag-Ni bimetallic nanoparticles [38, 39].

3.3.4. Effect of adsorbate concentration with contact time
Effect of different concentration of adsorbate (10 mg l\(^{-1}\), 20 mg l\(^{-1}\), 30 mg l\(^{-1}\), 40 mg l\(^{-1}\), 50 mg l\(^{-1}\)) against fixed adsorbent concentration (10 mg) was carried out at various time intervals from 30 min to 180 min. Adsorbed concentration M(mg g\(^{-1}\)) of Cr(VI) on Ag-Ni bimetallic nanoparticles with different time has been shown in figure 4(d). The figure illustrated that concentration of Cr(VI) adsorbed per gram of nanoparticles was increased with the increased contact time. It also showed a decrease in adsorption as concentration of metal solution increased from 10mg l\(^{-1}\) to 50mg l\(^{-1}\). This decrease in rate of adsorption was observed due to the fixed amount of adsorbent dosage that resulted in limited sites for adsorption.

As the concentration of metal solution was increased from 10 mg l\(^{-1}\) to 50 mg l\(^{-1}\), adsorption efficiency decreased because of the maximum coverage of available sites. While increase in adsorption rate was observed with the increasing time of contact beyond the point of saturation from 30–180 min for a particular concentration solution of adsorbate molecules [40].

3.4. Removal of congo red dye
3.4.1. Effect of temperature
Temperature is one of the significant factors which affect the rate of adsorption thereby affecting the removal efficiency. The effect of temperature on dye removal (\(C_{\text{dye}} = 5\) mg l\(^{-1}\); \(V = 25\) ml) was examined at varying temperature ranges from 25 °C to 65 °C using 10 mg of Ag-Ni bimetallic nanoparticles as shown in figure 5(a). The graph showed that adsorption of dye on unit gram of nanoparticles M(mg g\(^{-1}\)) increased with the temperature to a limit as the temperature increased above 55 °C removal efficiency was decreased. Rate of diffusion and mobility of the molecules of the dye was increased with temperature which resulted in increase in removal of dye up to a particular temperature [41].

3.4.2. Effect of pH
The process of adsorption can be considerably influenced by the pH value of the aqueous solution. It influences the ion exchange process along with ionization of various functional groups available on adsorbent surface. The influence of pH on removal of Congo red dye was investigated using dye (\(C_{\text{dye}} = 5\) mg l\(^{-1}\), \(V = 25\) ml) and 10 mg of adsorbent concentration. Removal of dye at varying pH values ranging from 2–10 have been illustrated in figure 5(b).

Concentration of dye adsorbed on Ag-Ni bimetallic nanoparticles M(mg g\(^{-1}\)) for the dye decreases as the value of pH increases. The graph depicts the highest adsorption at lower pH (acidic condition). As the pH value increased, the removal efficiency of adsorbent was decreased. This decrease in percentage removal was observed due to the impact of acidic conditions on the adsorbent molecules. It was noted that in alkaline conditions, concentration of hydrogen ions decreased that decrease the affinity of acidic dye towards the adsorbent surface while acidic conditions enhance the affinity of dye towards adsorbent [42].

3.4.3. Effect of adsorbate concentration with contact time
Influence of contact time on concentration of dye adsorbed was studied using fixed amount Ag-Ni bimetallic nanoparticles. The experiment was carried out using different dye concentrations (5 mg l\(^{-1}\), 10 mg l\(^{-1}\), 15 mg l\(^{-1}\), 20 mg l\(^{-1}\), 25 mg l\(^{-1}\); \(V = 25\) ml) and 10 mg of adsorbent concentration with time intervals from 30 min to 180 min. Influence of different dye concentrations on rate of adsorption with varying time interval has been illustrated in the figure 5(c).

The graphical data showed the similar effect as that observed for adsorption of dye i.e., as the concentration of dye was increased, adsorbate molecules were increased in number while the sites of their adsorption remained constant. Although number of sites remained same but the increase in adsorbed concentration was observed due to increase in time available for adsorption [43].

3.4.4. Effect of adsorbate concentration
Effect of adsorbate concentration, adsorbed on Ag-Ni bimetallic nanoparticles M (mg g\(^{-1}\)) was examined using different dye concentrations (5 mg l\(^{-1}\), 10 mg l\(^{-1}\), 15 mg l\(^{-1}\), 20 mg l\(^{-1}\), 25 mg l\(^{-1}\); \(V = 25\) ml). Influence of different adsorbate concentrations, on the concentration of dye adsorbed per gram of nanoparticles i.e. M(mg)
Increase in rate of adsorbate molecules was observed owing to increase in concentration of adsorbate molecules. Beyond a certain concentration of adsorbate i.e. 20mg{l}^{-1}, minor change was observed in adsorbed concentration. It was resulted due to the increase in rate of attraction of dye to the Ag–Ni bimetallic nanoparticles until all the sites available are occupied [39, 44].

**Figure 5.** (a) Effect of temperature on removal of dye using synthesized bimetallic nanoparticles M(mg g{l}^{-1}). (b) Effect of pH on removal of dye using synthesized bimetallic nanoparticles M(mg g{l}^{-1}). (c) Effect of contact time on concentrations of dye adsorbed on Ag-Ni bimetallic nanoparticles M(mg g{l}^{-1}). (d) Concentration of dye adsorbed on Ag-Ni bimetallic nanoparticle M(mg g{l}^{-1}).
4. Conclusion

In this report, we synthesized Ag-Ni bimetallic nanoparticles having an average diameter 23.67 nm and irregular cluster shape by fast, single step eco-friendly method using plant extract of Salvadora persica along with AgNO₃ and Ni(NO₃)₂·6H₂O as metal precursor. Resulted Silver-Nickel bimetallic nanocluster exhibited moderate antioxidant potential and good total antioxidant activity and also good total phenolic contents. Green synthesized Ag-Ni bimetallic nanoparticles were used for the removal of chromium (VI) and congo red dye (CR) from aquatic resources. Removal efficiency of synthesized nanoparticles was optimized by different factors such as temperature, pH, and concentration of adsorbent and effect of contact time on varying concentrations of solutions. Maximum removal of chromium (VI) and congo red dye was examined at acidic pH. Green synthesized Ag-Ni bimetallic nanoparticles showed good antioxidant potential and removal efficiency. Thus, it can be concluded that these nanoparticles have potential applications as antioxidant and also in the treatment of industrial waste water to prevent the environment from its adverse effects.

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References

[1] Sharma V K, Yagard R A and Lin Y 2009 silver nanoparticles; Green synthesis and their antimicrobial activities Adv. ColloidInterface Sci. 145 83–96
[2] Song J Y and Kim B S 2009 Rapid biological synthesis of silver nanoparticles using plant leaf extracts Bioprocess. Biosyst. Eng. 32 79–84
[3] Vigneshwaran N et al 2007 Biological synthesis of silver nanoparticles using the fungus Aspergillus flavus Mater. Lett. 61 1413–8
[4] Kalishwaralal K et al 2010 Biosynthesis of silver and gold nanoparticles using Brevibacterium casei Colloids Surf., B 77 257–62
[5] Kharisssova O V et al 2013 The greener synthesis of nanoparticles Trends Biotechnol. 31 240–8
[6] Bosetti M, Massé A, Tobin E and Cannas M 2002 Silver coated materials for external fixation devices: in vitro biocompatibility and genotoxicity Biomaterials 23 887–92
[7] Sharma G et al 2019 Novel development of nanoparticles to bimetallic nanoparticles and their composites: a review Journal of King Saud Universities—Science 31 257–69
[8] Kulkarni N and Muddapar U 2014 Biosynthesis of metal nanoparticles: a review Journal of Nanotechnology 1–8
[9] Ahmed S, Ahmad M, Swami B L and Ikra S 2016 A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise J. Adv. Res. 7 17–28
[10] Paulkumar K et al 2017 Green synthesis of silver nanoparticle and silver based chitosan bionanocomposite using stem extract of Saccharum officinarum and assessment of its antibacterial activity Nanoscienceand Nanotechnology 8 1–9
[11] Bhattacharyya et al 2016 One-pot fabrication and characterization of silver nanoparticles using Solanum lycopersicum: an eco-friendly and potent control tool against rose aphid, macrosporium rosae Journal of Nanoscience 2016 1–7
[12] Ali Z A, Yahya R, Sekaran S D and Puthch R 2016 Green synthesis of silver nanoparticles using apple extract and its antibacterial properties Adv. Mater. Sci. Eng. 2016 1–6
[13] Yu C et al 2019 Green biosynthesis of silver nanoparticles using Eriobotrya japonica (Thunb.) leaf extract for reductive catalysis Materials 12 189
[14] Jain P K, Huang X, El-Sayed I H and El-Sayed M A 2008 Noble metals on the nanoscale: the photothermal and photophysical properties and some applications in imaging, sensing, biology, and medicine Acc. Chem. Res. 41 1578–86
[15] Sharma G et al 2015 Lanthanum/ Cadmium/ Polyamine bimetallic nanocomposite for the photodegradation of organic pollutant Iran. Polym. J. 24 1003–13
[16] Verma S and Rajhala 2018 Study on phytochemical and pharmacological activity of miswak tree salvadora Persica (Salvadoraceae) International Journal of Current Research and Modern Education 3 11–4
[17] Prasad K S and Savithramma N 2015 Biosynthesis and Validation of Silver Nanoparticles from Nymphaea caerulea American Journal of Advanced Drug Delivery 3 149–59
[18] Akinusika A A et al 2018 Modeling and synthesis of Ag and Ag/ Ni alloyed bimetallic nanoparticles by green method: optical and biological properties International Journal of Nanomaterials 2018 1–17
[19] Lee K and Shihamoto T 2001 Antioxidant property of aroma extract isolated from clove buds Food Chem. 74 443–8
[20] Prieto P, Pineda M and Aguilar M 1999 Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphomolybdenum complex: specific application to the determination of vitamin E Anal. Biochem. 269 337–41
[21] Makkur H P, Bhumimel M, Borowy N K and Becker K 1993 Gravimetric determination of tannins and their correlations with chemical and protein precipitation methods J. Sci. Food Agric. 61 161–5
[22] Link S and El-Sayed M A 2003 Optical properties and ultrafast dynamics of metallic nanocrystals Annu. Rev. Phys. Chem. 54 331–66
[23] Srisharan K, Endo T, Cho S, Kim J, Park T J and Philip R 2013 Single step synthesis and optical limiting properties of Ni–Ag and Fe–Ag bimetallic nanoparticles Opt. Mater. 35 860–7
[24] Harshini M, Matheswaran M, Arthanareeswaram G, Kumaran S and Rajasree S 2015 Enhancement of antibacterial properties of silver nanoparticles–ceftriaxone conjugate through Mukia maderaspatana leaf extract mediated synthesis Ecotoxicology and Environmental Safety 121 135–41
[25] Song J Y, Janga H K and Kim B S 2009 Biological synthesis of gold nanoparticles using Mangolia kobus and Diospyros kaki leaf extract Process Biochem. 44 1133–8
[26] Basavaraj A, Balaji S, Laghettay A, Rajasah A and Venkataraman A 2008 Extracellular biosynthesis of silver nanoparticles using the fungus Fusarium semitectum Mater. Res. Bull. 43 1164–70
[27] Hall J R, Dobrovolskaia M A, Patri A K and McNeil S E 2007 Characterization of nanoparticles for therapeutics J. Nanomedicine 2 789–803
[28] Chekin F, Vahdat S M and Asadi M J 2016 Green synthesis and characterization of cobalt oxide nanoparticles and its electrocatalytic
behavior Russ. J. Appl. Chem. 89 816–22
[29] Singh D, Pandey D, Yadav R and Singh D 2013 A study of ZnO nanoparticles and ZnO–EG nanofluid J. Exp. Nanosci. 8 731–41
[30] Mntungwa N, Pullabhotla V S and Revaprasadu N 2012 Facile synthesis of organically capped CdTe nanoparticles J. Nanosci.
Nanotechnol. 12 2640–4
[31] Khan M A, Shahwar D, Ahmad N, Khan Z and Ajaib M 2010 Chemical constituents of Carissa opaca extracts and their evaluation as
antioxidants and preservatives in edible oils Asian J. Chem. 22 379–88
[32] Suja K P, Jayalekshmy A and Arumughan C 2004 Free radical scavenging behavior of antioxidant compounds of sesame (Sesamum
indicum L.) in DPPH system Journal of Agriculture Food Chemistry 52 912–5
[33] Balasundram N, Sundram K and Samman S 2006 Phenolic compounds in plants and agri-industrial by-products: antioxidant activity,
occurrence, and potential uses Food Chem. 99 191–203
[34] Makkar H P, Blümmel M, Borowy N K and Becker K 1993 Gravimetric determination of tannins and their correlations with chemical
and protein precipitation methods J. Sci. Food Agric. 61 161–5
[35] Riaz T et al 2011 Colebrookia oppositifolia: a valuable source for natural antioxidants Journal of Medicinal Plants Research 5 4180–7
[36] Nassar N N 2010 Rapid removal and recovery of Pb(II) from wastewater by magnetic nanoadsorbents J. Hazard. Mater. 184 538–46
[37] Al-Sou’od K 2012 Adsorption Isotherm Studies of Chromium (VI) from Aqueous Solutions Using Jordanian Pottery Materials APCBEE Procedia 1 116–25
[38] Ragab Abukhadra M 2015 Application of quadratic polynomial model for the uptake of iron from aqueous solutions by natural and
modified egyptian bentonite American Journal of Applied Chemistry 3 179–87
[39] Morais P C, Azevedo R B and Rabelo D 2003 Synthesis of magnetite nanoparticles in mesoporous copolymer template: a model system
for mass-loading control Chem. Mater. 15 2485–7
[40] Selim M K, Komarneni S and Abu Khadra M R 2016 Phosphate removal from solution by composite of MCM-41 silica with rice husk:
kinetic and equilibrium studies Microporous Mesoporous Mater. 224 51–7
[41] Cheng R, Xiang B, Li Y and Zhang M 2011 Application of dithiocarbamate-modified starch for dyes removal from aqueous solutions J.
Hazard. Mater. 188 254–60
[42] Batzias F and Sidiras D 2007 Simulation of dye adsorption by beech sawdust as affected by pH J. Hazard. Mater. 141 668–79
[43] Mozumder M S and Islam M A 2010 Development of treatment technology for dye containing industrial wastewater Journal of Scientific
Research 2 567
[44] Shen Y, Tang J, Nie Z, Wang Y, Ren Y and Zuo L 2009 Preparation and application of magnetic Fe3O4 nanoparticles for wastewater
purification Sep. Purif. Technol. 68 312–9