IRABCS INNOVATIVE RESEARCH IN APPLIED, BIOLOGICAL AND CHEMICAL SCIENCES
www.irabcs.com

Review Article

IRABCS, vol. 1, issue 2, pp. 62-67, 2023
Received: November 13, 2023
Revised: December 6, 2023
Accepted: December 10, 2023

Sustainable Ingenuity: Exploring the Supremacy of Green Synthesis in Nanoparticle Fabrication Compared to other conventional Methods

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How to cite: Khan F. Sustainable Ingenuity: Exploring the Supremacy of Green Synthesis in Nanoparticle Fabrication Compared to other conventional Methods. IRABCS. 2023, 1(2): 62-67

Abstract

Nanotechnology has surged in popularity all over the years. Nanoparticles are the essential component of nanotechnology. Nanoparticles are tiny particles that range in size from 1 to 100 nanometres and are made of carbon, metal, metal oxides, or organic substances. At the moment, nanoscale metals are mostly synthesized chemically, which has unexpected consequences such as excessive radiation and the use of extremely concentrated reductants and stabilizing agents that are hazardous to the environment and human health. In response to these obstacles, a comparatively new and largely unresolved area of study concentrating on synthesizing nanomaterial by biological method has arisen. Nanoparticles synthesized utilizing biological processes, often known as 'Green synthesis,' have a variety of properties, including higher stability and suitable diameters. Green synthesis employs ecologically beneficial, non-toxic, and risk-free chemicals. Hence, due to existing environmental risks and toxic wastes linked with chemical synthesis, green synthesis presents alternative advancement opportunities.

Keywords: nanoparticles, green synthesis, physical and chemical methods, advantages

Introduction

Nanotechnology is a field of science concerned with the analysis of materials in the nanoscale, typically ranging from 1 to 100 nm [1]. In terms of comparing to real items, an example that hair is 150,000 nanometers in diameter can be assumed. Nanotechnology is a rapidly emerging multidimensional research and advanced field of biology, chemistry, physics, food, medicine, electronics, aerospace, medicine etc., that evaluates the design, manufacture, assembly, and assessment of materials lesser than 100 nanometers in magnitude, along with the application of miniature functional structures made from these materials. It encompasses all development efforts.

Nanobiotechnology, in contrast, is the effect of an integration of biotechnology and nanotechnology fields with a shared functioning [2] Various ways are used to create nanoparticles. There is an expanding amount of research focused on the manufacturing of nanoscale metals utilizing chemical, physical, and green synthesis methods [3,4]. Chemical and physical methods are progressively being replaced by green synthesis [5] due to the problems associated with huge quantities of energy consumed [4], the generation of potentially hazardous chemicals [6] and the use of complicated instruments and the production conditions [7,8] Aerosols [9] ultraviolet (UV) rays [10] and thermal breakdown [11] are all physical processes that involve high temperatures as well as pressures [11].

The aerosol technique, for instance, involves a flame temperature of roughly 2400 K to create atomized aerosol crystals and nanoparticulate metals. The formation of PdO NPs via plasma-assisted physical vapor condensation necessitates three heat cycles around 250 ◦C and 800 ◦C, resulting in massive energy utilization. Chemical methods always involve sodium borohydride, a costly and hazardous reagent, alongside various dispersion stabilizers and organic solvents [12].

Green synthesis, on the other hand, uses natural and ecologically advantageous components (for example, reducing agents). Certain green elements may be utilized as both end-capping agents and dispersants [13] that not solely saves energy but effectively prevents the use of poisonous and dangerous chemicals. Currently, green synthesis is primarily based on microorganisms (fungi, bacteria, and algae) [14,15] or herbal extracts from leaves [13,16,17] flowers [18,19] roots, peels [20] fruits [21] and seeds [22,23] of many plants. Green products comprise polyphenols and proteins, which can be use instead of chemical reagents as reducing agents to decrease metallic ions to a decreased valence level [24]. Metal nanoparticles can be synthesized with the help of green materials within the appropriate circumstances (temperature, concentration, ambient air). Under some situations, the effectiveness of green synthesized metal nanoparticles surpass that of chemically synthesized metal nanoparticles. For instance, the particle size of Fe_3O_4 NPs synthesized using the green synthesis approach is 2-80 nanometers, which is extensively lower than the 87-400 nm particle size of particles created using the wet chemical technique [25]. The creation of nanoparticles via physical and chemical processes has been reported in prior research.

This review outlined the techniques involve in the synthesis of nanomaterials, as well as the key concerns and issues in traditional chemical and physical synthesis of nanoparticles. This study provides a more in-depth debate, and benefits of green synthesis, which has ability for development of green research in the future.

Methods for the synthesis of Nanoparticles

There are various methods used for the synthesis of nanoparticles, which are described below in the subsequent paragraphs.

Chemical method

Metallic precursors, stabilizing agents, and reducing agents (both inorganic and organic) are crucial components of the chemical technique. Reducing agents include sodium citrate, ascorbate, sodium borohydride ($NaBH_4$), elemental hydrogen, polyol process, tollens reagent, N, N-dimethylformamide (DMF), and poly (ethylene glycol)-block copolymers [26].

Physical method

The physical approach used to create NPs consists of a "top-down" strategy in which the material reduces in size use various physical procedures like ultrasonication, microwave (MW) irradiation, and electrochemical treatment. A tube heater with barometrical weight is utilized in this approach to integrate NPs via evaporation condensation. Evaporation condensation and removal with lasers are the two most important physical processes. Inside a pontoon centered around the heater, the source element is vaporized into a gas called the carrier. Previously, several NPs of Ag, Au, PbS, and Cd were synthesized and reported utilizing this dissipation build-up approach [27].

Green synthesis method

The biological methodology, provided as an alternate to chemical and physical methods, provides an environmentally friendly method of generating nanoparticles. Furthermore, no expensive, harmful, or deadly substances are used in this technique. A biological approach that has lately gained popularity may be used to create nanoparticles of various shapes, sizes, arrangements, and physicochemical properties. By using living organisms such as bacteria, actinobacteria, yeasts, moulds, algae, and plants, synthesis can be accomplished in a single step. Plants and microbes use enzymes, protein, phenolic compounds, amines, alkaloids, and pigments to produce nanoparticles via reduction [28–32].

In traditional chemical and physical methods, reducing reagents and stabilizing agents are required to avoid undesirable clumping of the manufactured nanoparticles, which is detrimental to the environment. Furthermore, the nanoparticles produced by these technologies pose a risk due to their composition, size, and surface chemistry. Nanoparticles with biocompatibility are manufactured using the green synthesis approach; these compounds are present naturally in living organisms [12].

Green synthesis from bacteria and actinobacteria

Bacteria are ideal candidates for the production of nanoparticles due to their rapid growth, low growing costs, and simplicity of control and adaptation to the surrounding environment. Simultaneously, many bacteria species have been revealed to have unique routes for reducing the hazardous properties of metals or chemicals. Bacteria are recommended for these characteristics since they can produce nanoparticles both in and out of the cell. Metal ions can be reduced and precipitated for nanoparticle formation by employing metabolic pathways and reducing agents present inside a bacterial cell, such as proteins and enzymes [23,33].

Actinobacteria are aerobic, inactive, gram-positive bacteria that create additional metabolic products such as antibiotics. They are resistant to the most toxic metallic substances due to their detoxifying abilities. Metal ions that are toxic are detoxified by intracellular or extracellular reduction or aggregation. As a result, antibacterial, antifungal, anticancer, antioxidant, antibio-contamination, and catalytic nanoparticles can be produced [34].

Green synthesis using enzymes

Using readily cultured and fast-breeding eukaryotic yeasts and moulds with minimal biomass design, nanoparticles may be created extracellularly or intracellularly with the aid of enzymes. The parameters such as, incubation conditions and metallic ion solutions are used to determine the shape and size of the nanoparticles. Some moulds are toxic to humans, hence, limiting their use in nanoparticle production [35].

Green synthesis from algae

Algae are eukaryotes aquatic photosites which break down metallic ions into nanoparticles using dyes, carbohydrate, lipid, protein, nucleic acid, and secondary metabolic products. The algal extract, which occurs in an aqueous medium at a certain temperature, is supplemented with metal solutions of the suitable pH and concentration, leading to the development of nanoparticles having antibacterial with no hazardous byproducts, are produced. The size of nanoparticles is regulated by factors such as solution incubation time, ambient temperature, mixture pH, and metal ion concentration. Because of the convenience of availability and utility, algae are also favorable to this synthesis approach. Furthermore, when bacteria and plant extracts are utilized, effective biomolecules in the reaction media are less destroyed by the created nanoparticles [36,37].

Vitamin-based green synthesis

A green mixture combination of Ag and palladium nanospheres, nanowires, and nanorods with vitamin B2 (as reducing and capping agents) has been presented. In the fabrication of nanowires and nanorods, vitamin B2 acts as a reducing agent. This is a unique strategy in the field of green nanotechnology, indicating the use of natural molecules with anticancer properties [38]. Chitosan is used as a stabilising agent, whereas ascorbic acid is used as a capping and reducing agent. Because chitosan binds with metal ions, the number of NPs produced is directly proportional to the chitosan quantity used [39]. Malassis L et al. reported a simple method for manufacturing uniformly sized NPs using ascorbic acid and capping material [40]. Furthermore, water-soluble Antioxidants like ascorbic acid seems to be the reason for the decrease in Ag NPs in Desmodium triflorum. During glycolysis, plants produce a large amount of H ions, which act as a potent reducing agent and likely to be effective in the production of Ag NPs [41].

Plants and phytochemicals

Plant-based NP synthesis is really feasible. As a result, they are an affordable and critical choice for large-scale NP manufacturing [42]. A Research on the antioxidant properties of extracts of blackberry, blueberry, turmeric, and pomegranate revealed that pomegranate has the ability to produce more homogenous dimensions and shapes of Au and Ag NPs in the 20-500 nm range. These nanoparticles have the potential to be used in the treatment of cancer and preventative medicine [43]. To reduce the platinum compound, F. herba isolate was used; the closeness of hydrogen and carbonyl in polyphenolic compounds predominantly works as a fixing agent for metal particles [44].

A number of factors including the nature of the plant extracts, NP production in salt solution may occur quickly; the main causes being the amount of the extracts, metallic salt, pH, and interaction. Dihydroquercetin, quercetin, and rutin reduced $AgNO_3$ to AgNPs, resulting in the creation of a strong surface plasmon resonance (SPR) band, signifying a reduction of this component [45]. Kou and Varma proposed a simple, green, and quick (5-minute) technique for generating Ag NPs by MW irradiation with beetroot pulp as a reducing reagent. The resulting material demonstrated excellent photocatalytic activity for the degradation of methyl orange (MO) dye [46].

Advantages of Green synthesis of nanoparticles over chemical and physical method

The advantages of using nanoparticles for drug delivery arise from two key factors. First, due to their small size, nanoparticles may travel through narrow capillaries and be taken up by cells, allowing for excellent medication retention at target locations. Secondly, the utilization of biodegradable materials in the creation of nanoparticles allows for prolonged drug distribution inside the target region over several days or weeks [47,48].

Nanoparticles are important not just for medicinal applications, but they also have the ability to revolutionize an extensive spectrum of electrical items and processes. When it comes to electrical equipment, the industries that benefit from the ongoing advancement of nanotechnology include nano diodes, nano transistors, OLED, plasma displays, quantum computers, and many more. Nanotechnology can potentially benefit the energy industry. The batteries, fuel cells, and solar cells, for instance, may be created in tiny quantities yet with greater efficacy using this method. Manufacturing, which utilizes materials like aerogels, nanotubes, nano particles, and other similar commodities to create their products, is another industry that can benefit from nanotechnology. These materials are often more durable, more robust, and cheaper than those created without the use of nanotechnology. There are some additional benefits to nanoparticles in terms of manufacturing and delivery of drugs. Nanoparticles improved both therapeutic efficacy and bioavailability. They decreased fed/fasted variation which improved medication stability. There is no biotoxicity of the carrier while conveying the medicine with nanoparticles. Nanoparticles provide no problems in large-scale manufacture or sterilization; however, they must be avoided when using organic solvents [47,48].

Conclusion

Several microorganisms and plant compounds are currently employed to successfully synthesize metal nanoparticles for green synthesis. As a result, green nanoparticle synthesis is the most feasible, simple, and sustainable method of creating nanoparticles since it avoids the consumption of poisonous substances and the formation of dangerous undesired byproducts. In this study, we addressed biological NP synthesis techniques that include living organisms such as algae, fungus, and plants. Nanoparticles are widely used due to their exceptional qualities and have received a lot of attention recently. Although, more research is needed to fully exploit the promise of green synthesis, such as optimizing synthesis conditions, investigating novel biomaterials for nanoparticle synthesis, and broadening the variety of novel green synthesis pathways for these ecologically friendly nanoparticles.

Ethical approval

The undertaken research is not associated with the usage of either human or animal use.

AI Disclosure

No Al-assisted tools were used during the write up.

Conflict of interest

The author declares no conflict of interest.

References

1. Rafique M, Sadaf I, Rafique MS, Tahir MB. A review on green synthesis of silver nanoparticles and their applications. Artif Cells Nanomed Biotechnol. 2017 Oct3;45(7):1272–91. https://doi.org/10.1080/21691401.2016.1241792

2. Pearce JM. Make nanotechnology research open source. Nature. 2012 Nov 21;491(7425):519–21. https://doi.org/10.1038/491519a

3. Wang X, Wang A, Ma J, Fu M. Facile green synthesis of functional nanoscale zero-valent iron and studies of its activity toward ultrasound-enhanced decolorization of cationic dyes. Chemosphere. 2017 Jan; 166:80–8. https://doi.org/10.1016/j.chemosphere.2016.09.056

4. Horwat D, Zakharov DI, Endrino JL, Soldera F, Anders A, Migot S, et al. Chemistry, phase formation, and catalytic activity of thin palladium-containing oxide films synthesized by plasma-assisted physical vapor deposition. Surf Coat Technol. 2011 Jul;205: S171–7. https://doi.org/10.1016/j.surfcoat.2010.12.021

5. Alsammarraie FK, Wang W, Zhou P, Mustapha A, Lin M. Green synthesis of silver nanoparticles using

turmeric extracts and investigation of their antibacterial activities. Colloids Surf B Biointerfaces. 2018Nov; 171:398–405. https://doi.org/10.1016/j.colsurfb.2018.07.059

6. Hoag GE, Collins JB, Holcomb JL, Hoag JR, Nadagouda MN, Varma RS. Degradation of bromothymol blue by 'greener' nanoscale zero-valent iron synthesized using tea polyphenols. J Mater Chem. 2009;19(45):8671. https://doi.org/10.1039/B909148C

7. Baruwati B, Polshettiwar V, Varma RS. Glutathione promoted expeditious green synthesis of silver nanoparticles in water using microwaves. Green Chemistry. 2009;11(7):926. https://doi.org/10.1039/B902184A

8. Saiqa Ikram SA. Silver Nanoparticles: One Pot Green Synthesis Using Terminalia arjuna Extract for Biological Application. J Nanomed Nanotechnol. 2015;06(04). https://doi.org/10.4172/2157-7439.1000309

9. Smirniotis PG, Boningari T, Inturi SNR. Single-step synthesis of N-doped TiO 2 by flame aerosol method and the effect of synthesis parameters. Aerosol Science and Technology. 2018 Aug 3;52(8):913–22. https://doi.org/10.1080/02786826.2018.1479059

10. Wojnarowicz J, Chudoba T, Gierlotka S, Lojkowski *W. Effect of Microwave Radiation Power on the Size of Aggregates of ZnO NPs Prepared Using Microwave Solvothermal Synthesis. Nanomaterials. 2018 May 18;8(5):343. https://doi.org/10.3390/nano8050343*

11. Ahmed S, Saifullah, Ahmad M, Swami BL, Ikram S. Green synthesis of silver nanoparticles using Azadirachta indica aqueous leaf extract. J Radiat Res Appl Sci. 2016 Jan;9(1):1–7. https://doi.org/10.1016/j.jrras.2015.06.006

12. Hussain I, Singh NB, Singh A, Singh H, Singh SC. Green synthesis of nanoparticles and its potential application. Biotechnol Lett. 2016 Apr 31;38(4):545–60. https://doi.org/10.1007/s10529- 015-2026-7

13. Devi HS, Boda MA, Shah MA, Parveen S, Wani AH. Green synthesis of iron oxide nanoparticles using Platanus orientalis leaf extract for antifungal activity. Green Processing and Synthesis. 2019 Jan 28;8(1):38–45. https://doi.org/10.1515/gps-2017-0145

14. Subramaniyam V, Subashchandrabose SR, Thavamani P, Megharaj M, Chen Z, Naidu R. Chlorococcum sp. MM11—a novel phyco- nanofactory for the synthesis of iron nanoparticles. J Appl Phycol. 2015 Oct 9;27(5):1861–9. https://doi.org/10.1007/s10811-014-0492-2

15. Arsiya F, Sayadi MH, Sobhani S. Green synthesis of palladium nanoparticles using Chlorella vulgaris. Mater Lett. 2017 Jan; 186:113–5. https://doi.org/10.1016/j.matlet.2016.09.101

16. Chahardoli A, Karimi N, Fattahi A. Nigella arvensis leaf extract mediated green synthesis of silver nanoparticles: Their characteristic properties and biological efficacy. Advanced Powder Technology. 2018 Jan;29(1):202–10. https://doi.org/10.1016/j.apt.2017.11.003

17. Leili M, Fazlzadeh M, Bhatnagar A. Green synthesis of nano-zero-valent iron from Nettle and Thyme leaf extracts and their application for the removal of cephalexin antibiotic from aqueous solutions. Environ Technol. 2018 May 3;39(9):1158–72. https://doi.org/10.1080/09593330.2017.1323956

18. Thovhogi N, Park E, Manikandan E, Maaza M, Gurib-Fakim A. Physical properties of CdO nanoparticles synthesized by green chemistry via Hibiscus Sabdariffa flower extract. J Alloys Compd. 2016 Jan; 655:314–20. https://doi.org/10.1016/j.jallcom.2015.09.063

19. Sone BT, Diallo A, Fuku XG, Gurib-Fakim A, Maaza M. Biosynthesized CuO nano-platelets: Physical properties & enhanced thermal conductivity nanofluidics. Arabian Journal of Chemistry. 2020 Jan;13(1):160–70. https://doi.org/10.1016/j.arabjc.2017.03.004

20. Ehrampoush MH, Miria M, Salmani MH, Mahvi AH. Cadmium removal from aqueous solution by green synthesis iron oxide nanoparticles with tangerine peel extract. J Environ Health Sci Eng. 2015 Dec 16;13(1):84. https://doi.org/10.1186/s40201-015- 0237-4

21. Kumar B, Smita K, Cumbal L, Debut A, Angulo Y. Biofabrication of copper oxide nanoparticles using Andean blackberry (Rubus glaucus Benth.) fruit and leaf. Journal of Saudi Chemical Society. 2017 Jan;21: S475–80. https://doi.org/10.1016/j.jscs.2015.01.009

22. Dhand V, Soumya L, Bharadwaj S, Chakra S, Bhatt D, Sreedhar B. Green synthesis of silver nanoparticles using Coffea arabica seed extract and its antibacterial activity. Materials Science and Engineering: C. 2016 Jan; 58:36–43. https://doi.org/10.1016/j.msec.2015.08.018

23. Gao Y, Wei Z, Li F, Yang ZM, Chen YM, Zrinyi M, et al. Synthesis of a morphology controllable Fe 3 O 4 nanoparticle/hydrogel magnetic nanocomposite inspired by magnetotactic bacteria and its application in H 2 O 2 detection. Green Chem. 2014;16(3):1255–61. https://doi.org/10.1039/C3GC41535J

24. Can M. Green gold nanoparticles from plant-derived materials: an overview of the reaction synthesis types, conditions, and applications. Reviews in Chemical Engineering. 2020 Oct 27;36(7):859–77. https://doi.org/10.1515/revce-2018-0051

25. Gokila VTP and RDJR. Qualitative comparison of chemical and green synthesized Fe3O4 nanoparticles. Techno Press Services. 2021 Jan;10(1):71–8. https://doi.org/10.12989/anr.2021.10.1.071

26. Zhang XF, Liu ZG, Shen W, Gurunathan S. Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches. Int J Mol Sci. 2016 Sep 13;17(9):1534. https://doi.org/10.3390/ijms170915344

27. Mathur P, Jha S, Ramteke S, Jain NK. Pharmaceutical aspects of silver nanoparticles. Artif Cells Nanomed Biotechnol. 2018 Oct 31;46(sup1):115–26. https://doi.org/10.1080/21691401.2017.1414825

28. Shah M, Fawcett D, Sharma S, Tripathy S, Poinern G. Green Synthesis of Metallic Nanoparticles via Biological Entities. Materials. 2015 Oct 29;8(11):7278–308. https://doi.org/10.3390/ma8115377

29. Nadaroglu H, Onem H, Alayli Gungor A. Green synthesis of Ce 2 O 3 NPs and determination of its antioxidant activity. IET Nanobiotechnol. 2017 Jun 26;11(4):411–9. https://doi.org/10.1049/ietnbt.2016.0138

30. Cicek S, Gungor AA, Adiguzel A, Nadaroglu H. Biochemical Evaluation and Green Synthesis of Nano Silver Using Peroxidase from Euphorbia (Euphorbia amygdaloides) and Its Antibacterial Activity. J Chem. 2015; 2015:1–7. https://doi.org/10.1155/2015/486948

31. Narayanan KB, Sakthivel N. Biological synthesis of metal nanoparticles by microbes. Adv Colloid Interface Sci. 2010 Apr;156(1–2):1–13. https://doi.org/10.1016/j.cis.2010.02.001

32. Mukhopadhyay NK, Yadav TP. Some Aspects of Stability and Nanophase Formation in Quasicrystals during Mechanical Milling. Isr J Chem. 2011 Dec 23;51(11–12):1185–96. https://doi.org/10.1002/ijch.201100145

33. Korbekandi H, Iravani S, Abbasi S. Production of nanoparticles using organisms. Crit Rev Biotechnol. 2009 Dec 5;29(4):279–306. https://doi.org/10.3109/07388550903062462

34. Manivasagan P, Venkatesan J, Sivakumar K, Kim SK. Actinobacteria mediated synthesis of nanoparticles and their biological properties: A review. Crit Rev Microbiol. 2014 Nov 28;1–13. https://doi.org/10.3109/1040841X.2014.917069

35. Boroumand Moghaddam A, Namvar F, Moniri M, Md. Tahir P, Azizi S, Mohamad R. Nanoparticles Biosynthesized by Fungi and Yeast: A Review of Their Preparation, Properties, and Medical Applications. Molecules. 2015 Sep 11;20(9):16540– 65. https://doi.org/10.3390/molecules200916540

36. Siddiqi KS, Husen A. Fabrication of Metal and Metal Oxide Nanoparticles by Algae and their Toxic Effects. Nanoscale Res Lett. 2016 Dec 17;11(1):363. https://doi.org/10.1186/s11671-016-1580-9

37. Karaduman I, Güngör AA, Nadaroğlu H, Altundaş A, Acar S. Green synthesis of γ-Fe2O3 nanoparticles for methane gas sensing. Journal of Materials Science: Materials in Electronics. 2017 Nov 14;28(21):16094–105. https://doi.org/10.1007/s10854-017-7510-5

38. Nadagouda MN, Varma RS. Green and controlled synthesis of gold and platinum nanomaterials using vitamin B2: density-assisted self-assembly of nanospheres, wires and rods. Green Chemistry. 2006;8(6):516. https://doi.org/10.1039/B601271J

39. Shao Y, Wu C, Wu T, Yuan C, Chen S, Ding T, et al. Green synthesis of sodium alginate-silver nanoparticles and their antibacterial activity. Int J Biol Macromol. 2018 May; 111:1281–92. https://doi.org/10.1016/j.ijbiomac.2018.01.012

40. Malassis L, Dreyfus R, Murphy RJ, Hough LA, Donnio B, Murray CB. One-step green synthesis of gold and silver nanoparticles with ascorbic acid and their versatile surface post-functionalization. RSC Adv. 2016;6(39):33092–100. https://doi.org/10.1039/C6RA00194G

41. Ahmad N, Sharma S, Singh VN, Shamsi SF, Fatma A, Mehta BR. Biosynthesis of Silver Nanoparticles from Desmodium triflorum: A Novel Approach Towards Weed Utilization. Biotechnol Res Int. 2011 Nov 1; 2011:1–8. https://doi.org/10.4061/2011/454090

42. Rastogi A, Zivcak M, Sytar O, Kalaji HM, He X, Mbarki S, et al. Impact of Metal and Metal Oxide Nanoparticles on Plant: A Critical Review. Front Chem. 2017 Oct 12;5. https://doi.org/10.3389/fchem.2017.00078

43. Nadagouda MN, Iyanna N, Lalley J, Han C, Dionysiou DD, Varma RS. Synthesis of Silver and Gold Nanoparticles Using Antioxidants from Blackberry, Blueberry, Pomegranate, and Turmeric Extracts. ACS Sustain Chem Eng. 2014 Jul 7;2(7):1717–23. https://doi.org/10.1039/B601271J

44. Dobrucka R. Biofabrication of platinum nanoparticles using Fumariae herba extract and their catalytic properties. Saudi J Biol Sci. 2019 Jan;26(1):31–7. https://doi.org/10.1016/j.sjbs.2016.11.012

45. Veisi H, Azizi S, Mohammadi P. Green synthesis of the silver nanoparticles mediated by Thymbra spicata extract and its application as a heterogeneous and recyclable nanocatalyst for catalytic reduction of a variety of dyes in water. J Clean Prod. 2018 Jan; 170:1536–43. https://doi.org/10.1016/j.jclepro.2017.09.265

46. Kou J, Varma RS. Beet Juice-Induced Green Fabrication of Plasmonic AgCl/Ag Nanoparticles. ChemSusChem. 2012 Dec 4;5(12):2435–41. https://doi.org/10.1002/cssc.201200477

47. Shinde NC, Keskar NJ and Argade PD. Types Of Nanoparticles Applied In Drug Delivery: The types of nanoparticles applied in the drug delivery system include. IJAPBC. 2012 Mar;1(1). https://www.ijapbc.com/files/20.pdf

48. Parveen K, Banse V, Ledwani L. Green synthesis of nanoparticles: Their advantages and disadvantages. In 2016. p. 020048. https://doi.org/10.1063/1.4945168