REVIEW PAPER

Plant extract mediated biosynthesis of Al_2O_3 nanoparticles- a review on plant parts involved, characterization and applications

Suresh Ghotekar *

Department of Chemistry, Sanjivani Arts, Commerce and Science College, Kopargaon 423 603, Savitribai Phule Pune University, Maharashtra, India

ARTICLE INFO

Article History:
Received 19 July 2019
Accepted 25 September 2019
Published 15 October 2019

Keywords:
Nanotechnology
Green synthesis
Plant extracts
Al_2O_3 NPs
Applications

ABSTRACT

Metal oxide nanoparticles (NPs) produced by green chemistry approaches have received notable attention because of their significant physico-chemical properties and their remarkable uses in the area of nanotechnology. Currently, the sustainable improvement of synthesizing NPs by distinctive parts of plant extract has become a major focus of scientists and researchers, because these NPs have a minimum detrimental effect on ecosystem and minimum noxiousness for the human health. Among the metal oxide nanoparticles, alumina nanoparticles (Al_2O_3 NPs) draw a special attention due to their significant applications in ceramics, textiles, drug delivery, catalysis, waste-water treatment and biosensor. Many natural biomolecules in plant extracts such as saponins, tannins, alkaloids, amino acids, enzymes, proteins, coumarins, polysaccharides, polyphenols, steroid and vitamins could be participated in bioreduction and stabilization of Al_2O_3 NPs. In the last decade, innumerable efforts were made to develop a sustainable eco-accommodating method of synthesis to avoid the perilous byproducts. This review focuses on the plants used for the green fabrication of Al_2O_3 NPs, their characterization methods and applications.

How to cite this article
Ghotekar S. Plant extract mediated biosynthesis of Al_2O_3 nanoparticles- a review on plant parts involved, characterization and applications. Nanochem Res, 2019; 4(2):163-169. DOI: 10.22036/ncr.2019.02.008

INTRODUCTION

Nowadays, metal oxide nanomaterials are found to have peculiar uses in the area of catalysis, ceramics, semiconductors, space industry, medical science, agriculture, capacitors, batteries, absorbents, defense, chemical and biological sensors, optoelectronics, textile and food industry [1-34]. Among all known metal oxide nanomaterials, Al_2O_3 NPs have drawn remarkable attention in the cutting edge of particular innovation, in the formulation and designing of recent antimicrobial agents for sustainable biomedical applications; because Al_2O_3 NPs are chemically bio-inert and hydrolytically more stable [35]. The biocompatibility of Al_2O_3 ceramic has already been mentioned by many researchers [36]. Al_2O_3 NPs with high purity were the first bio-ceramics widely utilized in clinical application, and it was recommended that the lifespan of Al_2O_3 is longer than the concerned patients [37]. Accordingly, Al_2O_3 NPs have been utilized in several branches (Fig. 1.) consisting of structural ceramics [36], catalysis [38], textiles [39], wastewater treatment [40] and protein separation/ purification [41]. Moreover, Al_2O_3 NPs also find extensive biomedical applications in biosensors [42], bio-filtration [41] and drug delivery [43].

Al_2O_3 NPs can be easily synthesized using several methods such as combustion [44], hydrothermal [45], laser ablation [46], mechanochemical [47], sol-gel [48], template method [49], microwave-assisted [50], pechini method [51], precipitation method [52], solvothermal [53], pyrolysis [54] and ball milling [55]. However, these synthetic routes are quite expensive, potentially hazardous and require

* Corresponding Author Email: *ghotekarsuresh7@gmail.com*

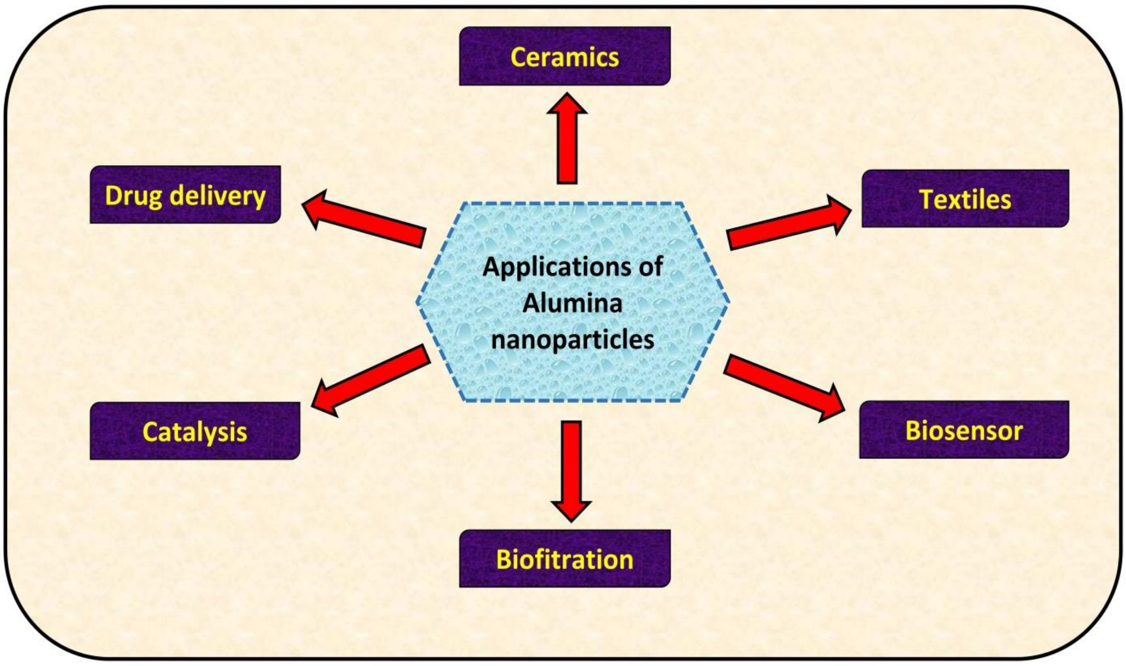

Fig. 1. Various applications of Al_2O_3 NPs

long reaction time, perilous chemical precursors and special instruments for experimental work. Therefore, these routes create a bad impact on the ecosystem. This enhances the urgent need to replace or modify chemical preparation methodology and develop a sustainable, clean, non-toxic, cost effective and environmentally gracious process through green synthesis and other biological approaches. It is one of the promising pathways for fabrication of NPs as it is free from perilous chemicals as well as providing natural or herbal capping agents such as plant extracts, algae, fungi, bacteria, sugars, biodegradable polymers for the stabilization of Al_2O_3 NPs.

The present review article highlights the current scenario and knowledge concerning the capability of various plant materials for eco-benevolent synthesis of Al_2O_3 NPs and presents a database that future researchers may be based on the biosynthesis of Al_2O_3 NPs using various plant material sources.

GREEN SYNTHESIS OF Al_2O_3 NPs

Nowadays, several methods have been successfully used to fabricate the Al_2O_3 NPs, however, they have some demerits such as the higher cost of the method and not being eco-benevolent since they make lots of pollution in the ecosystem because of using perilous solvents and toxic reducing agent. To mitigate these drawbacks, green chemistry approaches have been employed for the fabrication of Al_2O_3 NPs which are sustainable, less energy-intensive, eco-accommodating and increase the efficiency of the methods. Although chemical stabilizers are utilized more than plants part extract, that materials are not safe for the ecosystem and aspects of human health. The stabilization of Al_2O_3 NPs is dependent on biomolecules such as amino acids, enzymes, proteins, steroids, phenols, tannins, sugar and flavonoids, which are already present in the plant extracts having medicinal importance and are eco-benign [2-3]. The main principle in the green chemistry approaches (Fig. 2.) is that the phytoconstituents are present in the plant parts serve the dual role of a natural reducing agent and a NP stabilizer. Some plants are already reported to facilitate Al_2O_3 NPs biosynthesis and all of them are described in this review (Table 1). The various parts of plant such as leaves, seed fruit and flower are used to fabricate Al_2O_3 NPs in different morphologies and sizes by biological approaches. The aqua soluble heterocyclic constituents are mainly accountable for formation and stabilization of nanoparticles. Thereafter, the biosynthesized NPs need to be characterized by using numerous techniques.

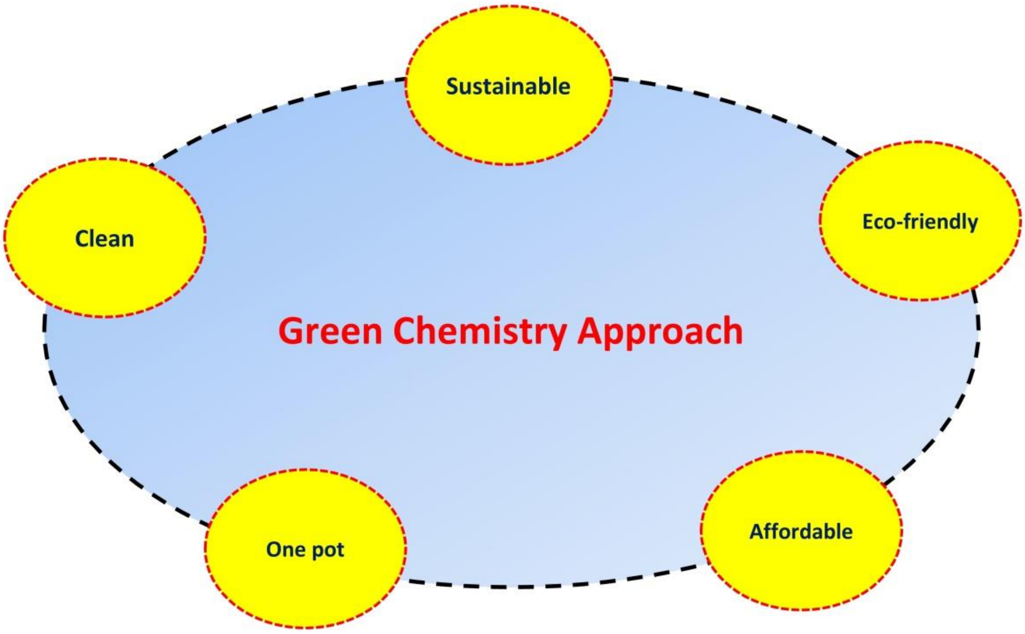

Fig. 2. Importance of green chemistry

Table 1. Biosynthesis of Al_2O_3 NPs using different plant sources with morphology and size

Sr. No	Name of Plants	Part	Shape	Size	References
1.	*Cymbopogon citratus*	Leaf	Spherical	34.5 nm	56
2.	*Lemon*	-	-	460 nm	57
3.	*Lemongrass*	Leaf	Spherical	34.5 nm	58
4.	*Muntingia calabura*	Leaf	-	-	59
5.	*Neem*	Leaf	-	-	60
6.	*Syzygium aromaticum*	-	Spherical	8 nm	61
7.	*Origanum vulgare*	-	Spherical	3 nm	61
8.	*Origanum majorana*	-	Spherical	5 nm	61
9.	*Theobroma cacao*	-	Spherical	2 nm	61
10.	*Cichorium intybus*	-	Spherical	9 nm	61
11.	*Parthenium*	Leaves Flower	-	42 nm	62
12.	*Prunus xyedonesis*	Leaf	Spherical & Hexagonal	50-100 nm	63
13.	*Rosa*	Leaves	Spherical	24.53 nm	64
14.	*Sargassum ilicifolium*	-	Rhombohedral	35 nm	65
15.	*Tea*	Leaves	Spherical	50-200 nm	50
16.	*Coffee*	-	Spherical	50-200 nm	50
17.	*Triphala*	Fruit	Spherical	200-400 nm	50
18.	*Aerva lanta*	Leaves	Spherical	50-70 nm	66
19.	*Terminalia chebula*	Seed	Spherical	50-100 nm	66

PROTOCOL FOR BIOSYNTHESIS OF Al_2O_3 NPs

Bio-fabrication of Al_2O_3 NPs is an effortless, rapid, one pot synthesis and eco-friendly route without participation of any harmful and perilous chemical. Al_2O_3 NPs are synthesized using distinctive parts of plants such as leaves, fruit, seed and flower (Table 1). A completely easy and clean protocol is implemented for their biosynthesis (Fig. 3). The plant parts such as leaves, flowers, seeds, fruits, etc. are collected from distinctive sources and thoroughly washed with

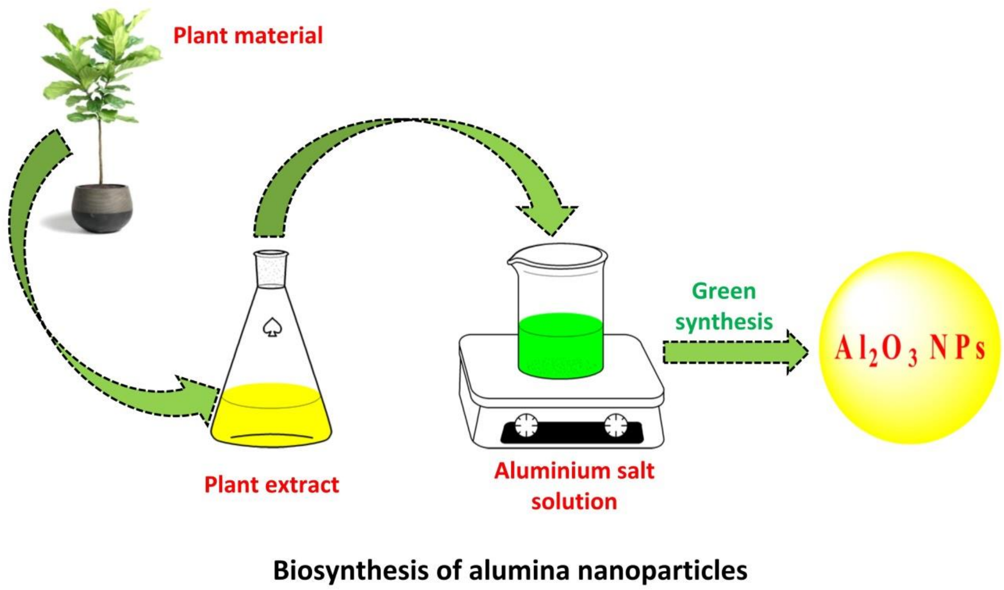

Fig. 3. Schematic representation of green synthesis of Al_2O_3 NPs

ordinary water as well as double distilled water to remove other undesirable materials. The plant materials are either grinded or dried to form the fine powder or used directly to obtain extract. The plant parts are hewed into small pieces or ground to fine powder and boiled in different special solvents (ethanol, water, and many others) and boiled at a suitable temperature to acquire extract. Different concentrations of aluminum salts as a metallic precursor and as-prepared plant extract can be used for the biosynthesis of Al_2O_3 NPs. There may be no need to add external chemical reducing agents or stabilizers, simply plant extract is mixed with aluminum salt solution and the phytochemical present in plant extract acts as a bio-reducing agent as well as stabilizing agent for the biosynthesis of Al_2O_3 NPs. The precise protocol of biosynthesis of Al_2O_3 NPs by *Cymbopogon citratus* leaf extract is mentioned by authors reported in literature [43]. The synthesized Al_2O_3 NPs solution is further centrifuged to separate out the NPs at excessive rpm, and wash thoroughly with suitable solvents. A fine powder of Al_2O_3 NPs is obtained and this is carefully collected for further characterization purposes.

CHARACTERIZATION TECHNIQUES FOR Al_2O_3 NPs

To study the effect of synthesized Al_2O_3 NPs on ecosystem and human health, and affirmation in their formation, diverse routes of their formation and monitoring their typical effect are needed. Different instrumental techniques are used to characterize synthesis of Al_2O_3 NPs.

Size

There are various methods to measure crystalline particles size of Al_2O_3 NPs. X-ray Diffraction (XRD) is also used to determine the particle size and exact phase identification of Al_2O_3 NPs. The size of suspended NPs in liquid phase is described by dynamic light scattering (DLS).

Crystallography

X-ray diffraction (XRD) is used to determine each and every crystal structure of Al_2O_3 NPs.

Morphology

Accurate morphology of Al_2O_3 NPs may be examined by using electron microscopies such as transmission electron microscope (TEM), atomic force microscopy (AFM) and scanning electron microscope (SEM).

Specific surface Area

The nitrogen absorption technique based on Brunauer–Emmett–Teller (BET) isotherm is most commonly used for solid state, and nuclear magnetic resonance (NMR) technique is among the techniques could be used for liquid state.

Elemental composition

Mass spectrometry (MS), X-ray photoelectron spectroscopy (XPS), energy dispersive spectroscopy (EDS) and atomic emission spectroscopy (AES) could be used to examine purity and elemental composition of Al_2O_3 NPs.

APPLICATIONS OF BIOGENICALLY SYNTHESIZED Al_2O_3 NPs

Al_2O_3 NPs have many captivated applications in several branches of science and technology. However, the ceramics, textiles, biosensor and antimicrobial activities of the biosynthesized Al_2O_3 NPs are very prominent nowadays. Accordingly, their peculiar applications are described here as a guidance to new researchers for future prospects.

Jalal et al. reported the *Cymbopogon citratus* leaf extract mediated Al_2O_3 NPs with the size of 34.5 nm and investigated the antifungal activity of Al_2O_3 NPs against various *Candida spp.* isolated from oropharyngeal mucosa of HIV^+ patients [56].

Ansari et al. reported the biosynthesis of Al_2O_3 NPs using leaf extract *lemongrass* and analyzed the antibacterial activity of the prepared NPs. These Al_2O_3 NPs exhibited an excellent antibacterial activity against MDR strains of *P. aeruginosa*, indicating their compatibility for pharmaceutical and other biomedical applications [58].

Besides, Manikandan et al. reported plant mediated synthesis of Al_2O_3 NPs using *Prunus xyedonesis* and examined the antibacterial activity of Al_2O_3 NPs against pathogenic bacteria. These biosynthesized Al_2O_3 NPs displayed effective antibacterial activity against gram-positive *S. aureus* and gram-negative *E. coli* bacteria. The synthesized Al_2O_3 NPs also showed nitrate removal ability. From the results, green synthesized Al_2O_3 NPs is found to have promising applications in pollutant ion removal from aquatic systems [63].

CONCLUSION

This review has summarized the current scenario of the research work in the area of green synthesis of Al_2O_3 NPs by using distinctive plant parts. This literature surveys displayed the multifarious experimental works on biosynthesis of NPs of silver, zinc, gold and copper NPs in comparison to Al_2O_3 NPs. Therefore, special attention of scientific community is required to develop this efficient, swift, sustainable, noxious, affordable and environmentally gracious method for biosynthesis of Al_2O_3 NPs through this green chemistry bottom to top approach. Furthermore, multifarious plant species could be exploited in future era towards completely facile and rapid biosynthesis of metal oxide NPs. Further research needs to develop outstanding applications, use of distinctive plant parts for fabrication and highlight the exact mechanism behind the synthesis of Al_2O_3 NPs.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the author.

REFERENCES

1. Gawande MB, Goswami A, Felpin F-X, Asefa T, Huang X, Silva R, et al. Cu and Cu-Based Nanoparticles: Synthesis and Applications in Catalysis. Chemical Reviews. 2016;116(6):3722-811.
2. Ghotekar S. A review on plant extract mediated biogenic synthesis of CdO nanoparticles and their recent applications. Asian Journal of Green Chemistry. 2019;3(2):187-200.
3. Sorbiun M, Shayegan Mehr E, Ramazani A, Mashhadi Malekzadeh A. Biosynthesis of metallic nanoparticles using plant extracts and evaluation of their antibacterial properties. Nanochemistry Research. 2018;3(1):1-16.
4. Nikam A, Pagar T, Ghotekar S, Pagar K, Pansambal S. A review on plant extract mediated green synthesis of zirconia nanoparticles and their miscellaneous applications. Journal of Chemical Reviews. 2019;1(3. pp. 154-251):154-63.
5. Pansambal S, Deshmukh K, Savale A, Ghotekar S, Pardeshi O, Jain G, et al. Phytosynthesis and biological activities of fluorescent CuO nanoparticles using Acanthospermum hispidum L. extract. Journal of Nanostructures. 2017;7(3):165-74.
6. Ghotekar SK, Pande SN, Pansambal SS, Sanap DS, Mahale KM, Sonawane B. Biosynthesis of silver nanoparticles using unripe fruit extract of Annona reticulata L. and its characterization. World J Pharm and Pharm Sci. 2015;4(11):1304-12.
7. Gebre SH, Sendeku MG. New frontiers in the biosynthesis of metal oxide nanoparticles and their environmental applications: an overview. SN Applied Sciences. 2019;1(8).
8. Pagar T, Ghotekar S, Pagar K, Pansambal S, Oza R. A Review on Bio-Synthesized Co3O4 Nanoparticles Using Plant Extracts and their Diverse Applications. Journal of Chemical Reviews. 2019;1(4):260-70.
9. Kamble DR, Bangale SV, Ghotekar SK, Bamane SR. Efficient Synthesis of CeVO4 Nanoparticles Using Combustion Route and Their Antibacterial Activity. Journal of Nanostructures. 2018;8(2):144-51.
10. Ghotekar S, Savale A, Pansambal S. Phytofabrication of fluorescent silver nanoparticles from Leucaena leucocephala L. leaves and their biological activities. Journal of Water and Environmental Nanotechnology. 2018;3(2):95-105.
11. Ghotekar S. Green Synthesis of Fluorescent CdO Nanoparticles using Leucaena leucocephala L. Extract and their Biological Activities. Journal of Bacteriology & Mycology: Open Access. 2017;5(5).
12. Ghotekar SK, Vaidya PS, Pande SN, Pawar SP. Synthesis

of silver nanoparticles by using 3-methyl pyrazol 5-one (chemical reduction method) and its characterizations. Int J Multidis Res and Deve. 2015;2(5):419-22.
13. Pansambal S, Gavande S, Ghotekar S, Oza R, Deshmukh K. Green Synthesis of CuO Nanoparticles using Ziziphus Mauritiana L. Extract and Its Characterizations. Int J Sci Res in Sci and Tech. 2017;3:1388-92.
14. Pansambal S, Ghotekar S, Oza R, Deshmukh K. Biosynthesis of CuO nanoparticles using aqueous extract of Ziziphus mauritiana L. leaves and their Catalytic performance for the 5-aryl-1, 2, 4-triazolidine-3-thione derivatives synthesis. Int J Sci Res Sci Technol. 2019;5(4):122-8.
15. Pande SN BK, Wakchure SK, Ghotekar SK, Gujrathi DB, Phatangare ND. Green synthesis of silver nanoparticles by Caralluma Fimbriata and its characterization. Indian Journal of Applied Reaserch. 2015;5(2):748-9.
16. Pagar K, Ghotekar S, Pagar T, Nikam A, Pansambal S, Oza R, et al. Antifungal activity of biosynthesized CuO nanoparticles using leaves extract of Moringa oleifera and their structural characterizations. Asian Journal of Nanosciences and Materials. 2020;3(1):15-23.
17. Pansambal S, Ghotekar S, Shewale S, Deshmukh K, Barde N, Bardapurkar P. Efficient synthesis of magnetically separable CoFe2O4@SiO2 nanoparticles and its potent catalytic applications for the synthesis of 5-aryl-1,2,4-triazolidine-3-thione derivatives. Journal of Water and Environmental Nanotechnology. 2019;4(3):174-86.
18. Ghotekar S, Pansambal S, Pawar SP, Pagar T, Oza R, Bangale S. Biological activities of biogenically synthesized fluorescent silver nanoparticles using Acanthospermum hispidum leaves extract. SN Applied Sciences. 2019;1(11).
19. Ghotekar S, Pansambal S, Pagar K, Pardeshi O, Oza R. Synthesis of CeVO4 nanoparticles using sol-gel auto combustion method and their antifungal activity. Nanochemistry Research. 2018;3(2):189-96.
20. Taghavi Fardood S, Moradnia F, Mostafaei M, Afshari Z, Faramarzi V, Ganjkhanlu S. Biosynthesis of MgFe2O4 magnetic nanoparticles and its application in photo-degradation of malachite green dye and kinetic study. Nanochemistry Research. 2019;4(1):86-93.
21. Bangale S, Ghotekar S. Bio-fabrication of silver nanoparticles using Rosa Chinensis L.extract for antibacterial activities. International Journal of Nano Dimension. 2019;10(2):217-24.
22. Fardood ST, Ramazani A. Black Tea Extract Mediated Green Synthesis of Copper Oxide Nanoparticles. Journal of Applied Chemical Research. 2018;12(2):8-15.
23. Taghavi FS, Ramazani A, Golfar Z, WOO JS. Green Synthesis of α-Fe2O3 (hematite) Nanoparticles using Tragacanth Gel. Journal of Applied Chemical Research. 2017;11(3):19-27.
24. Taghavi Fardood S, Ramazani A, Woo Joo S. Sol-gel Synthesis and Characterization of Zinc Oxide Nanoparticles Using Black Tea Extract. Journal of Applied Chemical Research. 2017;11(4):8-17.
24. Fardood ST, Ramazani A, Moradi S. Green synthesis of Ni–Cu–Mg ferrite nanoparticles using tragacanth gum and their use as an efficient catalyst for the synthesis of polyhydroquinoline derivatives. Journal of Sol-Gel Science and Technology. 2017;82(2):432-9.
25. Atrak K, Ramazani A, Taghavi Fardood S. Eco-friendly synthesis of Mg0.5Ni0.5AlxFe2-xO4 magnetic nanoparticles and study of their photocatalytic activity for degradation of direct blue 129 dye. Journal of Photochemistry and Photobiology A: Chemistry. 2019;382:111942.
26. Atrak K, Ramazani A, Taghavi Fardood S. A novel sol–gel synthesis and characterization of MgFe2O4@γ–Al2O3 magnetic nanoparticles using tragacanth gel and its application as a magnetically separable photocatalyst for degradation of organic dyes under visible light. Journal of Materials Science: Materials in Electronics. 2018;29(8):6702-10.
27. Atrak K, Ramazani A, Taghavi Fardood S. Green synthesis of amorphous and gamma aluminum oxide nanoparticles by tragacanth gel and comparison of their photocatalytic activity for the degradation of organic dyes. Journal of Materials Science: Materials in Electronics. 2018;29(10):8347-53.
28. Moradnia F, Ramazani A, Fardood ST, Gouranlou F. A novel green synthesis and characterization of tetragonal-spinel MgMn2O4 nanoparticles by tragacanth gel and studies of its photocatalytic activity for degradation of reactive blue 21 dye under visible light. Materials Research Express. 2019;6(7):075057.
29. Taghavi Fardood S, Ramazani A, Woo Joo S. Eco-friendly Synthesis of Magnesium Oxide Nanoparticles using Arabic Gum. Journal of Applied Chemical Research. 2018;12(1):8-15.
30. Taghavi Fardood S, Moradnia F, Ramazani A. Green synthesis and characterisation of ZnMn2O4 nanoparticles for photocatalytic degradation of Congo red dye and kinetic study. Micro & Nano Letters. 2019;14(9):986-91.
31. Ramazani A, Taghavi Fardood S, Hosseinzadeh Z, Sadri F, Joo SW. Green synthesis of magnetic copper ferrite nanoparticles using tragacanth gum as a biotemplate and their catalytic activity for the oxidation of alcohols. Iranian Journal of Catalysis. 2017;7(3):181-5.
32. Taghavi Fardood S, Ramazani A, Joo SW. Green Chemistry Approach for the Synthesis of Copper Oxide Nanoparticles Using Tragacanth Gel and Their Structural Characterization. Journal of Structural Chemistry. 2018;59(2):482-6.
33. Taghavi Fardood S, Ramazani A, Golfar Z, Joo SW. Green Synthesis Using Tragacanth Gum and Characterization of Ni–Cu–Zn Ferrite Nanoparticles as a Magnetically Separable Catalyst for the Synthesis of Hexabenzylhexaazaisowurtzitane Under Ultrasonic Irradiation. Journal of Structural Chemistry. 2018;59(7):1730-6.
34. Taghavi Fardood S, Ramazani A, Asiabi PA, Joo SW. A Novel Green Synthesis of Copper Oxide Nanoparticles Using a Henna Extract Powder. Journal of Structural Chemistry. 2018;59(7):1737-43.
35. Meder F, Kaur S, Treccani L, Rezwan K. Controlling Mixed-Protein Adsorption Layers on Colloidal Alumina Particles by Tailoring Carboxyl and Hydroxyl Surface Group Densities. Langmuir. 2013;29(40):12502-10.
36. Gopi D, Gopi D, Shinyjoy E, Kavitha L, Rajeswari D. Carbon Nanotubes-reinforced Bioceramic Composite: An Advanced Coating Material for Orthopedic Applications. Advanced Composite Materials: John Wiley & Sons, Inc.; 2016. p. 399-452.
37. Ceramic Materials. ISTE; 2007.
38. Čejka J. Organized mesoporous alumina: synthesis, structure and potential in catalysis. Applied Catalysis A: General. 2003;254(2):327-38.

39. Cervantes FJ, Gómez R, Alvarez LH, Martinez CM, Hernandez-Montoya V. Efficient anaerobic treatment of synthetic textile wastewater in a UASB reactor with granular sludge enriched with humic acids supported on alumina nanoparticles. Biodegradation. 2015;26(4):289-98.
40. Afkhami A, Saber-Tehrani M, Bagheri H. Simultaneous removal of heavy-metal ions in wastewater samples using nano-alumina modified with 2,4-dinitrophenylhydrazine. Journal of Hazardous Materials. 2010;181(1-3):836-44.
41. Ke X, Huang Y, Dargaville TR, Fan Y, Cui Z, Zhu H. Modified alumina nanofiber membranes for protein separation. Separation and Purification Technology. 2013;120:239-44.
42. Liu X, Luo L, Ding Y, Xu Y. Amperometric biosensors based on aluminananoparticles-chitosan-horseradish peroxidase nanobiocomposites for the determination of phenolic compounds. The Analyst. 2011;136(4):696-701.
43. Lin W, Stayton I, Huang Y-w, Zhou X-D, Ma Y. Cytotoxicity and cell membrane depolarization induced by aluminum oxide nanoparticles in human lung epithelial cells A549. Toxicological & Environmental Chemistry. 2008;90(5):983-96.
44. Prashanth PA, Raveendra RS, Hari Krishna R, Ananda S, Bhagya NP, Nagabhushana BM, et al. Synthesis, characterizations, antibacterial and photoluminescence studies of solution combustion-derived α-Al2O3 nanoparticles. Journal of Asian Ceramic Societies. 2015;3(3):345-51.
45. Hakuta Y, Nagai N, Suzuki YH, Kodaira T, Bando KK, Takashima H, et al. Preparation of α-alumina nanoparticles with various shapes via hydrothermal phase transformation under supercritical water conditions. IOP Conference Series: Materials Science and Engineering. 2013;47:012045.
46. Al-Mamun SA, Nakajima R, Ishigaki T. Tuning the size of aluminum oxide nanoparticles synthesized by laser ablation in water using physical and chemical approaches. Journal of Colloid and Interface Science. 2013;392:172-82.
47. Gao H, Li Z, Zhao P. Green synthesis of nanocrystalline α-Al2O3 powders by both wet-chemical and mechanochemical methods. Modern Physics Letters B. 2018;32(08):1850109.
48. Rajaeiyan A, Bagheri-Mohagheghi MM. Comparison of Urea and Citric Acid Complexing Agents and Annealing Temperature Effect on the Structural Properties of - and -Alumina Nanoparticles Synthesized by Sol-Gel Method. Advances in Materials Science and Engineering. 2013;2013:1-9.
49. Hardy CG, Ren L, Ma S, Tang C. Self-assembly of well-defined ferrocenetriblock copolymers and their template synthesis of ordered iron oxide nanoparticles. Chem Commun. 2013;49(39):4373-5.
50. Sutradhar P, Debnath N, Saha M. Microwave-assisted rapid synthesis of alumina nanoparticles using tea, coffee and triphala extracts. Advances in Manufacturing. 2013;1(4):357-61.
51. Zaki T, Kabel KI, Hassan H. Using modified Pechini method to synthesize α-Al2O3 nanoparticles of high surface area. Ceramics International. 2012;38(6):4861-6.
52. Banerjee S, Gautam RK, Jaiswal A, Chandra Chattopadhyaya M, Chandra Sharma Y. Rapid scavenging of methylene blue dye from a liquid phase by adsorption on alumina nanoparticles. RSC Advances. 2015;5(19):14425-40.
53. Chu T, Nguyen N, Vu T, Dao T, Dinh L, Nguyen H, et al. Synthesis, Characterization, and Modification of Alumina Nanoparticles for Cationic Dye Removal. Materials. 2019;12(3):450.
54. Martín MI, Gómez LS, Milosevic O, Rabanal ME. Nanostructured alumina particles synthesized by the Spray Pyrolysis method: microstructural and morphological analyses. Ceramics International. 2010;36(2):767-72.
55. Reid CB, Forrester JS, Goodshaw HJ, Kisi EH, Suaning GJ. A study in the mechanical milling of alumina powder. Ceramics International. 2008;34(6):1551-6.
56. Jalal M, Ansari MA, Shukla AK, Ali SG, Khan Haris M, Pal R, et al. Green synthesis and antifungal activity of Al2O3NPs against fluconazole-resistant Candida spp isolated from a tertiary care hospital. RSC Advances. 2016;6(109):107577-90.
57. Narayanan MV, Rakesh SG. Synthesis of colloidal alumina nanoparticles using green method. IOP Conference Series: Materials Science and Engineering. 2018;402:012150.
58. Ansari MA, Khan HM, Alzohairy MA, Jalal M, Ali SG, Pal R, et al. Green synthesis of Al2O3 nanoparticles and their bactericidal potential against clinical isolates of multi-drug resistant Pseudomonas aeruginosa. World Journal of Microbiology and Biotechnology. 2014;31(1):153-64.
59. Sumesh KR, Kanthavel K. Green Synthesis of Aluminium Oxide Nanoparticles and its Applications in Mechanical and Thermal Stability of Hybrid Natural Composites. Journal of Polymers and the Environment. 2019;27(10):2189-200.
60. Sumesh KR, Kanthavel K, Ajithram A, Nandhini P. Bioalumina Nano Powder Extraction and its Applications for Sisal, Coir and Banana Hybrid Fiber Composites: Mechanical and Thermal Properties. Journal of Polymers and the Environment. 2019;27(9):2068-77.
61. Hasanpoor M, Aliofkhazraei M, Delavari H. Microwave-assisted Synthesis of Zinc Oxide Nanoparticles. Procedia Materials Science. 2015;11:320-5.
62. Ramamurthy SK, Sridhar C. PARTHENIUM MEDIATED SYNTHESIS OF ZINC OXIDE NANOPARTICLES AND ITS CHARACTERIZATION. International Journal of Applied Pharmaceutics. 2019;11(1):113.
63. Manikandan V, Jayanthi P, Priyadharsan A, Vijayaprathap E, Anbarasan PM, Velmurugan P. Green synthesis of pH-responsive Al2O3 nanoparticles: Application to rapid removal of nitrate ions with enhanced antibacterial activity. Journal of Photochemistry and Photobiology A: Chemistry. 2019;371:205-15.
64. Goutam SP, Avinashi SK, Yadav M, Roy D, Shastri R. Green Synthesis and Characterization of Aluminium Oxide Nanoparticles Using Leaf Extract of Rosa. Advanced Science, Engineering and Medicine. 2018;10(7):719-22.
65. Koopi H, Buazar F. A novel one-pot biosynthesis of pure alpha aluminum oxide nanoparticles using the macroalgae Sargassum ilicifolium: A green marine approach. Ceramics International. 2018;44(8):8940-5.
66. Duraisamy P. Green Synthesis of Aluminium Oxide Nanoparticles by using Aerva Lanta and Terminalia Chebula Extracts. International Journal for Research in Applied Science and Engineering Technology. 2018;6 (1):428-33.