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Silver Nanoparticles Synthesis from Different Plant Extracts-A Mini Review

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Abstract

Till date various methods of chemical synthesis of silver nanoparticles (AgNps) are known. Most of the protocols concerning the chemical synthesis of AgNps involve high pressure, temperature, energy and technical skills. Thus, the methods with much greener approach is the necessity of the hour. Accordingly, the groups of researchers have developed the methods that are cost-effective, energy-efficient and easy methods for the synthesis of AgNps. The AgNps were synthesized by using various plant extract. These nanoparticles were characterized by visual observation, ultraviolet-visible (UV-vis) spectrophotometry, Fourier transform infrared (FTIR), nanoparticle tracking and analysis (NTA) and transmission electron microscopy (TEM). Formation of AgNps were primarily detected by change in color of reaction mixture from colourless to yellow after treatment with silver salt ($AgNO_3$). UV-vis spectroscopy showed peak at 400-460 nm. TEM demonstrated the presence of spherical AgNps in the range of 10-80 nm. The various methods confirm the synthesis of AgNps by using different parts of plant extract. AgNPs synthesis was done employing plant extracts as a reducing, stabilizing, and capping agent. The synthesized silver nanoparticles showed various biological activities. The method is simple, eco-friendly and economically sustainable. This report would facilitate the industries and researchers connected with AgNPs synthesis and their applications.

KEYWORDS: Silver nanoparticles, Plant, Extracts from different plant parts

INTRODUCTION

The field of nanoscience draw an attention significantly nearly in the last two decades, and scientist are exploring more and more fields of applications continuously. Nanotechnology is a scientific process to synthesize particles in the nanoscale range, from 1 to 100 nm [1]. The high surface to volume ratio of NPs facilitate augmented optical characteristics [2]. There are different types of metal nanoparticles, which consist of nanoparticles of iron, gold, silver, titanium, cerium, platinum, thallium, and so on [3]. However, AgNPs are gaining significant attention by the scientific community and the industries due to their characteristic physicochemical and biological properties, viz, large surface area to volume ratio, excellent surface plasmon resonance, ease of functionalization or conjugation with different types of ligands to get desired tailored properties, toxicity against pathogens, efficient cytotoxicity towards cancer cells, catalytic applications and so on [4,5]. There are different synthesis methods like physical, chemical, biological, and green approaches are found in order to synthesize metallic AgNPs. Silver nanoparticles are notable among the other metal nanoparticles and nanocomposites due to their tremendous potential and significant applications in the textile and food industries, water purification plants, environmental pollution protection, biomedical/therapeutics (anticancer, antimicrobial, antiangiogenic, contrast agents in imaging techniques for the diagnosis of diseases, biomedical devices, diagnostic probes in biological systems for the detection of several dreadful diseases or complications, conjugation with drugs to overcome the resistance or hindrances facing to their efficient delivery and also to increase the potency and therapeutic index of drugs) [6,7].

Green synthesis of metallic nanoparticles is gaining a central research interest for interdisciplinary scientists throughout the world as the traditional chemical methods require more energy and reagents (sometimes harmful and toxic, too) consumption, compared to biological methods. The biological approaches used for AgNP synthesis are plant extracts (stems, flowers, barks, and heartwoods) [8,9,10], chitosan [11], bacteria [12], fungi [13], algae [14], and so on. However, due to availability and cost effectiveness, plant extracts have become more widespread for research purposes. Hence, massive research is directed to investigating plants and their different parts around the world. Comparatively, plant extracts are handier, as there is no risk of bacterial development/contamination during storage, as opposed to microorganism-based synthesis [15,16].

In this review, an attempt has been made to highlight some of the essential, highly significant green synthesis of AgNPs and their miscellaneous applications so that the readers can understand the importance and significance of synthesis of silver nanoparticles using plant parts and their potential in novel applications of science or nanotechnology. The reading of this review will enhance the fervor for the development of AgNPs using green methods.

SYNTHESIS PROCEDURE OF AgNPs

Two main categories of AgNP synthesis are Top down and Bottom up (Figure 1). The top-down approach is the mechanical alteration of bulk metal into nanostructures with appropriate stabilizing agents. Conflicting to this, the bottom-up approach is the alteration or nucleation and consequent stabilization of substance at the atomic scale into nanostructures [17]. Generally all the bottom-up approaches assign some common features, i.e., reduction of metal ions obtained from metal

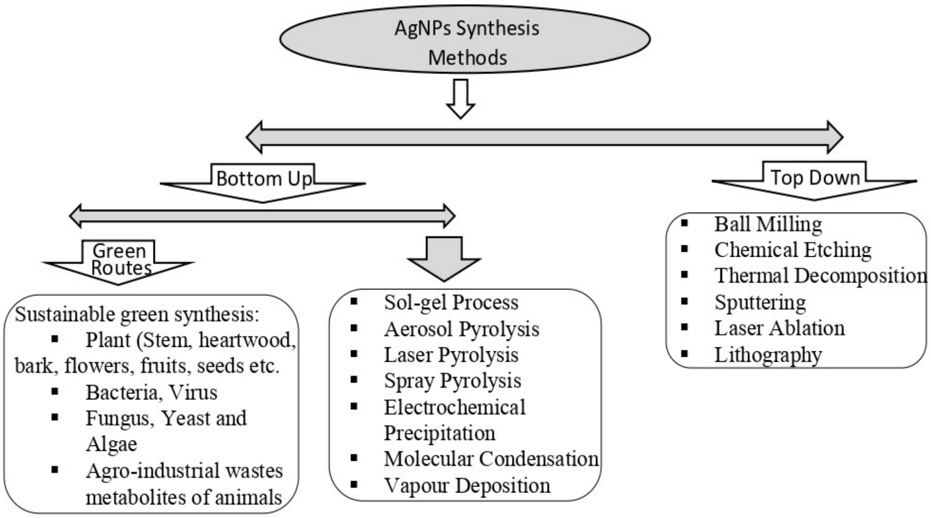

Figure 1. AgNPs can be synthesized by different synthesis approaches.

precursors by utilizing appropriate reducing agents, capping, or stabilizing agents in the preparation and providing the stability to the nanoparticles or nanostructures. AgNPs most commonly synthesize by chemical reduction, physical and biological/green synthesis methods. The several physical methods involve laser ablation, spark discharging, tube furnace (evaporation–condensation), pyrolysis, gamma-irradiation, microwave processing, and so on. These methods include some demerits or downsides, like low yield, high energy consumption, and uneven distribution of nanoparticles, but no use of environmentally hazardous chemicals is the positive side. Chemical methods for synthesizing AgNPs involve Sol-Gel method, Pyrolysis, Co-precipitation, Electro-chemical methods, Sono-chemical, etc. These methods stand as easy, cheap, and efficiently productive as compared to the physical methods. Previously, chemical synthesis methods were commonly utilized on that time biological synthesis was not studied significantly. However, chemical synthesis protocols involved the use of some reagents that were not all the time considered harmless [18]. Recently to minimize the toxic and environmental encumbrances from the allied products, biosynthesis of metallic AgNPs have drawn tremendous research attention [19, 20]. Most plants are natural capping agents that are expected to be free of health hazards. Therefore, plant related materials offer a significant and better platform to greenly synthesize AgNPs. The basic mechanisms related to AgNP synthesis is the stabilization and reduction of $AgNO_3$ with different plant extracts. The functional groups present in the biomolecules control the stabilization and reduction of Ag(+1) to Ag(0) [21]. Moreover, the biological synthesis of AgNPs show higher tolerance to metallic NPs, hence could easily be controlled. However, the mechanism of AgNPs synthesis is not yet fully understood. The main reason is the variation from plant to plant, species to species, and plant part to plant part. The work becomes more complex, as nearly 4000 phytochemicals have been discovered in plants to date [22].

It has been also observed that temperature, pressure, pH, type of reducing agent, and precursor agents have a important influence on monitoring the shape, size, surface area to volume ratio, size distribution, morphology, and bioactivity of synthesized silver nanomaterials [23,24].

DIFFERENT PARTS OF THE PLANTS FOR AgNPs SYNTHESIS

Plants are usually considered as freely available, easy to handle, harmless and cheap material for synthesis of many types of nanoparticles [25]. The biosynthesis process used definite parts like roots, leaves, flowers, fruits, seeds, peels, petals, seed husk and whole plant because these are rich with different biomolecules like carbohydrates, flavonoids, proteins, amino acids, saponins, terpenoids, nitrogenous compounds. These biomolecules can function as a reducer, stabilizer, redox mediators and capping agents in the synthesis of nanoparticles [26,27].

Biosynthesis of the metallic Ag is gaining much popularity with the advancements of science and technology to fulfill environmental requirements and standards. There are many routes of AgNPs synthesis, but bio-inspired methods are most popular because of providing minimized risk issues in terms of health hazard problems. In order to fulfill the increasing demands of AgNPs worldwide, plant-based extracts have potential to many advantages for production of AgNP synthesis (Figure 2). Many active biomolecules present in plants have enough capability to provide stability and reduce the silver ions present in the precursors.

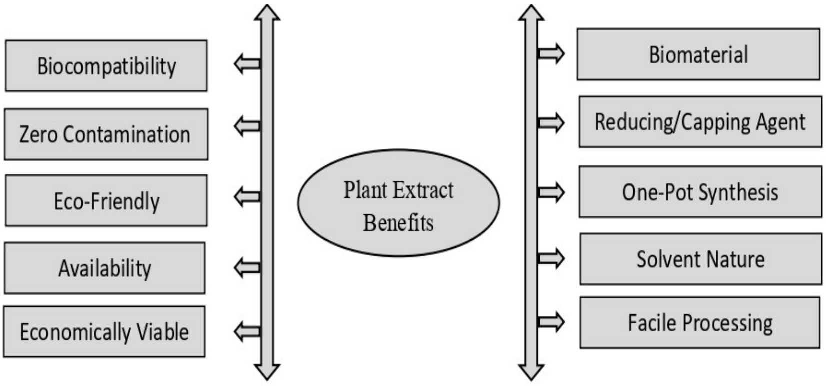

Figure **2. Benefits of biosynthesized AgNPs using different parts of plant extracts.**

This is actually the key difference between the plant extract based nanosilver compared to the chemical-based methods. The size and shape of AgNPs mainly differ with certain factors [28], listed below:

(a) Concentrations of silver precursor like $AgNO_3$, (b) Plant extracts Concentration, (c) Types of plant and associated parts used, (d) Reaction time, (e) Reaction Condition, (f) pH of the medium, and (g) Temperature.

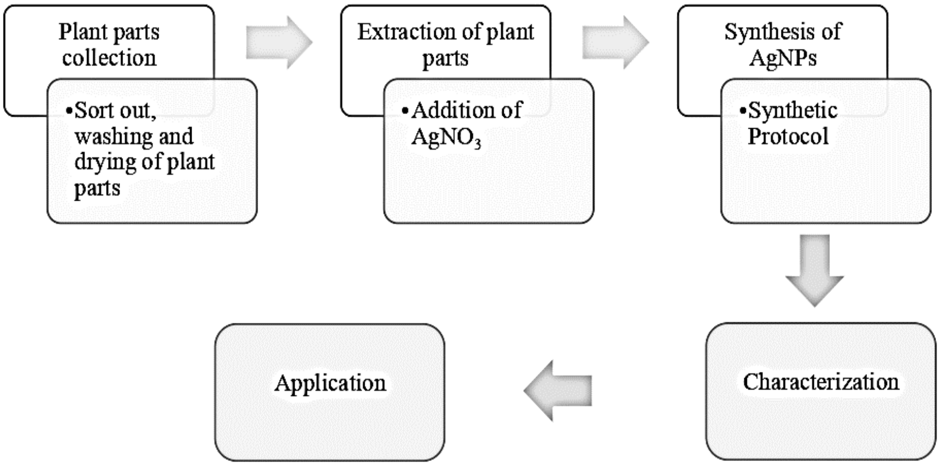

Figure 3. Synthesis of flow process of AgNPs utilizing plant extract.

Primarily, identification of plant parts like heartwood, leaf, bark, flower, fruit, roots, pulp, stem, latex, seeds, and rhizomes need to be confirmed for the green synthesis of AgNPs. Later, the selected plant materials are washed with clean water to eliminate any adhered debris, mud, and stones from the surfaces. The plant parts were then dried at room temperature to remove the volatile biomolecules. The collected plant parts are then crushed to get a powder form to assist the easy extraction in aqueous medium. The boiled plant extracts are then filtered by laboratorygrade filter paper. The filtered aqueous solutions are then kept at around $4^{O}C$ in the refrigerator for future usage [29–31]. Later, the silver salt solution were made generally within 0.5–5 mM concentrations with the precursor. Different volumes of plant extracts like 2/3/4/5% (v/v) are then added to the silver precursor for the synthesis of silver nanoparticles. The resulting solutions were then homogenized by continuous stirring and the color of the solutions began to change from a milky/colorless state to a transparent yellow/brown, revealing a successful formation of AgNPs [32]. Usually, such kind of color alterations be seen even at ambient temperatures like 25 OC, however, some of the reports also record applying heat around 80 OC or higher [33].

By the way, more research is required to discover the right biomolecules functioning as the stabilizer and capping agent. A detailed process about the synthesis of AgNPs from different plant extracts are presented in Figure 3. Ginkgo biloba leaves have polyphenols identified by an FTIR study [34]. The plant extract possessing hydroxyl groups are oxidized, hence Ag(+1) are reduced to AgNPs. A similar reaction mechanism was also reported in another study where two benzene rings present in the phytochemical of plant material extract taking part in reduction of Ag(+1) [35]. The free electrons formed during the synthesis process smooth the progress of the reduction of silver ions toward zero valence silver [35]. The synthesis of AgNPs was performed by water extract of clammy cherry (Cordia obliqua Willd) fruit which was utilized as the green reductant, and capping agent for [36]. Moreover, different reports regarding plant materials extracted AgNPs synthesis is listed in Table 1 [37–57].

Table 1. Examples of numerous synthesized AgNPs with associated particle sizes using extracts of different plant parts

Names of plants	Plant/Plant parts	Size of AgNPs (nm)	Properties	References
Aaronsohnia factorovskyi	Plant	104–140	Antibacterial, medicine	[37]
Berberis vulgare, Brassica nigra, Capsella bursa-pastoris, Lavandula angustifolia and *Origanum vulgare*	Plant	14.7±7.9 to 75.7 ± 17.1	Antibacterial	[38]
Turmeric	Plant	5 to 35	Antimicrobial activity	[39]
Capsicum annum L.	Chili plant	30 to 70	Bio-synthesis AgNPs	[40]
Salacia Chinensis	Plant	100 to 200	Antibacterial activity	[41]
Impatiens balsamina and *Lantana camara*	Leaves	3.2±1.2 to 20±3.3	Antimicrobial activity	[42]
Azadirachta indica	Leaves		Antimicrobial activity	[43]
Artemisia vulgaris	Leaves	~25	Biomedical	[44]
Lonicera japonica	Leaves	20 to 60	Antidiabetic activity	[45]

Skimmia laureola	Leaves	46	Antibacterial activity	[46]
Ixora coccinea	Leaves	15 to 37	-	[47]
Aloe vera	Leaves	15.5±4	Biological activity	[48]
Felty Germander	Stem and flower	10 to 1000	Antifungal activity	[49]
Thunbergia grandiflura	Flower		Catalytic reduction	[50]
Fritillaria	Flower	5 to 10	Antimicrobial activity	[51]
Fraxinus excelsior	Flower	15 to 115	Coloration	[52]
Carcia papya	Fruit	60 to 80	-	[53]
Orange	Fruit	25±2	Antimicrobial activity	[54]
Apple	Fruit	30±2	Antimicrobial activity	[54]
Red pepper	Fruit	19±2	Antimicrobial activity	[54]
Tomato	Fruit	9.58 to 72.69	Antifungal activity	[55]
Citrus sinensis	Fruit peels	23.81	-	[56]
Zinger (*Zingiber officinale*)	Modified plant stem	2.89	Antibacterial activity	[57]
Garlic	Modified stem	Amorphous	Antimicrobial activity	[54]

CHARATERISATION OF SILVER NANOPARTICLE SYNTHESIZED BY PLANT EXTRACTS

The physicochemical functions of nanoparticles are vital for their behavior, bio-distribution, safety, and efficacy. For that reason, characterization of AgNPs is important in order to assess the functional characteristics of the synthesized nanoparticles. Characterization is done with the use of a variety of analytical techniques, consist of UV-vis spectroscopy, X-ray diffractometry (XRD), X-ray photoelectron spectroscopy (XPS), dynamic light scattering (DLS), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and atomic force microscopy (AFM). UV-vis spectroscopy is an extremely useful and dependable technique for the initial characterization of synthesized nanoparticles which is also utilized to monitor the synthesis and stability of AgNPs [58]. AgNPs show unique optical properties which construct them strongly to interact with specific wavelengths of light [59]. XRD has been proved a common analytical technique which is used for the analysis of both molecular and crystal structures, qualitative identification of various compounds [60], quantitative resolution of chemical species [61], measuring the degree of crystallinity [62], isomorphous substitutions [63], particle sizes [64], and others. DLS probe can be used to the size distribution of small particles a scale ranging from submicron down to one nanometer in solution or suspension. Dynamic light scattering method depends on the interaction of light with particles. Narrow particle size distributions, especially in the range of 2–500 nm can be determined using this method [65]. Among various electron microscopy techniques, SEM is a surface imaging method. SEM is fully capable of resolving different particle sizes, size distributions, nanomaterial shapes, and the surface morphology of the synthesized particles at the micro and nanoscales [66]. The morphological studies are mostly done by using SEM and TEM analysis at different magnifications. TEM is one of the most adapted techniques to report the size and shape of the nanoparticles and show their distribution. AFM is also used to characterize the interaction of nanomaterials with supported lipid bilayers in real time, which is not feasible with current electron microscopy (EM) techniques [67]. The localized surface plasmon resonance (LSPR) condition can be described by several factors, including the electronic properties of the nanoparticle, the size and shape of the particle, temperature, the dielectric environment, and so on. The chemical bonding in the AgNPs coated substrates can be characterized by FTIR (Fourier transform infrared spectroscopy) analysis.

APPLICATION OF AgNPs

Silver nanoparticles contain large application potential in several fields. Utilizations of novel AgNPs could be traced back even before in Neolithic revolution that is mentioned by some authors [68]. However, the utilization of AgNPs as medicinal material was observed first in the 8th century [69]. AgNPs are going to be extensively utilized metallic materials due to their availability, low cost, and overall higher chemical solubility. Green AgNPs are displaying enormous potential for the biomedical field, consumer products, agriculture, cosmetics, air, and water purification, textile industries, automobiles, and so forth [70,71]. These applications describe the universal role of nanosilver in the present era of science and technology. Particularly, AgNPs are also utilized for wound dressing, catheters, and household applications where bacterial resistivity is essential. AgNPs are being used in dentistry as dental alloys, dental resins, prostheses, and dental coatings, in that way protecting the transplants from biofilm formation and continuing long-term oral hygiene [72]. Silver nanoparticles are also used in textile industry to generate antimicrobial fabrics. AgNPs are combined with fabrics and expose them exclusive properties like durability, disinfecting, hygienic, and color performance or brightness enhancers [7]. Silver nanoparticles are gradually utilized in consumer products succeeding in marketplaces with preferred and unique functions. For example, the uses are in kitchen scrubbers, antimicrobial toys, personal health care products (deodorants, skin creams, body lotions, soaps, toothpaste, antimicrobial socks), disinfecting sprays, pesticides, keyboard covers, detergents, air and water treatment/ purification devices, automobile interiors, facial masks, packaging of food materials and many more [71,73].

Apart from health related application, nanoparticles' distinctive chemical and physical features construct them ideal for many high-tech applications, for example the development of new and better-quality sensing devices, acutely electrochemical sensors and biosensors. AgNPs is also useful to mark biomolecules in electroanalysis. An electrochemical DNA biosensor based on the AgNPs label have potential to sensing target oligonucleotides at concentrations as low as 0.5 pM [74].Additionally, various studies is also reported that AgNPs can be utilized as an electrical bridge for electron transmission between cytochrome c and the electrode [74,75]. The silver nanoparticles are a better option for utilization as adhesives and conductive inks due to its potential thermal conductivity, low cost, electrical conductivity and chemical stability [76]. It is a fact that nanosilver-based consumer products are gradually used for their attending properties. In fact, they are flooding the markets. However, evaluation work regarding the sustained release, accumulation, clearance, other toxicity profiles and risk assessments in biological systems and the environment, is unsatisfactory. This is an alarming situation, and a wake-up call that needs to be addressed scientifically at the earliest.

CONCLUSIONS

Since ancient times, to create efficient and functional products, nature found resourceful and elegant paths. Consciousness is increasing all over the world to explore green chemistry for executing safer routes, materials, and technologies to produce industrial products in an eco-friendly way. AgNPs exhibit outstanding potential to fulfill this objective by creating safer products and reducing waste to look after healthy societies, environment, and workshops.

Additionally, use of greenly synthesized AgNPs reduce utilization of synthetic chemical reagents. This is why sustainable AgNPs are working to show a significant role in the forthcoming decades. There is necessary to identify biomolecules present in naturally derived materials for AgNPs extraction properly which would lead to a drop in energy and utilities consumption to create green and efficient technologies. Though, the long-term outcome of the use of nanoparticles on human health and crops is not clear. A huge number of nanoparticles have to be explored in various areas of biotechnology, industry technology and agriculture.

Further, collection of current work evidences that so far various queries about the parameters controlling size, shape, yield of the nanoparticles produced and precise properties of the nanoparticles synthesized using green approach are still not elucidated. Hence, further research in these directions is exceedingly necessary to fill these lacunas and come up with more controlled studies.

REFERENCES:

[1] Mittal A.K., Chisti Y., Banerjee U.C. (2013). Synthesis of metallic nanoparticles using plant extracts. Biotechnol. Adv. 31 (2): 346–356.

[2] Endo T., Shibata A., Yanagida Y., Higo Y., Hatsuzawa T. (2010). Localized surface plasmon resonance optical characteristics for hydrogen peroxide using polyvinylpyrrolidone coated silver nanoparticles. Mater. Lett. 64 (19): 2105–2108.

[3] Piñón-Segundo E., Mendoza-Muñoz N., Quintanar-Guerrero D. (2013). Nanoparticles as dental drug-delivery systems. In: Nanobiomaterials in Clinical Dentistry. William Andrew Publishing. 475–495.

[4] Jain P.K., Huang X., El-Sayed I.H., El-Sayed M.A. (2008). Noble metals on the nanoscale: optical and photothermal properties and some applications in imaging, sensing, biology, and medicine. Acc. Chem. Res. 41 (12): 1578–1586.

[5] Akter M., Sikder M.T., Rahman M.M. et al (2018). A systematic review on silver nanoparticles-induced cytotoxicity: physicochemical properties and perspectives. J. Adv. Res. 9: 1–16.

[6] Butola B.S., Mohammad F. (2016). Silver nanomaterials as future colorants and potential antimicrobial agents for natural and synthetic textile materials. RSC Adv. 6 (50): 44232–44247.

[7] Deshmukh S.P., Patil S.M., Mullani S.B., Delekar S.D. (2019). Silver nanoparticles as an effective disinfectant: a review. Mater. Sci. Eng. C 97: 954–965.

[8] Geethika B., Sameer S., Vishal L.A. et al (2018). Green synthesis of silver nanoparticles from heartwood extracts-Family of Fabaceae. Drug Invent. Today 10 (3): 3210–3213.

[9] Anbu P., Gopinath S.C., Yun H.S., Lee C.-G. (2019). Temperature-dependent green biosynthesis and characterization of silver nanoparticles using balloon flower plants and their antibacterial potential. J. Mol. Struct. 1177: 302–309.

[10] Tanase C., Berta L., Mare A. et al (2020). Biosynthesis of silver nanoparticles using aqueous bark extract of Picea abies L. and their antibacterial activity. Eur. J. Wood Wood Prod. 78 (2): 281–291.

[11] Hasan K.F., Wang H., Mahmud S. et al (2020). Colorful and antibacterial nylon fabric via in-situ biosynthesis of chitosan mediated nanosilver. J. Mater. Res. Technol. 9 (6): 16135–16145.

[12] Singh R., Shedbalkar U.U., Wadhwani S.A., Chopade B.A. (2015). Bacteriagenic silver nanoparticles: synthesis, mechanism, and applications. Appl. Microbiol. Biotechnol. 99 (11): 4579–4593.

[13] Krishnaraj C., Ramachandran R., Mohan K., Kalaichelvan P.T. (2012). Optimization for rapid synthesis of silver nanoparticles and its effect on phytopathogenic fungi. Spectrochim. Acta Part A: Mol. Biomolecul. Spectros. 93: 95–99.

[14] Venkatesan J., Kim S.-K., Shim M.S. (2016). Antimicrobial, antioxidant, and anticancer activities of biosynthesized silver nanoparticles using marine algae Ecklonia cava. Nanomaterials 6 (12): 235.

[15] Patil M.P., Kim G.-D. (2017). Eco-friendly approach for nanoparticles synthesis and mechanism behind antibacterial activity of silver and anticancer activity of gold nanoparticles, Appl. Microbiol. Biotechnol. 101 (1): 79–92.

[16] Manivasagan P., Nam S.Y., Oh J. (2016). Marine microorganisms as potential biofactories for synthesis of metallic nanoparticles. Crit. Rev. Microbiol. 42 (6): 1007–1019.

[17] Richards R., Bönnemann H. (2005). Synthetic approaches to metallic nanomaterials. Nanofabrication Towards Biomed. Appl. 1–32.

[18] Iravani S., Korbekandi H., Mirmohammadi S.V., Zolfaghari B. (2014). Synthesis of silver nanoparticles: chemical, physical and biological methods. Res. Pharm. Sci. 9 (6): 385.

[19] Hasan K., Horvath P.G., Koczan Z., Bak M., Alpár T. (2021). Colorful and facile in situ nanosilver coating on sisal/cotton interwoven fabrics mediated from European larch heartwood. Scintific Reports 11 (1): 1–13.

[20] Hasan K.F., Wang H., Mahmud S., Islam A., Habib M.A., Genyang C. (2022). Enhancing mechanical and antibacterial performances of organic cotton materials with greenly synthesized colored silver nanoparticles, Int. J. Cloth. Sci. Technol. 34 (4): 549–565.

[21] Vadlapudi V., Kaladhar D. (2014). Review: green synthesis of silver and gold nanoparticles, Middle East. J. Sci. Res. 19 (6): 834–842.

[22] Das R.K., Brar S.K. (2013). Plant mediated green synthesis: modified approaches. Nanoscale 5 (21): 10155–10162.

[23] Voronov A., Kohut A., Vasylyev S., Peukert W. (2008). Mechanism of silver ion reduction in concentrated solutions of amphiphilic invertible polyesters in nonpolar solvent at room temperature. Langmuir 24 (21): 12587–12594.

[24] Wongpreecha J., Polpanich D., Suteewong T., Kaewsaneha C., Tangboriboonrat P. (2018). One-pot, large-scale green synthesis of silver nanoparticles-chitosan with enhanced antibacterial activity and low cytotoxicity. Carbohydr. Polym. 199: 641–648.

[25] Noruzi M. (2015). Biosynthesis of gold nanoparticles using plant extracts. Bioprocess Biosyst Eng. 38(1): 1-14.

[26] Mondal P., Anweshan A., Purkait, M. K. (2020). Green Synthesis and Environmental Application of Iron-Based Nanomaterials and Nanocomposite: A Review. Chemosphere 259: 127509.

[27] Vasantharaj S., Sathiyavimal S., Senthilkumar P., LewisOscar F., Pugazhendhi A. (2019). Biosynthesis of Iron Oxide Nanoparticles Using Leaf Extract of Ruellia Tuberosa: Antimicrobial Properties and Their Applications in Photocatalytic Degradation. J. Photochem. Photobiol. B: Biol. 192: 74–82.

[28] Bhaumik J., Thakur N.S., Aili P.K., Ghanghoriya A., Mittal A.K., Banerjee U.C. (2015). Bioinspired nanotheranostic agents: synthesis, surface functionalization, and antioxidant potential. ACS Biomater. Sci. Eng. 1 (6): 382–392.

[29] Hasan K.F., Horváth P.G., Kóczán Z., Bak M., Horváth A., Alpár T. (2021). Coloration of flax woven fabric using Taxus baccata heartwood extract mediated nanosilver. Colour Technol. 1–11.

[30] Hasan K.F., Horvath P.G., Zsolt K., Kóczán Z. (2021). Hemp/glass woven fabric reinforced laminated nanocomposites via in-situ synthesized silver nanoparticles from Tilia cordata leaf extract. Compos Interfaces. 29(4):1-19.

[31] Hasan K.F., Liu X., Kóczán Z. et al (2021). Nanosilver coating on hemp/cotton blended woven fabrics mediated from mammoth pine bark with improved coloration and mechanical properties. J. Text. Inst. 2641-2650.

[32] Mythili R., Selvankumar T., Kamala-Kannan S. et al (2018). Utilization of market vegetable waste for silver nanoparticle synthesis and its antibacterial activity. Mater. Lett. 225: 101–104.

[33] Hasan K.F., Wang H., Mahmud S., Taher M.A., Genyang C. (2020). Wool functionalization through AgNPs: coloration, antibacterial, and wastewater treatment. Surf. Innov. 9 (1): 25–36.

[34] Ren Y.-y., Yang H., Wang T., Chuang W. (2016). Green synthesis and antimicrobial activity of monodisperse silver nanoparticles synthesized using Ginkgo Biloba leaf extract. Phys. Lett. A. 380 (45): 3773–3777.

[35] Rao K.J., Paria S. (2013). Green synthesis of silver nanoparticles from aqueous Aegle marmelos leaf extract. Mater. Res. Bull. 48 (2): 628–634.

[36] Saidu F.K., Mathew A., Parveen A., Valiyathra V., Thomas V.G. (2019). Novel green synthesis of silver nanoparticles using clammy cherry (Cordia obliqua Willd) fruit extract and investigation on its catalytic and antimicrobial properties. SN Appl. Sci. 1: 1368.

[37] Al-Otibi F., Al-Ahaidib R.A., Alharbi R.I., Al-Otaibi R.M., Albasher G. (2021). Antimicrobial potential of biosynthesized silver nanoparticles by Aaronsohnia factorovskyi extract. Molecules 26 (1): 130.

[38] Salayova A., Bedlovicova Z., Daneu N. et al (2021). Green synthesis of silver nanoparticles with antibacterial activity using various medicinal plant extracts: morphology and antibacterial efficacy. Nanomaterials 11 (4): 1005.

[39] Alsammarraie F.K., Wang W., Zhou P., Mustapha A., Lin M. (2018). Green synthesis of silver nanoparticles using turmeric extracts and investigation of their antibacterial activities. Colloids Surf. B Biointerfaces 171: 398–405.

[40] Li S., Shen Y., Xie A., et al (2007). Green synthesis of silver nanoparticles using Capsicum annuum L. extract. Green Chem. 9 (8) 852–858.

[41] Jadhav K., Dhamecha D., Dalvi B., Patil M. (2015). Green synthesis of silver nanoparticles using Salacia chinensis: characterization and its antibacterial activity. Part. Sci. Technol. 33 (5): 445–455.

[42] Aritonang H.F., Koleangan H., Wuntu A.D. (2019). Synthesis of silver nanoparticles using aqueous extract of medicinal plants'(Impatiens balsamina and Lantana camara) fresh leaves and analysis of antimicrobial activity. Int. J. Microbiol. 2019: 1–8.

[43] Roy P., Das B., Mohanty A., Mohapatra S. (2017). Green synthesis of silver nanoparticles using Azadirachta indica leaf extract and its antimicrobial study. Appl. Nanosci. 7 (8): 843–850.

[44] Rasheed T., Bilal M., Iqbal H.M., Li C. (2017). Green biosynthesis of silver nanoparticles using leaves extract of Artemisia vulgaris and their potential biomedical applications. Colloids Surf. B Biointerfaces 158: 408–415.

[45] Balan K., Qing W., Wang Y. et al (2016). Antidiabetic activity of silver nanoparticles from green synthesis using Lonicera japonica leaf extract. RSC Adv. 6 (46): 40162–40168.

[46] Ahmed M.J., Murtaza G., Mehmood A., Bhatti T.M. (2015). Green synthesis of silver nanoparticles using leaves extract of Skimmia laureola: characterization and antibacterial activity. Mater. Lett. 153: 10–13.

[47] Karuppiah M., Rajmohan R. (2013). Green synthesis of silver nanoparticles using Ixora coccinea leaves extract. Mater. Lett. 97: 141–143.

[48] Chandran S.P., Chaudhary M., Pasricha R., Ahmad A., Sastry M. (2006). Synthesis of gold nanotriangles and silver nanoparticles using Aloevera plant extract. Biotechnol. Prog. 22 (2): 577–583.

[49] Ghojavand S., Madani M., Karimi J. (2020). Green synthesis, characterization and antifungal activity of silver nanoparticles using stems and flowers of felty germander. J. Inorg. Organomet. Polym. Mater. 30 (8): 2987–2997.

[50] Varadavenkatesan T., Selvaraj R., Vinayagam R. (2020). Green synthesis of silver nanoparticles using Thunbergia grandiflora flower extract and its catalytic action in reduction of Congo red dye. Mater. Today Proc. 23: 39–42.

[51] Hemmati S., Rashtiani A., Zangeneh M.M., Mohammadi P., Zangeneh A., Veisi H. (2019). Green synthesis and characterization of silver nanoparticles using Fritillaria flower extract and their antibacterial activity against some human pathogens, Polyhedron 158: 8–14.

[52] Hasan K.F., Horváth P.G., Horváth A., Alpár T. (2021). Coloration of woven glass fabric using biosynthesized silver nanoparticles from Fraxinus excelsior tree flower. Inorg. Chem. Commun. 126: 108477.

[53] Mude N., Ingle A., Gade A., Rai M. (2009). Synthesis of silver nanoparticles using callus extract of Carica papaya—a first report. J. Plant Biochem. Biotechnol. 18 (1): 83–86.

[54] Wasilewska A., Klekotka U., Zambrzycka M., Zambrowski G., Święcicka I., Kalska-Szostko B. (2022). Physico-chemical properties and antimicrobial activity of silver nanoparticles fabricated by green synthesis. Food Chem. 400: 133960.

[55] Mohamed M., Faraj K.M., Al-Jobori K. (2020). Green synthesis of silver nanoparticles using tomato (Lycopersicon esculentum) extract and evaluation of their antifungal activities. Plant Archives 20(2): 5773–5786.

[56] Omran B.A., Nassar H.N., Fatthallah N.A., Hamdy A., El-Shatoury E.H., El-Gendy N.S. (2018). Waste upcycling of Citrus sinensis peels as a green route for the synthesis of silver nanoparticles. Energ. Sources Part A: Recovery, Utilization, and Environ. Effects. 40 (2): 227–236.

[57] Priyaa G.H., Satyan K.B. (2014). Biological Synthesis of Silver Nanoparticles using Ginger (Zingiber Officinale) Extract. J. Environ. Nanotechnol. 3(4): 32–40

[58] Sastry M., Patil V., Sainkar S.R. (1998). Electrostatically controlled diffusion of carboxylic acid derivatized silver colloidal particles in thermally evaporated fatty amine films. J. Phys. Chem. B. 102: 1404–1410.

[59] Saxena A., Tripathi R., Zafar F., Singh P. (2012). Green synthesis of silver nanoparticles using aqueous solution of Ficus benghalensis leaf extract and characterization of their antibacterial activity, Mater. Lett. 67 (1): 91–94.

[60] Ivanisevic I. (2010). Physical stability studies of miscible amorphous solid dispersions. J. Pharm. Sci. 99: 4005–4012.

[61] Cabral M., Pedrosa F., Margarido F., Nogueira C.A. (2013). End-of-life Zn-MnO2 batteries: Electrode materials characterization. Environ. Technol. 34: 1283–1295.

[62] Dey A., Mukhopadhyay A.K., Gangadharan S., Sinha M.K., Basu D. (2009). Characterization of microplasma sprayed hydroxyapatite coating. J. Therm. Spray Technol. 18: 578–592.

[63] Ananias D., Paz F.A., Carlos L.D., Rocha J. (2013). Chiral microporous rare-earth silico-germanates: Synthesis, structure and photoluminescence properties. Microporous Mesoporous Mater. 166: 50–58.

[64] Singh D.K., Pandey D.K., Yadav R.R., Singh D. (2013). A study of ZnO nanoparticles and ZnO-EG nanofluid. J. Exp. Nanosci. 8: 567–577.

[65] Tomaszewska E., Soliwoda K., Kadziola K. et al (2013). Detection limits of DLS and UV-vis spectroscopy in characterization of polydisperse nanoparticles colloids. J. Nanomater. 2013: 313081.

[66] Fissan H., Ristig S., Kaminski H., Asbach C., Epple M. (2014). Comparison of different characterization methods for nanoparticle dispersions before and after aerosolization. Anal. Methods. 6: 7324–7334.

[67] Stephan T.S., Scott E.M., Anil K.P., Marina A.D. (2006). Preclinical characterization of engineered nanoparticles intended for cancer therapeutics. In: Amiji MM, editor. Nanotechnology for Cancer Therapy. CRC Press: Boca Raton, FL, USA. 105–137.

[68] Gangadoo S., Stanley D., Hughes R.J., Moore R.J., Chapman J. (2016). Nanoparticles in feed: Progress and prospects in poultry research. Trends Food Sci. Technol. 58: 115–126.

[69] Ravindran A., Chandran P., Khan S.S. (2013). Biofunctionalized silver nanoparticles: advances and prospects. Colloids Surfaces B: Biointerfaces. 105: 342–352.

[70] Kumar P., Pahal V., Gupta A., Vadhan R., Chandra H., Dubey R.C. (2020). Effect of silver nanoparticles and Bacillus cereus LPR2 on the growth of Zea mays. Sci. Rep. 10 (1): 1–10.

[71] Shafique M., Luo X. (2019). Nanotechnology in transportation vehicles: an overview of its applications, environmental, health and safety concerns. Materials 12 (15): 2493.

[72] Yin I.X., Zhang J., Zhao I.S., Mei M.L., Li Q., Chu C.H. (2020). The antibacterial mechanism of silver nanoparticles and its application in dentistry. Int. J. Nanomed. 15: 2555.

[73] McGillicuddy, E., Murray, I., Kavanagh, S. et al (2017). Silver nanoparticles in the environment: sources, detection and ecotoxicology. Sci. Total Environ. 575: 231–246.

[74] Luo X., Morrin A., Killard A., Smyth M. (2006). Application of nanoparticles in electrochemical sensors and biosensors. Electroanalysis 18 (4): 319–326.

[75] Liu T., Zhong J., Gan X., Fan C., Li G., Matsuda N. (2003). Wiring electrons of cytochrome c with silver nanoparticles in layered films. Eur. J. Chem. Phys. Phys. Chem. 4 (12): 1364–1366.

[76] Ren, H.M., Guo Y., Huang S.-Y. et al (2015). One-step preparation of silver hexagonal microsheets as electrically conductive adhesive fillers for printed electronics. ACS Appl. Mater. Interfaces 7: 13685–13692.