Studies in Medical Sciences, Vol. 34(10), January 2024

Original Article

Facile fabrication and characterization of silver nanoparticles by sunn pest (Eurygaster integriceps puton) damaged wheat and evaluation of its antibacterial and cellular toxicity toward liver cancer cell lines

Mohammad Nateq Golestan[1], *Mohammad Reza Abbasi*[2], *Hasan Rakhshandeh*[3]*,
Mohammad Ehsan Taghavizadeh Yazdi[4*]

Received 16 August 2023, **Accepted** for publication 25 December 2023

Abstract

***Background & Aims*:** Silver nanoparticles (AgNPs) are among the most explored nanomaterials and are widely employed in medical, pharmaceutical, and bioengineering application. The aim of this study was to investigate the antibacterial and cell toxicity effects of fabricated AgNPs by green method at room temperature.

Materials & Methods: In this work, AgNPs were fabricated by green method, which uses the seed extract of *Triticum aestivum* damaged by sunn pest (*Eurygaster integriceps* Puton) (SPDSPDWAgNPs) at room temperature. Powder X-ray Diffraction (PXRD) and Transmission Electron Microscopy (TEM) were used for characterization of synthesized nanoparticles. Disk diffusion method and MTT analysis were used for antibacterial and cell toxicity effects, respectively.

***Results*:** The synthesis of SPDSPDWAgNPs was relevant by color change of solution, turning from light-yellow to dark-brown, respectively. α-glycosidase, protease and α-amylase are some identified enzymes of salivary glands of sunn pest which can affect the synthesis of nanoparticles. The results showed that SPDSPDWAgNPs have spherical shapes and had a different range from 1 to 25 nm. Moreover, the biosynthesized SPDSPDWAgNPs have high antibacterial properties toward the most common inflectional bacteria. Furthermore, the cytotoxicity results show the fabricated SPDSPDWAgNPs prevent the growth of cancer cells.

Conclusion: We concluded that this production manner of nanoparticles could be employed for large-scale synthesis of AgNPs, pharmaceutical, and antiseptic uses.

***Keywords*:** Silver nanoparticle, Anticancer, Antimicrobial, Green chemistry.

***Address*:** Pharmacological Research Center of Medicinal Plants, Mashhad University of Medical Sciences, Mashhad, Iran.

***Tel*:** +985138803004

***Email*:** Rakhshandehh@mums.ac.ir; metyazdi@gmail.com

Introduction

Silver nanoparticles (AgNPs) have lately gained popularity for an extensive variety of biological uses due to their increased and exclusive biochemical activities (1, 2). The performance of silver nanorates in-fighting and eliminating pathogenic agents is well known due to its interaction with the surface of the cell membrane of microbes, and research in this field is still ongoing (3-

[1] *Plant Protection Research Department, Khorasan Razavi Agricultural and Natural Resources Research and Education Center, AREEO, Mashhad, Iran*
[2] *Agricultural and Natural Resources Research Center of Khorasan-e Razavi, AREEO, Mashhad, Iran*
[3] *Pharmacological Research Center of Medicinal Plants, Mashhad University of Medical Sciences, Mashhad, Iran (Corresponding Author)*
[4] *Applied Biomedical Research Center, Mashhad University of Medical Sciences, Mashhad, Iran (Corresponding Author)*

5). The Ag ions reduce sheath penetrability, causing the death of microbes (6). Investigations displays that AgNPs activity against microbes are more effective than Ag in their bulk (7-9). In recent years, AgNPs have gained substantial consideration and are widespread considered nanostructures (10). Because of distinctive physical and biochemical activities, they have enormous applications in medicine, pharmaceutical industries, horticulture, and catalysis (11, 12). There are various reports that show that silver nanoparticles are made in different ways and each of the final products has its own properties (13-15).

Physicochemical ways are being used for AgNPs fabrication (16, 17). These ways have their specific benefits and difficulties. Physical ways need for example high pressure and therefore particular tools are required (17, 18). Chemical ways have the advantage that the size of nanoparticles can be controlled but leads to non-ecofriendly and toxic products (19-21). Biological ways of AgNPs fabrication do not need the employ of toxic materials and act as an ecofriendly way (22-24). Green synthesis ways have attracted many considerations in the recent years due to the employ of safe materials, and permit the production of ecofriendly materials with least toxic effects (25-27). These ways typically use natural-based materials to fabrication of nanostructures (28). Plants-mediated ways are known as one of the safe and reliable ways in the synthesis of nanoparticles (29-31). Nevertheless, it is beneficial to employ plants for fabrication of nanoparticles as it does not need specialized tools (32). Various parts of a plant such as fruits, leaf or stem can participate in the synthesis of nanoparticles (33, 34). There are important and valuable secondary metabolites such as phenols and flavonoids in plants, which can play a critical role in the synthesis and improvement of the quality of nanoparticles (35-37). Wheat is one of the important grains all over the world, which is abundantly found everywhere and can be used as a reliable and affordable source in the synthesis of various nanoparticles.

The purpose of this work was to examine the fabrication of silver nanoparticles by *Triticum aestivum* damaged by sunn pest *(Eurygaster integriceps Puton)* (SPDWAgNPs) as they organize a resource of materials, which makes them candidates for fabricating nanoparticles without the requirement addition of any things to the fabrication.

Materials & Methods

Wheat seeds as prepared from research and innovation Agriculture Institute of Mashhad, Iran. $AgNO_3$ with purity of 99% was obtained from Sharlu-Spain. Other materials were obtained from Merck. The biosynthesized silver nanoparticles were fully characterized by transmission electron microcopy (TEM) and powder X-ray diffraction (PXRD) techniques.

Preparation of Wheat Extract:

Wheat grains were first powdered with a mill, and then 3 grams of powder and mixed with 300 grams of deionized water and stirred for 24 hours. The mixture was filtered with a filter paper and the resulting solution were stored in the refrigerator at a temperature of 5 °C for later use. The final solution as a reducing factor is employed for the fabrication of nanoparticles.

Biosynthesis and Characterization of Silver Nanoparticles:

$AgNO_3$ was selected as the initiator for the fabrication of nanoparticles. The AgNPs were made using the reaction of wheat solution and one mM solution of silver nitrate. 1 mM Silver nitrate solution was combined with the solution of wheat at a ratio of 90:10 (v/v). After that, the solution was placed on the stirrer for 48 hours. The biosynthesized colloidal AgNPs were characterized using X-ray diffraction (XRD) analysis and Transmission Electron Microscopy (TEM).

Antibacterial Activity of AgNPs:

The disk diffusion technique was applied to assess the bactericidal properties of SPDWAgNPs towards *Bacillus subtilis* as a Gram-positive bacterium and *Escherichia coli* as a Gram-negative bacterium. The bacterial culture was regulated to 1:5*10^8 colonies. The surface of agar was injected three times by bacterial suspension. At that time, disks soaking in SPDWAgNPs solution, were placed on the agars. The extract was used as negative control. The plates were kept in the incubator for 24 seconds. Gentamicin and streptomycin were employed as positive control in the antibacterial tests.

Cell Toxicity Properties Against Liver Cancer Cell Lines:

The cell toxicity of biosynthesized SPDWAgNPs was measured against liver cancerous cell lines (HepG2) by MTT method. HepG2 cell line was obtained from the medicinal school of Mashhad, Iran. The cells which were established in the DMEM and FBS. The medium was adjusted to comprise 1% penicillin, streptomycin and l-glutamine. Diverse treatments (e.g., 0, 0.5, 1, 2, 4, 8, 15, 30, 60, 125, and 250µg/mL) of SPDWAgNPs were tested in bactericidal evaluation.

Results

Biofabrication of SPDWAgNPs:

The SPDWAgNPs biofabrication reaction has speciously been persuaded after the seeds parts of the extract have been added into the one mM $AgNO_3$ solution. Following to spending 48h in 25 °C, the color of the combination reaction was perceived to alteration into a dark brown colored, which verified the biofabrication of SPDWAgNPs (Figure 1). This change of color has occurred because of the presence of the biomolecules in the extract which lead to the reduction of Ag ions into SPDWAgNPs.

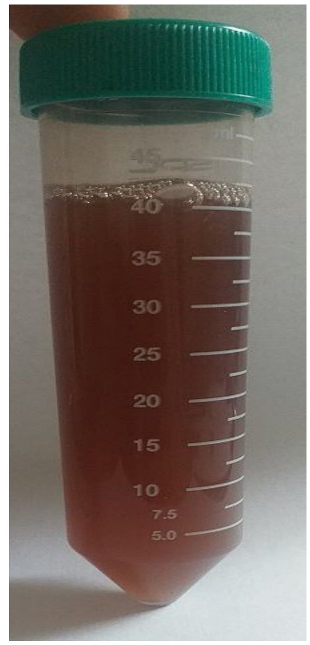

Fig 1. Formation of biosynthesized silver nanoparticles using wheat extract.

Characterization of Ag-NPs:

The explained PXRD design in **Figure 2** displays the specific peaks at 32.19º, 38.15º, 44.28º, 64.46º in regard to the biofabricated SPDWAgNPs from the extract of wheat seeds, respectively. This data confirms the preparation of face-centered cubic (FCC) crystalline elemental silver that is in agree with pervious published resources (38).

Transmission electron microscopy (TEM) has been utilized for identifying the form, dimension, and morphology of nanoparticles. It has been detected that the SPDWAgNPs are actually well dispersed and contain sphere shaped particles, as it is revealed in Figure 3. The variety of particles size has been dignified to be in 1 25 nm.

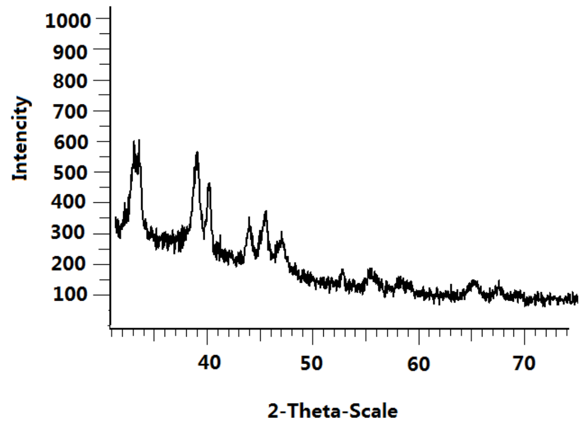

Fig 2. The PXRD pattern of biosynthesized AgNps.

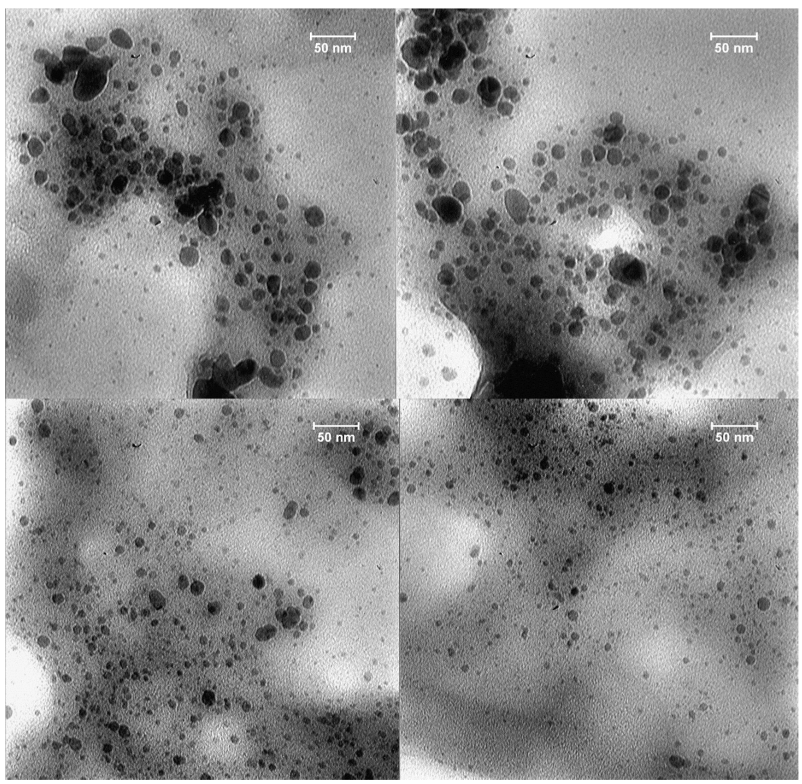

Fig 3. TEM images of biosynthesized AgNPs.

Bactericidal Activity of Biosynthesized AgNPs:

There is a report that shows, the AgNps strongly inhibited the bacterial growth and propose using of Ag-coated surfaces can release antibacterial factors (39). As a result of their bactericidal properties, AgNPs have been used generally in the numerous arenas of food, pharmaceutical industries, and ecological uses (40). These specific NPs have been tested for their bactericidal activities toward both gram positive

(B.subtilis) and gram negative (E.coli) bacteria displaying the areas of reticence. Based on the IZ (Inhibition Zone) created biofabricated AgNPs, the accommodation of great antibacterial properties has been detected toward all of the identified infective bacteria. The control treatment was not able to show any bactericidal properties. The calculation results in the case of antibacterial properties of synthesized AgNPs, which have been obtained from the disc diffusion technique, are specified and existing in Figure 4 while the IZ of antibacterial has been revealed in Table 1. The AgNPs have shown an effectual antimicrobial property that is purportedly a result of the massive surface area, which offers an improved interaction with the cell wall of bacteria. In the existence of oxygen, the redox reaction produces OH radicals that oxidase could be employed as an antimicrobial factor. The contact of bacteria and nanomaterial surface at the interface is multifaceted and is influenced by the surface assets of nanomatter, the adjacent environment and the kind of bacteria. The mechanism of the bactericidal influence of Ag is usually supposed to include the contact of Ag-ions with (-) charged types existent in the cytoplasm membrane. It is also suggested that the decrease of cytoplasmic membrane or segregate from the cell wall cause to condensed-DNA with subsequent damage in capability to multiply on being infiltrated using Ag-ions.

Fig 4. Antibacterial properties of biofabricated of AgNPs against E. coli. and B. subtilis (Gentamycin and extract used as control+ and control- respectively).

Table 1. Diameter zones of inhibition (mm) using AgNPs toward pathogenic bacteria.

Bacteria	Test (AgNPs)	Control negative (Extract)	Control positive (Gentamycin)
Bacillus subtilis	15	0	26
Escherichia coli	12	0	19

Cytotoxicity activity:

Biocompatibility is related to the behavior of biological materials in diverse situations and refers to the ability of a material to perform with the appropriate host-response in a particular state and one of these important cases is cellular toxicology (41-44). The cell toxicity activity of the biofabricated SPDWAgNPs on cancer cells (HepG2) has been studied using the MTT analyze. The cell treatments have been done with a diverse dose of SPDWAgNPs (0, 0.5, 1, 2, 4, 8, 15, 30, 60, 125 and 250µg/mL). As it is shown in Figure 5, the MTT analyze has displayed a dose-dependent on the %viability of HepG2 cells. The cytotoxicity influences of SPDWAgNPs are perhaps as a result of the effectual contact of Ag-atoms with various bio-groups inside the cell. According to the results obtained in this research, it can be concluded that the use of green synthesized silver nanowires can be used as antipathogenic agents and also in the treatment of cancer.

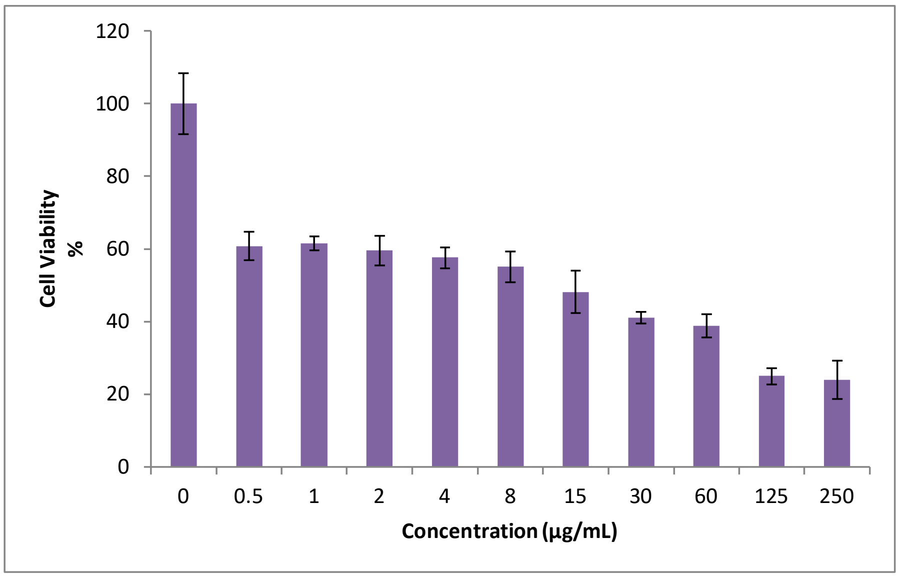

Fig 5. The cell toxicity results of green bio-fabricated SPDWAgNPs.

Discussion

Nanoscience and nanotechnology has grown rapidly (45). One of the most important branches of the nanoscience is nanomedicine (46, 47). Nanomedicine has a wide range of application from the diagnosis and treatment of modern diseases (48, 49). There are several ways to synthesis of nanoparticles but most of them are ineffective because of harmful substances used in the synthesis of nanoparticles, which ultimately have various side effects and the production of nanoparticles with these methods is either not cost-effective or has negative effects on the environment (39, 50). The usefulness of metal and metal oxide nanoparticles, including silver and silver oxide nanoparticle, has long been recognized. Silver nanoparticles and silver-based nanocomposites have been used for a variety of uses in recent decades (51). Many investigations about the silver nanoparticles (AgNPs) proved their significance as effective antimicrobial factors toward several pathogenic microorganisms (52-54). The antimicrobial activities of AgNPs have been relevant in the medical area for regulating microbial infections. Furthermore, AgNPs have shown great potential in the treatment of diverse types of tumors, most especially cancer cell lines. In the present research, the successful synthesis of silver nanoparticles using sunn pest damaged wheat was shown. The structures of nanoparticles were investigated using PXRD and TEM, and the results revealed spherical shape nanoparticles with a size of 1-25 nm. The synthesized nanoparticles showed a high ability to inhibit the growth of pathogenic bacteria. In a study, the effects of silver nanoparticles, which were made by the green method using *Premna integrifolia*, were tested on pathogenic bacteria (*Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli*) and the results showed an inhibitory effect on bacteria, which is consistent with our results (55). In the study of the effect of silver nanoparticles synthesized by the green method, they were tested against *Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus,* and *Streptococcus pyogenes* (56). The results of antibacterial effects in this study are consistent with the findings of the present study. The cytotoxicity results of the present study showed the effect of synthesized nanoparticles on the destruction of cancer cells. In various studies, the effect of silver nanoparticles prepared by the green method on different cancer cells was tested, and all of them showed the toxicity effect of nanoparticles against A549 lung cancer cells (57), breast cancer cells (58), and liver cancer cells (59), which are consistent with the cytotoxicity results of the present study.

Studies have shown that plant-mediated synthesized nanoparticles increase ROS levels that cause cancer cell death (60-62). Although various studies have shown the involvement of ROS in causing toxicity in cancer cells, the exact mechanism of this process is still unclear. The results of the present work showed that the synthesized nanoparticles can be produced on a large scale and used in disinfection industries. Also, the studies conducted in the future and in vivo can determine the interactions of nanoparticles with other biological molecules in the animal model and clarify other mechanisms.

Disclosure statement

No potential conflict of interest was stated by the authors.

Funding

Investigation described in this publication was supported by the Mashhad University of Medical Sciences Mashhad, Iran [Number: 980829] and Agricultural and Natural Resources Research Center of Khorasan-e Razavi, AREEO, Mashhad, Iran [Number: 991134].

Conflict of interest

None of the authors have any interest that conflicts with this study.

References

1. Taghavizadeh Yazdi ME, Qayoomian M, Beigoli S, Boskabady MH. Recent Advances in Nanoparticles Applications in Respiratory Disorders, a Review. Front Pharmacol 2023;14:1059343. https://doi.org/10.3389/fphar.2023.1059343
2. Shariatzadeh SMA, Soleimani Mehranjani M, Solgi F, Maleki P. Stereological Study Of The Protective Effect Of Alpha-Lipoic Acid On The Testis Tissue After Treatment With Silver Nanoparticles In The Nmri Mouse. Stud Med Sci 2021;31(12):944-55. http://umj.umsu.ac.ir/article-1-5036-en.html
3. Ke M, Qu Q, Peijnenburg W, Li X, Zhang M, Zhang Z, et al. Phytotoxic effects of silver nanoparticles and silver ions to Arabidopsis thaliana as revealed by analysis of molecular responses and of metabolic pathways. Sci Total Environ 2018;644:1070-9. https://doi.org/10.1016/j.scitotenv.2018.07.061
4. Afkhami F, Forghan P, Gutmann JL, Kishen A. Silver Nanoparticles and Their Therapeutic Applications in

Endodontics: A Narrative Review. Pharmaceutics 2023;15(3):715. https://doi.org/10.3390/pharmaceutics15030715

5. Luceri A, Francese R, Lembo D, Ferraris M, Balagna C. Silver nanoparticles: review of antiviral properties, mechanism of action and applications. Microorganisms 2023;11(3):629. https://doi.org/10.3390/microorganisms11030629
6. Yazdi MET, Nourbakhsh F, Mashreghi M, Mousavi SH. Ultrasound-based synthesis of ZnO· Ag 2 O 3 nanocomposite: characterization and evaluation of its antimicrobial and anticancer properties. Res Chem Intermed 2021;47(3):1285-96. DOI: 10.1007/s11164-020-04355-w
7. Ankegowda VM, Kollur SP, Prasad SK, Pradeep S, Dhramashekara C, Jain AS, et al. Phyto-mediated synthesis of silver nanoparticles using Terminalia chebula fruit extract and evaluation of its cytotoxic and antimicrobial potential. Molecules 2020;25(21):5042. https://doi.org/10.3390%2Fmolecules25215042
8. Baker A, Iram S, Syed A, Elgorban AM, Bahkali AH, Ahmad K, et al. Fruit derived potentially bioactive bioengineered silver nanoparticles. Int J Nanomed 2021;16:7711. https://doi.org/10.2147%2FIJN.S330763
9. Rezaei MR, Es-haghi A, Yaghmaei P, Ghobeh M. Biological fabrication of Ag/Ag2O nanoparticles by Haplophyllum obtusifolium watery extract: characterisation and estimation of its biochemical activities. Micro Nano Lett 2020;15(13):898-902. https://doi.org/10.1049/mnl.2020.0269
10. Mobaraki F, Momeni M, Jahromi M, Kasmaie FM, Barghbani M, Yazdi MET, et al. Apoptotic, antioxidant and cytotoxic properties of synthesized AgNPs using green tea against human testicular embryonic cancer stem cells. Process Biochem 2022. https://doi.org/10.1016/j.procbio.2022.05.021
11. Darroudi M, Yazdi MET, Amiri MS. Plant-Mediated Biosynthesis of Nanoparticles. 21st Century Nanoscience–A Handbook: CRC Press; 2020. p. 1-18.
12. Zarei M, Karimi E, Oskoueian E, Es-Haghi A, Yazdi MET. Comparative study on the biological effects of sodium citrate-based and apigenin-based synthesized silver nanoparticles. Nutr Cancer 2021;73(8):1511-9. https://doi.org/10.1080/01635581.2020.1801780
13. Wasilewska A, Klekotka U, Zambrzycka M, Zambrowski G, Święcicka I, Kalska-Szostko B. Physico-chemical properties and antimicrobial activity of silver nanoparticles fabricated by green synthesis. Food Chem 2023;400:133960. https://doi.org/10.1016/j.foodchem.2022.133960
14. Logambal S, Thilagavathi T, Chandrasekar M, Inmozhi C, Kedi PBE, Bassyouni F, et al. Synthesis and antimicrobial activity of silver nanoparticles: incorporated couroupita guianensis flower petal extract for biomedical applications. J King Saud Univ Sci 2023;35(1):102455. https://doi.org/10.1016/j.jksus.2022.102455
15. Essghaier B, Dridi R, Mottola F, Rocco L, Zid MF, Hannachi H. Biosynthesis and Characterization of Silver Nanoparticles from the Extremophile Plant Aeonium haworthii and Their Antioxidant, Antimicrobial and Anti-Diabetic Capacities. Nanomaterials 2023;13(1):100. https://doi.org/10.3390/nano13010100
16. Naganthran A, Verasoundarapandian G, Khalid FE, Masarudin MJ, Zulkharnain A, Nawawi NM, et al. Synthesis, characterization and biomedical application of silver nanoparticles. Materials 2022;15(2):427. https://doi.org/10.3390%2Fma15020427
17. Sharma D, Gulati SS, Sharma N, Chaudhary A. Sustainable synthesis of silver nanoparticles using various biological sources and waste materials: A review. Emergent Mater 2022;5(6):1649-78. http://dx.doi.org/10.1007/s42247-021-00292-5
18. Sharma R, Tripathi A. Green synthesis of nanoparticles and its key applications in various sectors. Mater Today Proc 2022;48:1626-32. https://doi.org/10.1016/j.matpr.2021.09.512
19. Yuan Y, Ding L, Chen Y, Chen G, Zhao T, Yu Y.

Nano-silver functionalized polysaccharides as a platform for wound dressings: A review. Int J Biol Macromol 2022;194:644-53. https://doi.org/10.1016/j.ijbiomac.2021.11.108

20. Roy A, Murthy HA, Ahmed HM, Islam MN, Prasad R. Phytogenic synthesis of metal/metal oxide nanoparticles for degradation of dyes. J. Renewable Mater 2022;10(7):1911. http://dx.doi.org/10.32604/jrm.2022.019410
21. Zarharan H, Bagherian M, Rokhi AS, Bajgiran RR, Yousefi E, Heravian P, et al. The anti-angiogenesis and antioxidant activity of chitosan-mediated synthesized selenium-gold nanostructure. Arabian J Chem 2023;16(7):104806. http://dx.doi.org/10.1016/j.arabjc.2023.104806
22. Ghorani-Azam A, Mottaghipisheh J, Amiri MS, Mashreghi M, Hashemzadeh A, Haddad-Mashadrizeh A, et al. Resveratrol-Mediated Gold-Nanoceria Synthesis as Green Nanomedicine for Phytotherapy of Hepatocellular Carcinoma. Front Biosci Landmark 2022;27(8):227. https://doi.org/10.31083/j.fbl2708227
23. Shakerimanesh K, Bayat F, Shahrokhi A, Baradaran A, Yousefi E, Mashreghi M, et al. Biomimetic synthesis and characterisation of homogenous gold nanoparticles and estimation of its cytotoxity against breast cancer cell line. Mater Technol 2022:1-8. http://dx.doi.org/10.1080/10667857.2022.2081287
24. Mousavi-Kouhi SM, Beyk-Khormizi A, Mohammadzadeh V, Ashna M, Es-haghi A, Mashreghi M, et al. Biological synthesis and characterization of gold nanoparticles using Verbascum speciosum Schrad. and cytotoxicity properties toward HepG2 cancer cell line. Res Chem Intermed 2022;48(1):167-78. https://link.springer.com/article/10.1007%2Fs11164-021-04600-w
25. Ashna M, Es-Haghi A, Karimi Noghondar M, Al Amara D, Yazdi MET. Greener synthesis of cerium oxide nanoemulsion using pollen grains of Brassica napus and evaluation of its antitumour and cytotoxicity properties. Mater Technol 2022;37(8):525-32. http://dx.doi.org/10.1080/10667857.2020.1863558
26. Es-haghi A, Javadi F, Yazdi MET, Amiri MS. The Expression of Antioxidant Genes and Cytotoxicity of Biosynthesized Cerium Oxide Nanoparticles Against Hepatic Carcinoma Cell Line. Avicenna Med Biochem 2019;7(1):16-20. https://doi.org/10.34172/ajmb.2019.04
27. Yazdi MET, Amiri MS, Akbari S, Sharifalhoseini M, Nourbakhsh F, Mashreghi M, et al. Green synthesis of silver nanoparticles using helichrysum graveolens for biomedical applications and wastewater treatment. BioNanoSci 2020;10(4):1121-7. https://link.springer.com/article/10.1007/s12668-020-00794-2
28. Amiri MS, Mohammadzadeh V, Yazdi MET, Barani M, Rahdar A, Kyzas GZ. Plant-based gums and mucilages applications in pharmacology and nanomedicine: a review. Molecules 2021;26(6):1770. https://doi.org/10.3390/molecules26061770
29. Modarres M, Taghavizadeh Yazdi ME. Elicitation improves phenolic acid content and antioxidant enzymes activity in salvia leriifolia cell cultures. Iran J Sci 2021;45(3):849-55. http://dx.doi.org/10.1007/s40995-021-01070-y
30. Yazdi MET, Amiri MS, Darroudi M. Biopolymers in the Synthesis of Different Nanostructures. In: Hashmi S, Choudhury IA, editors. Encyclopedia of Renewable and Sustainable Materials. Oxford: Elsevier; 2020. p. 29-43. http://dx.doi.org/10.1016/B978-0-12-803581-8.10560-0
31. Ahmadi R, Es-haghi A, Zare-Zardini H, Taghavizadeh Yazdi ME. Nickel oxide nanoparticles synthesized by Rose hip extract exert cytotoxicity against the HT-29 colon cancer cell line through the caspase-3/caspase-9/Bax pathway. Emergent Mater 2023:1-12. https://doi.org/10.1007/s42247-023-00572-2
32. Garibo D, Borbón-Nuñez HA, de León JND, García Mendoza E, Estrada I, Toledano-Magaña Y, et al. Green synthesis of silver nanoparticles using Lysiloma

acapulcensis exhibit high-antimicrobial activity. Sci Rep 2020;10(1):1-11. https://doi.org/10.1038/s41598-020-69606-7

33. Amiri MS, Yazdi MET, Rahnama M. Medicinal plants and phytotherapy in Iran: Glorious history, current status and future prospects. Plant Sci Today 2021;8(1):95-111. https://orcid.org/0000-0002-3429-4479

34. Nadaf M, Amiri MS, Joharchi MR, Omidipour R, Moazezi M, Mohaddesi B, et al. Ethnobotanical Diversity of Trees and Shrubs of Iran: A Comprehensive Review. Int J Plant Biol 2023;14(1):120-46. https://doi.org/10.3390/ijpb14010011

35. Yazdi MET, Modarres M, Amiri MS, Darroudi M. Phyto-synthesis of silver nanoparticles using aerial extract of Salvia leriifolia Benth and evaluation of their antibacterial and photo-catalytic properties. Res Chem Intermed 2019;45(3):1105-16. https://link.springer.com/article/10.1007/s11164-018-3666-8

36. Yazdi T, Ehsan M, Housaindokht MR, Sadeghnia HR, Esmaeilzadeh Bahabadi S, Amiri MS, et al. Assessment of phytochemical components and antioxidant activity of Rheum turkestanicum Janisch. Stud Med Sci 2020;31(2):75-81. http://umj.umsu.ac.ir/article-1-4660-en.html

37. Nadaf M, Halimi Khalil Abad M, Gholami A, Taghavizadeh Yazdi ME, Iriti M, Mottaghipisheh J. Phenolic content and antioxidant activity of different Iranian populations of Anabasis aphylla L. Nat Prod Res 2022:1-5. https://doi.org/10.1080/14786419.2022.2150621

38. Yazdi MET, Darroudi M, Amiri MS, Hosseini HA, Nourbakhsh F, Mashreghi M, et al. Anticancer, antimicrobial, and dye degradation activity of biosynthesised silver nanoparticle using Artemisia kopetdaghensis. Micro Nano Lett 2020;15(14):1046-50. https://doi.org/10.1049/mnl.2020.0387

39. Yazdi MET, Khara J, Sadeghnia HR, Bahabadi SE, Darroudi M. Biosynthesis, characterization, and antibacterial activity of silver nanoparticles using Rheum turkestanicum shoots extract. Res Chem Intermed 2018;44(2):1325-34. https://link.springer.com/article/10.1007/s11164-017-3169-z

40. Taghavizadeh Yazdi ME, Hamidi A, Amiri MS, Kazemi Oskuee R, Hosseini HA, Hashemzadeh A, et al. Eco-friendly and plant-based synthesis of silver nanoparticles using Allium giganteum and investigation of its bactericidal, cytotoxicity, and photocatalytic effects. Mater Technol 2019;34(8):490-7. http://dx.doi.org/10.1080/10667857.2019.1583408

41. Halimi Khalil Abad MMN, Yazdi MET. Biosynthesis of ZnO.Ag2O3 using aqueous extract of Haplophyllum obtusifolium: Characterization and cell toxicity activity against liver carcinoma cells. Micro Nano Lett 2023;18. https://doi.org/10.1049/mna2.12170

42. Mousavi-Kouhi SM, Beyk-Khormizi A, Amiri MS, Mashreghi M, Hashemzadeh A, Mohammadzadeh V, et al. Plant Gel Mediated Synthesis of Gold Coated Nanoceria Using Ferula gummosa: Characterization and Estimation of Its Cellular Toxicity toward Breast Cancer Cell Lines. J Funct Biomater 2023;14(7):332. https://doi.org/10.3390%2Fjfb14070332

43. Sepahi S, Gerayli S, Delirrad M, Taghavizadeh Yazdi ME, Zare-Zardini H, Bushehri B, et al. Biochemical responses as early and reliable biomarkers of organophosphate and carbamate pesticides intoxication: A systematic literature review. J Biochem Mol Toxicol 2022:e23285. https://doi.org/10.1002/jbt.23285

44. Seyedi Z, Amiri MS, Mohammadzadeh V, Hashemzadeh A, Haddad-Mashadrizeh A, Mashreghi M, et al. Icariin: A Promising Natural Product in Biomedicine and Tissue Engineering. J Funct Biomater 2023;14(1):44. https://doi.org/10.3390/jfb14010044

45. Farahi SMM, Yazdi MET, Einafshar E, Akhondi M, Ebadi M, Azimipour S, et al. The effects of titanium dioxide (TiO2) nanoparticles on physiological, biochemical, and antioxidant properties of Vitex plant

(Vitex agnus-Castus L). Heliyon 2023. https://doi.org/10.1016%2Fj.heliyon.2023.e22144

46. Mohammadzadeh V, Rahiman N, Cabral H, Quader S, Zirak MR, Yazdi MET, et al. Poly-γ-glutamic acid nanoparticles as adjuvant and antigen carrier system for cancer vaccination. J Controlled Release 2023;362:278-96. https://doi.org/10.1016/j.jconrel.2023.08.049
47. Alabyadh T, Albadri R, Es-Haghi A, Yazdi MET, Ajalli N, Rahdar A, et al. ZnO/CeO2 Nanocomposites: Metal-Organic Framework-Mediated Synthesis, Characterization, and Estimation of Cellular Toxicity toward Liver Cancer Cells. J Funct Biomater 2022;13(3):139. https://doi.org/10.3390/jfb13030139
48. Mohammadzadeh V, Barani M, Amiri MS, Yazdi MET, Hassanisaadi M, Rahdar A, et al. Applications of plant-based nanoparticles in nanomedicine: A review. Sustainable Chem Pharm 2022;25:100606. http://dx.doi.org/10.1016/j.scp.2022.100606
49. Javad Farhangi M, Es-haghi A, Taghavizadeh Yazdi ME, Rahdar A, Baino F. MOF-Mediated Synthesis of CuO/CeO2 Composite Nanoparticles: Characterization and Estimation of the Cellular Toxicity against Breast Cancer Cell Line (MCF-7). J Funct Biomater 2021;12(4):53. https://doi.org/10.3390/jfb12040053
50. Taghavizadeh Yazdi ME, Amiri MS, Nourbakhsh F, Rahnama M, Forouzanfar F, Mousavi SH. Bio-indicators in cadmium toxicity: Role of HSP27 and HSP70. Environ Sci Pollut Res 2021;28(21):26359-79. https://doi.org/10.1007/s11356-021-13687-y
51. Mousavi-Kouhi SM, Beyk-Khormizi A, Amiri MS, Mashreghi M, Yazdi MET. Silver-zinc oxide nanocomposite: From synthesis to antimicrobial and anticancer properties. Ceramics Int 2021;47(15):21490-7. http://dx.doi.org/10.1016/j.ceramint.2021.04.160
52. Taghavizadeh Yazdi ME, Darroudi M, Amiri MS, Zarrinfar H, Hosseini HA, Mashreghi M, et al. Antimycobacterial, anticancer, antioxidant and photocatalytic activity of biosynthesized silver nanoparticles using Berberis Integerrima. Iran J Sci 2022;46(1):1-11. http://dx.doi.org/10.1007/s40995-021-01226-w
53. Yazdi MET, Amiri MS, Hosseini HA, Oskuee RK, Mosawee H, Pakravanan K, et al. Plant-based synthesis of silver nanoparticles in Handelia trichophylla and their biological activities. Bullet Mater Sci 2019;42(4):155. http://dx.doi.org/10.1007/s12034-019-1855-8
54. Yazdi MET, Khara J, Housaindokht MR, Sadeghnia HR, Bahabadi SE, Amiri MS, et al. Role of Ribes khorassanicum in the biosynthesis of AgNPs and their antibacterial properties. IET Nanobiotech 2018;13(2):189-92. https://doi.org/10.1049%2Fiet-nbt.2018.5215
55. Singh C, Anand SK, Upadhyay R, Pandey N, Kumar P, Singh D, et al. Green synthesis of silver nanoparticles by root extract of Premna integrifolia L. and evaluation of its cytotoxic and antibacterial activity. Mater Chem Physic 2023:127413. http://dx.doi.org/10.1016/j.matchemphys.2023.127413
56. Alzubaidi AK, Al-Kaabi WJ, Ali AA, Albukhaty S, Al-Karagoly H, Sulaiman GM, et al. Green synthesis and characterization of silver nanoparticles using flaxseed extract and evaluation of their antibacterial and antioxidant activities. Applied Sci 2023;13(4):2182. https://doi.org/10.3390/app13042182
57. Rajivgandhi G, Chelliah CK, Ramachandran G, Chackaravarthi G, Maruthupandy M, Alharbi NS, et al. Morphological modification of silver nanoparticles against multi-drug resistant gram–negative bacteria and cytotoxicity effect in A549 lung cancer cells through in vitro approaches. Arch Microbiol 2023;205(8):282. https://doi.org/10.1007/s00203-023-03611-y
58. Al-Sheddi ES, Alsohaibani N, bin Rshoud N, Al-Oqail MM, Al-Massarani SM, Farshori NN, et al. Anticancer efficacy of green synthesized silver nanoparticles from Artemisia monosperma against human breast cancer cells. S Afr J Bot 2023;160:123-31. https://doi.org/10.1155/2018/9390784

59. Fateme Momen Eslamieh-ei NS, Samira Amin Poustchi Tousi, Samira Basharkhah, Javad Mottaghipisheh, Ali Es-haghi, Mohammad Ehsan Taghavizadeh Yazdi & Marcello Iriti. Synthesis and its characterisation of selenium/silver/chitosan and cellular toxicity against liver carcinoma cells studies. Nat Prod Res 2023. https://doi.org/10.1080/14786419.2023.2256023

60. Chang X, Niu S, Shang M, Li J, Guo M, Zhang W, et al. ROS-Drp1-mediated mitochondria fission contributes to hippocampal HT22 cell apoptosis induced by silver nanoparticles. Redox Biol 2023;63:102739. https://doi.org/10.1016%2Fj.redox.2023.102739

61. Naik J, David M. ROS mediated apoptosis and cell cycle arrest in human lung adenocarcinoma cell line by silver nanoparticles synthesized using Swietenia macrophylla seed extract. J Drug Delivery Sci Technol 2023;80:104084. https://doi.org/10.1016/j.jddst.2022.104084

62. Hamidi A, Yazdi MET, Amiri MS, Hosseini HA, Darroudi M. Biological synthesis of silver nanoparticles in Tribulus terrestris L. extract and evaluation of their photocatalyst, antibacterial, and cytotoxicity effects. Res Chem Intermed 2019;45(5):2915-25. https://link.springer.com/article/10.1007/s11164-019-03770-y