One-pot biosynthesis of CdS quantum dots through *in vitro* regeneration of hairy roots of *Rhaphanus sativus* L. And their apoptosis effect on MCF-7 and AGS cancerous human cell lines

Zahra Gholami¹, Mehdi Dadmehr*, Nadali Babaeian Jelodar¹, Morteza Hosseini³⁴, Fatemeh oorojalian⁵⁶ and Ali Pakdin Parizi⁷

¹ Department of plant breeding and biotechnology, Faculty of crop sciences, Sari Agricultural Sciences and Natural Resources University, Sari, Iran
² Department of Biology, Payame Noor University, Tehran, Iran
³ Department of Life Science Engineering, Faculty of New Sciences & Technologies, University of Tehran, Tehran, Iran
⁴ Medical Biomaterials Research Center, Tehran University of Medical Sciences, Tehran, Iran
⁵ Department of advanced Sciences and Technologies, School of medicine, North Khorasan University of Medical Sciences, Bojnurd, Iran
⁶ Natural Products and medicinal plants research center, North Khorasan University of Medical Sciences, Bojnurd, Iran
⁷ Genetics and Agricultural Biotechnology Institute of Tabarestan, Sari Agricultural Sciences and Natural Resources University, Sari, Iran

E-mail: mdadmehr@ut.ac.ir

Keywords: CdS quantum dots, biosynthesis, hairy roots, apoptosis

Abstract

Development of green based synthesis of nanoparticles has been regarded as a novel and safe alternative method compared to conventional methods. Semiconductor cadmium sulfide quantum dots (CdS QDs) possess unique biological and medical applications including labeling cells, diagnosing of diseases and imaging intercellular events. The present paper reports the biosynthesis of CdS QDs through aqueous extracts of the regenerated hairy roots of *Rhaphanus sativus* L. as the organic source for both reducing and stabilizing of Cd and S precursor ions. The characterization of synthesized QDs showed maximum absorbance peak of 460 nm and fluorescence spectrum of cadmium sulfide at 530 nm. The results of Transmission Electron Microscope (TEM) and EDS analysis demonstrated that the particles were morphologically spherical with size distribution between 2–7 nm and confirmed presence of CdS QDs. Fourier transform infrared spectroscopy (FT-IR) also showed the active presence of aromatic, amino, and carboxyl groups on the surface of quantum dots. Cytotoxicity effect of the synthesized CdS QDs on two cell lines include MCF-7 breast cancer and AGS gastric cancer were assayed through MTT assay. The results showed significant inhibitory effects of synthesized QDs on treated cells in a dose dependent manner. It was also concluded that CdS QDs had more apoptosis effect on MCF-7 cells rather than AGS cell lines. The obtained results clearly illustrated that the synthesis of CdS quantum dots with standard features would be possible through cost-effective, reliable, environmentally friendly and less toxic alternative method compared to chemical and physical processes and the MTT toxicity assay also illustrated the significant apoptotic effects of synthesized CdS QDs on carcinogenesis.

Introduction

Recently, many attempts have been made to discover and introduce novel therapeutic agents to target different cancers [1–3]. Nanomaterials are a novel group of materials with diameter between 1–100 nm that could present in different shapes and proportions. Given their shapes, they are classified into Zero-dimensional, one-dimensional, and two-dimensional [4]. Recently, some of advanced types of metallic nanomaterials have been applied in pharmaceutical applications such as anti-cancer [5–8], antimicrobial [9, 10] effects. QDs are considered as semi-conductive zero-dimensional nanocrystals with sizes in range of 1–20 nm. These materials are characterized by a nanoparticle core consisting of hundreds or thousands of elements in group II and VI.
(Cadmium, Tectentium, Zinc, Selenium) or III (Tantalum) and V (Indium) [11, 12]. The photophysical properties of quantum dots is dependent to their particle size, therefore, controlling the particles growth is crucially important. The quantum dots with larger size create shorter band gap and the more spectral power distribution. Accordingly, the color distribution in various wavelengths can be created by variations in nanoparticle size [13, 14]. Among them, Cadmium sulfide QDs (CdS QDs) displays upper direct band gap of 2.4 eV and a small Excitation Bohr Radius of 2.4 nm [15, 16]. They are also characterized by their high quantum function, large molar extinction coefficients, narrow/width absorption, balanced photoluminescence (PL), near infrared (NIR) UV spectrum and high efficiencies compared with other fluorescence probes [17]. These features have made them interesting for their possible application in industry such as in light emitting diodes (LEDs), solar cells, lasers, absorption filters, piezoelectric converters, and biological sensors [18–30].

Commonly, chemical synthesis of quantum dots produces a measure of toxic components which preclude them for biological applications. It has been found in recent decade that biological systems including bacteria [31], yeast [32] and fungi [33], could revitalize and convert metallic ions into metallic nanoparticles by their proteins and metabolites. These studies showed that plant synthesis of quantum dots is very considerable due to their low costs, short production time, safety and large production amounts. Plant metabolites like terpenoids, polyphenols, alkaloids, phenolic acids, and proteins play a vital role in revitalizing metallic ions [34]. The reduction of metallic ions and producing nanoparticles are dependent to a variety of factors. In additions to the presence of biologically active molecules, the factors include pH level of reaction mixture, incubation temperature, reaction time, concentration of salts and ionic electrochemical potential are determining factors during QDs biosynthesis [35]. So, production of QDs through green synthesis could be consider as a novel and safe alternative approach through biological processes. One popular method in such synthesis was exploiting of plant organs, tissues, or cells [36]. Among them hairy roots were preferred over other plant organs due to their high capacity for accumulation of heavy metals [37] and it was regarded as a successful method in producing important secondary metabolites that could contribute to nanoparticle formation [38]. The induction of hairy roots would be possible by infecting the plant tissue with Agrobacterium rhizogenes bacterium. In this way, the resultant transformed roots are genetically stable with quick growth pattern in hormone-free environment. Rhapahas sativus L. is an annual plant of Brassicaceae family that has high food value because of high content of anti-oxidants, glucozinoids, isothiocyanate, diet dissolved fibers and vitamins B and C [39]. It also has 4-(methylthio)-3-butenyl isothiocyanate, allyl isothiocyanate, benzyl isothiocyanate and phenethyl isothiocyanate as well as flavonoids such as kaempheral glycosides, peroxidases and antioxidants [40]. These plants derived substances could play an important role for reduction and following green synthesis of metal ions present in their growth medium. Peptides and proteins also have functional groups in their lateral chains that facilitate the attachment of metal ions and may facilitate nanoparticles formation [41]. In the present paper, a novel and facile one-pot approach was introduced for biological synthesis of cadmium sulfide via hairy roots of Rhapahas sativus L. As illustrated in scheme 1(A) the Rhapahas sativus L plant explant was infected by Agrobacterium rhizogenes and finally resulted to hairy root induction. Next for synthesis process, first, the medium containing hairy root extract was prepared and Na2S and CdSO4 precursor salts were added to the medium respectively under different pH condition (scheme 1(B)). Finally, the structure, morphology and

![Scheme 1. Schematic representation of biological synthesized CdS QDs.](image)
centrifuged at 12 000 rpm for 15 min. Then pH level of liquid extract of Green synthesis of QDs was done via producing hairy roots of Preparation of hairy roots Materials and methodology provides an economical and safe approach for synthesis of QDs were analyzed through determination of their apoptosis effect on two human cancer cell lines. The study luminescence of the synthesized CdS QDs were characterized. The toxicity effect of these green synthesized CdS QDs were analyzed for their various features includes absorption spectrum, emission spectrum, morphology, crystallographic structure, presence of functional groups and average size of synthesized particles which determined by UV–vis spectrophotometer (PerkinElmer LAMBDA 950), Fluorescence spectrophotometry (PerkinElmer LS 55), Field emission scanning electron microscopy (FESEM), X’Pert PRO MPD x-ray diffraction, Fourier-transform infrared spectroscopy (FTIR) (IF505 manufactured by BRUKER) and Zetasizer Nano Series model of Dynamic Light Scattering (DLS) instrument by Malvern Corporation, respectively.

Cell culture
The human cell lines including MCF-7 breast cancer cells and AGS gastric cancer cells were cultured in DMEM medium supplemented with 10% FBS and 60 mg ml\(^{-1}\) penicillin and 100 mg ml\(^{-1}\) streptomycin antibiotics, in a humidified 5% CO\(_2\) atmosphere at 37 °C for 72 h (medium refreshed after 48 h) to ensure the cell growth.

MTT assay
The cytotoxic effects of CdS QDs on human cancer cells were determined using colorimetric MTT assay. The initial density of 1 × 10\(^4\) cells per well was chosen to culture were grown in 96-well plates containing 100 ml DMEM medium with 10% FBS for 24 h. For determining of cytotoxicity effect, different concentration of CdS QDs was prepared upon addition of distilled water to the stock solution with serial dilution method. The increasing concentration of CdS QDs solution (3.25, 6.25, 12.5, 25, 50, 100 mg ml\(^{-1}\)) were added to the wells. As control, the same concentrations of plant extract were used to compare with obtained results. After incubation of plates for 24 h, the medium was removed and replaced by fresh medium and incubated for additional 24 h. Then wells were filled with 20 μl of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) (5 mg ml\(^{-1}\) in phosphate buffered saline (PBS), pH 7.4) and incubated in a humidified atmosphere for 4 h at 37 °C. After the incubation, the containing media were removed and 100 ml of 99.9% dimethyl sulfoxide (DMSO) was added to dissolve formazan crystals. Absorbance was immediately determined at 570 nm (reference wavelength 630 nm) using a microplate reader (infinite NanoQuant M 200), Tecan (Zurich, Switzerland). Treated cells in CdS QDs containing medium were compared to control cells in blank plant extract medium (Cell viability = \(A_{treated}/A_{control} \times 100\) and expressed as the mean ± SD of triplicates [43, 44].
Results and discussion

Characterization of synthesized CdS QDs

The particle size distribution histogram determined from FESEM image is shown in figure 1(a). It was found that quantum dots of cadmium sulfide synthesized by aqueous extract of hairy roots of radish (*Raphanus sativus* L.) were well dispersed with spherical morphology with average size of 2–7 nm. DLS analysis was also used in order to determine the QDs size more accurately. The particle size histogram of synthesized QDs in figure 1(b) showed narrow size distribution having 2–7 nm in diameter. For further confirmation, TEM analysis was also performed and TEM image (figure 1(C)) verified the size of QDs around 3 nm. In order to obtain further insight to the features of the CdS QDs, EDX analysis was also performed. According to EDX analysis the presence of Cd, S, Na and K ions in the reaction was confirmed (figure 2). The weight percentage composition of synthesized CdS QDs were 13.87, 8.58 for Cd and S elements respectively. Presence of Cd, S and Na ions are due to CdSO₄ and Na₂S salt precursors and presence of K ions was attributed to either the water or plant cell tissue.

Figure 1. Characterization of CdS QDs, (A) FESEM images of CdS quantum dots synthesized in aqueous extract of hairy roots of radish (*Raphanus sativus* L.), (B) Size distribution of synthesized CdS QDs by DLS analysis, (C) TEM image of CdS QDs.
UV–visible spectrophotometry

UV visible analysis is critical in investigating the behavior of nanocrystalline semiconductors. The absorption wavelength range for both crude extract of hairy roots and synthesized quantum dots was measured at 200–600 nm. As it was illustrated in figure 1, the absorption spectrum of hairy roots extract shows an absorption band around 260 nm, while the synthesized QDs solution shows an absorption band between 350–550 nm with the maximum wavelength occurring at 460 nm. It was concluded that the peak at 460 nm corresponds to the QDs nanoparticles with a diameter 4–6 nm. In similar studies, aqueous extract of hairy roots of Linaria maroccana L [38] and Fusarium oxysporum [34] were used for synthesis of cadmium sulfide quantum dots, and the wavelength range of 450–462 nm was determined as the absorption spectrum. The aqueous solution of QDs exhibited bright yellow color as demonstrated in inset of figure 3.

Luminescence of CdS QDs

Luminescence property is considered as the most significant and applicable feature of QDs due to its broad application in many studies. Fluorescence emission spectra of QDs were analyzed at different excitation wavelengths ranging from 300 to 600 nm. The highest emission intensity at 520 nm was observed for excitation at 370 nm. Figure 2 shows the luminescence spectrum for crude sample compared to synthesized CdS QDs after excitation at 370 nm wavelength. As it is shown, the fluorescence emission of synthesized QDs observed at 520 nm with red shift compared to control sample at 370 nm wavelength. The aqueous solution of CdS QDs exhibited bright green luminescence compared to control sample under UV light as illustrated inset of figure 4. It was also reported previously that luminescence band was found at 425–500 nm in a study which applied aqueous extract of hairy roots of Linaria maroccana L [38] and R.palustris [45] for the synthesis of cadmium sulfide quantum dots. Absorption and luminescence of semiconductor nanoparticles depend on type, size, and surface properties and is affected by the reciprocal impact between nanoparticles surface and the environment and the reciprocal impact among the nanoparticles themselves [46]. The colloidal solution storage of CdS QDs was extremely stable and did not show aggregation even after three months.
In order to obtain information about composition and internal structure of CdS QDs XRD analysis was used. The XRD patterns for sulfide nanocrystals appeared on the spectrometer in \(2\theta\) position in angles 23.01, 26.20, 31.20, 33.55, and 46.80 while the crystalline phase was found to be in line with the face centered hexagonal crystal (figure 5). These results were comparable with the peaks of CdS pure samples published by Joint Committee for Powder Diffraction Standards (JCPDS) file number 10–454. Same results were reported in a biosynthesis of cadmium sulfide by Bacillus licheniformis in \(2\theta\) position in angles 26.03, 31.07, 43.5, and 51.5 [47].

Fourier transform infrared spectroscopy (FTIR)

FTIR analysis was performed to study the mechanism of CdS QDs formation and also determine the presence of functional group on the surface of QDs. FTIR spectrometry shows that absorption vector in a 1634.32 cm\(^{-1}\) point belongs to Amide compounds (N-H) of the polypeptides or proteins while 2069.29 cm\(^{-1}\) is the absorption frequency of (C-H) asymmetric groups and 3436.05 cm\(^{-1}\) belongs to hydroxyl groups (OH) (figure 6). Similar results also reported previously on the synthesis of CdS QDs synthesis by F. axysporium [33]. FTIR spectrum revealed the presence of hydrophilic functional groups over the surface of QDs leading to their excellent water solubility. Also, presence of proteins, functional groups and carbohydrates play crucial roles in bio functionalization and further application of QDs nanoparticles in biosynthesis.
Optimization of synthesis procedure

In order to evaluate the effect of pH on biosynthesis of cadmium sulfide QDs, the reaction was performed at different pH using aqueous extract of hairy roots of radish. It was found that maximum fluorescence intensity of synthesized quantum dots was progressively enhanced with an increase in the hydroxyl ion concentration. Comparing the pH values showed approximately 2-fold increase in the fluorescence intensity of CdS QDs at pH = 11 compared to that at pH = 3 (figure 7(A)). It was also found that pH level of aqueous extract plays a major part in formation of nanoparticles with different fluorescence intensity correspond to their sizes and may indicating the growth of CdS QDs during the biochemical process [48]. Any variation in natural pH levels of the aqueous extract affects the attachment or recovery of metallic cations and anions during the synthesis. It was assumed that separating a proton from ugenol OH group would lead to resonance and, through further oxidation and this construct may recovers metallic cations and consequently, nanoparticles are formed.

The optimum temperature for synthesis of QDs were determined through incubation of reaction at varying temperature. As it was shown in figure 7(B) the highest intensity of synthesized QDs was at 28 °C, and this temperature was selected as optimum point. Another determining factor for the synthesis of CdS QDs is the reaction time. In order to determine the optimum period, the fluorescence emission of synthesized QDs were monitored during the reaction. The obtained results showed the maximum intensity was obtained after 4 days and the fluorescence emission remained stable in next days (figure 7(C)). So, the 4 days reaction time was selected as the optimum reaction time.

Cytotoxicity of synthesized CdS QDs

MCF-7 and AGS cancerous cell lines were treated with concentration series of CdS QDs (0-100 mg ml⁻¹) and cell viability was determined. The results of MTT assay showed the dose dependent decrease in cell viability of treated cells with CdS QDs solution compared to treated cells with blank plant extract as a control. As shown in figure 8, the amount of cell viability decreased upon addition of higher concentration of QDs in both cell lines. Although this effect was more significant for MCF-7 cells. Viability of MCF-7 cells inhibited significantly at 12.5 mg ml⁻¹ and reached its highest effectiveness (20%) at maximum concentration of CdS QDs (figure 8(A)). On the other side CdS QDs induced significant apoptosis on AGS cells at 25 mg ml⁻¹ and its maximum concentration led to 50% viability of treated cells (figure 8(B)). Plant hairy root extract alone could not play significant role for inhibition of both cell lines (figures 8(C), (D)). So, it was concluded that the MCF-7 cells showed more sensitivity to toxicity of CdS QDs compared to AGS cells. Also, in order to confirm the apoptosis effect of CdS QDs on MCF-7 cells, microscopic images were shown in figures 8(a)–(c) that illustrated after incubation of cells with 3 doses of incubated synthesized CdS QDs at 100, 50 and 25 mg ml⁻¹ respectively, resulted to cell apoptosis. The plant extract (figure 8(d)) and control (figure 8(e)) couldn’t induce any apoptosis effects on MCF-7 cells.
Conclusion

Remarkable properties of QDs in industries and medicine, made them as interesting targets. They are usually produced by costly chemical methods which leave a measure of toxic agents on nanoparticles that might cause problems in later applications. Recently, plant extracts have been introduced as convenient alternatives in producing metallic nanoparticles. In the present experiment regenerated induced hairy roots were used in biosynthesis of CdS QDs, since they are capable of quick controlled growth in lab setting and have superior property rather than the original plant in aspect of secondary metabolites content. The UV-Vis spectrophotometry and luminescence were used in determining optical properties of synthesized CdS QDs. The absorption and fluorescence emission spectrum of synthesized QDs were in 460 nm and 520 nm wavelengths respectively. Morphologically spherical and structurally crystalline, the synthesized particles showed acceptable stability due to presence of proteins and functional groups. According to TEM results QDs were found to be mostly 2–10 nm. The apoptosis effect of synthesized CdS QDs were investigated on MCF-7 and AGS cell lines. Obtained results showed both cells experienced decreased viability over increased concentration of applied QDs samples and the MCF-7 cells were more sensitive to applied CdS QDs. According to these results, aqueous extract of hairy roots of radish (Raphanus sativus L.) is a potential factory for producing CdS QDs and their
biological inhibitory effects on cancer cells which was directly dependent to QDs presented their possible therapeutic application.

**ORCID iDs**

Mehdi Dadmehr @ https://orcid.org/0000-0002-6016-5988

**References**

[1] Atif M, Firdous S, Khurshid A, Noreen L, Zaidi S and Ikram M 2009 In vitro study of 5-aminolevulinic acid-based photodynamic therapy for apoptosis in human cervical HeLa cell line Laser Phys. Lett. 6 686

[2] Atif M et al 2011 Cytotoxic and photocytotoxic effect of photofrin® on human laryngeal carcinoma (Hep2c) cell line Laser Phys. 21 1235–42

[3] Atif M, Fakhar-e-Alam M, Firdous S, Zaidi S, Suleman R and Ikram M 2010 Study of the efficacy of 5-ALA mediated photodynamic therapy on human rhabdomyosarcoma cell line Laser Phys. Lett. 7 575

[4] Fang X et al 2011 ZnS nanostructures: from synthesis to applications Prog. Mater Sci. 56 175–287

[5] Iqbal S et al 2019 Application of silver oxide nanoparticles for the treatment of cancer J Med 1189 203–9

[6] Iqbal S et al 2020 Photodynamic therapy, facile synthesis, and effect of sintering temperature on the structure, morphology, optical properties, and anticancer activity of Co3O4 nanocrystalline materials in the HepG2 cell line J Photoch Photobio A 386 121120

[7] Akram M W et al 2019 Tailoring of Au–TiO2 nanoparticles conjugated with doxorubicin for their synergistic response and photodynamic therapy applications J Photoch Photobio A 384 112040

[8] Atif M et al 2016 In vitro cytotoxicity of mesoporous SiO2@ Eu (OH) 3 core–shell nanospheres in MCF-7 J. Nanomater. 2016 7691861
[9] Iqbal S et al 2019 Structural, morphological, antimicrobial, and in vitro photodynamic therapeutic assessments of novel Zn + 2-
substituted cobalt ferrite nanoparticles Results Phys 15 102529
[10] Atif M et al 2019 Manganese-doped cerium oxide nanocomposite induced photodynamic therapy in MCF-7 cancer cells and antibacterial activity BioMed Res Int 2019 716828
[11] Gao X, Yang L, Petros J A, Marshall F F, Simons J W and Nie S 2005 In vivo molecular and cellular imaging with quantum dots Curr.
Opin. Biotechnol. 16 63–72
[12] Medintz L I, Uyeda H T, Goldman E R and Mattoussi H 2005 Quantum dot bioconjugates for imaging, labelling and sensing Nature
Mater. 4 435
[13] Li H 2008 Synthesis and Characterization of Aquasol Quantum Dots for Biomedical Applications Drexel University
[14] Costa-Fernández J M, Pereiro R and Sanz-Medel A 2006 The use of luminescent quantum dots for optical sensing TrAC, Trends Anal.
Chem. 25 207–18
[15] Mandal S, Rautaray D, Sanyal A and Sastry M 2004 Synthesis and assembly of CdS nanoparticles in Keigin ion colloidal particles as templates J. Phys. Chem. B 108 7126–31
[16] Faridbod F, Jamali A, Ganjali M R, Hosseini M and Norouzi P 2015 A novel cobalt-sensitive fluorescent chemosensor based on ligand
capped CdS quantum dots J. Fluoresc. 25 613–9
[17] Brucher J, Moronne M, Gin P, Weiss S and Alivisatos A P 1998 Semiconductor nanocrystals as fluorescent biological labels Science 281
2013–6
[18] Kim T-H et al 2011 Full-colour quantum dot displays fabricated by transfer printing Nat. Photonics 5 176
[19] Bör O 2011 Cadmium sulfide enhances solar cell efficiency Energy Convers. Manage. 52 426–30
[20] Zou B, Little R, Wang J and El-Sayed M 1999 Effect of different capping environments on the optical properties of CdS nanoparticles in reverse micelles Int. J. Quantum Chem. 72 439–50
[21] Hosseini M, Khaki F, Shokri E, Khazbuz H, Dadmehr M, Ganjali M R, Feizabadi M and Ajjoo D 2017 Study on the interaction of the
Cu6+ alternating DNA with CdTe quantum dots J. Fluoresc. 27 2059–68
[22] Fadzi S, Dadmehr M, Hosseini M, Ahmadzade Kermani H and Ganjali M R 2019 A fluorometric study on the effect of DNA methylolation on DNA interaction with graphene quantum dots Methods. Appl. Fluoresc. 7 025001
[23] Ahmadzade Kermani H, Hosseini M, Dadmehr M, Hosseinkhani S and Ganjali M R 2017 DNA methyltransferase activity detection based
on graphene quantum dots using fluorescence and fluorosceine anisotropy Sens. Actuators B 241 217–23
[24] Hosseini M, Ganjali M R, Vaezi Z, Arabosorkhi B, Dadmehr M, Faridbod F and Norouzi P 2015 Selective recognition histidine and
tryptophan by enhanced chemiluminescence ZnSe quantum dots Sens. Actuators B 210 349–54
[25] Hosseini M, Khazbuz H, Shiralizadeh Dezfooli A, Ganjali M R and Dadmehr M 2013 Selective recognition of Glutamate based on
fluorescence enhancement of graphene quantum dot Spectrochim. Acta, Part A 136 1962–6
[26] Hosseini M, Ganjali M R, Jarrahi A, Vaezi Z, Mirzaz F and Faridbod P 2014 Enhanced chemiluminescence CdSe quantum dots by
histidine and tryptophan Spectrochim. Acta, Part A 132 629–33
[27] Nemati F, Hosseini M, Zare-Dorabei R, Salehnia F and Ganjali M 2018 Fluorescent turn on sensing of Caffeine in food sample based
on sulfur-doped carbon quantum dots and optimization of process parameters through response surface methodology Sens. Actuators B 273
25–34
[28] Nemati F, Zare-Dorabei M, Hosseini R and Ganjali M R 2018 Fluorescent turn-on sensing of thiamine based on Arginine–
functionalized graphene quantum dots (Arg-GQDs): central composite design for process optimization Sens. Actuators B 255 2078–85
[29] Borghesi Y S and Hosseini M 2018 An approach toward miRNA detection via different thermo–responsive aggregation/disaggregation
of CdTe quantum dots RSC Adv. 8 30148–54
[30] Borghesi Y S, Hosseini M and Ganjali M R 2017 Fluorometric determination of microRNA via FRET between silver nanoclusters and
CdTe quantum dots Microchim. Acta 184 4713–21
[31] Devourd B, Posfai M, Hua X, Bazylnski D A, Frankel R B and Busc F P K 1998 Magnetite from magnetotactic bacteria: size
distributions and twinning Ant. Miner. Vol. 83 1387–98
[32] Kowshik M et al 2002 Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3 Nanotechnology 14 95
[33] Ahmad A et al 2002 Enzyme mediated extracellular synthesis of CdS nanoparticles by the fungus, Fusarium oxysporum J. Am. Chem.
Soc. 124 12108–9
[34] Malavos V et al 2014 ‘Green’ nanotechnologies: synthesis of metal nanoparticles using plants Acta Naturae 6 20
[35] Ravendran P, Fu J and Wallen S L 2003 Completely ‘green’ synthesis and stabilization of metal nanoparticles Journal of the American
Chem Soc. 125 13940–1
[36] Haverkamp R and Marshall A 2009 The mechanism of metal nanoparticle formation in plants: limits on accumulation J. Nanopart.
Res. 11 1453–63
[37] Guillon S, Trémouillaux-Guiller J, Pati P K, Rideau M and Gantet P 2006 Hairy root research: recent scenario and exciting prospects
Curr. Opin. Plant Biol. 9 541–6
[38] Borovaya M N, Naumenko A P, Matveieva N A, Blume Y B and Yermets A I 2014 Biosynthesis of luminescent CdS quantum dots using
plant hairy root culture Nanoscale Res. Lett. 9 686
[39] Gutiérrez R M P and Perez R L 2004 Raphanus sativus (Radish): their chemistry and biology Science World J 14 811–37
[40] Hara M, Ito F, Asai T and Kuboi T 2009 Variation in amylase activities in radish (Raphanus sativus) cultivars Plant Foods For Human
Nutrition 64 188–92
[41] Lin H et al 2006 Prediction of the functional class of metal-binding proteins from sequence derived physicochemical properties by
support vector machine approach BMC Bioinf. 7 189
[42] Pakd J, Farsi M, Nematzadeh G and Mirshamsi Kakhki A 2015 Effect of different Agrobacterium rhizogenes strains on hairy root
induction in Valeriana officinalis L. Continental J. Biology. 69 9–15
[43] Oroojalian F, Babaei M, Taghdisi S M, Abnous K, Ramezani M and Aliholland M 2018 Encapsulation of thermo-responsive gel in pH-
sensitive polysommes as dual-responsive smart carriers for controlled release of doxorubicin J. Control. Release 288 45–61
[44] Oroojalian F, Rezayan A H, Shier W T, Abnous K and Ramezani M 2017 Megalin-targeted enhanced transfection efficiency in cultured
human HK-2 renal tubular proximal cells using aminoglycoside-carboxyalkyl-polyethyleneimine-containing nanoplexes Int. J. Pharm.
523 102–20
[45] Bai H, Zhang Z, Guo Y and Yang G 2009 Biosynthesis of cadmium sulphide nanoparticles by photosynthetic bacteria Rhodospseudomonas palustris Collo Surfaces B 70 142–6
[46] Dhatge S R, Colorado H A and Hahn H T 2013 Photoluminescence properties of thermally stable highly crystalline CdS nanoparticles
Mater. Res. 16 504–7
[47] Shivashankarappa A and Sanjay K 2015 Study on biological synthesis of cadmium sulfide nanoparticles by Bacillus licheniformis and its antimicrobial properties against food borne pathogens Nanosci Nanotechnol Res 3 6–15

[48] Chen G et al 2014 Facile green extracellular biosynthesis of CdS quantum dots by white rot fungus Phanerochaete chrysosporium Coll Surfaces B 117 199–205