IJPSR (2021), Volume 12, Issue 11 **(Review Article)**

INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES AND RESEARCH

Received on 19 September 2020; received in revised form, 15 May 2021; accepted, 25 May 2021; published 01 November 2021

GREEN NANOTECHNOLOGY AND NANOPARTICLES: AN ECO-FRIENDLY APPROACH

Hema Kumari and Kiranmai Mandava *

Department of Pharmaceutical Chemistry, St Pauls College of Pharmacy, RR (Dist.), Turkayamjal - 50151, Telangana, India.

Keywords:

Green Nanotechnology, Metallic Nanoparticles, Biomaterials, Green Synthesis

Correspondence to Author:
Kiranmai Mandava

Department of Pharmaceutical Chemistry, St Pauls College of Pharmacy, RR (Dist.), Turkayamjal - 50151, Telangana, India.

E-mail: gchaitra.kiran@gmail.com

ABSTRACT: The field of nanotechnology is one of the notable active analysis areas in modern material science. Recent advances in Nanoscience and nanotechnology have led to the development of nanoparticles, which ultimately decrease potential health and environment hazards. Interest in developing environmentally friendly procedures for the synthesis of metallic nanoparticles has been increased. The purpose is to minimize the negative impact of synthetic procedures, their accompanying chemicals, and derivative compounds. Nanoparticles produced by green technology are more superior when compared to those manufactured with physical and chemical methods based on it eliminates the use of most expensive chemicals and also use less energy along with formation of environmental byproducts. In the synthesis of metallic nanoparticles, natural resources have been used. The exploitation of different biomaterials for the synthesis of nanoparticles is considered a valuable approach in green nanotechnology. This review provides an overview of the mechanisms of green synthesis of metallic nanoparticles and their application.

INTRODUCTION: There have been enormous advancements in the arena of Nanotechnology within the recent years related to the green synthesis of nanoparticles using plant extracts, microorganisms and human genes. Green nanotechnology means the application of green chemistry and green engineering principles in the field of Nanotechnology. Nanoparticles can be synthesized using a variety of methods such as physical method, chemical method, biological method and hybrid method [1-3]. The production of nanoparticles through conventional (physical and chemical) methods results in toxic by-products that are environmental hazards. Additionally, these products cannot be used in medicine due to health-related issues [4]. Conventional methods can be used to produce nanoparticles in large quantities with defined sizes and shapes in a shorter period of time; however, these techniques are complicated, costly and outdated.

In recent years, there has been growing interest in the synthesis of environmentally friendly nanoparticles that do not produce toxic waste [5, 6]. This can only be achieved through biological nature using biotechnological tools that are considered safe and ecologically good for fabrication as an alternative to conventional methods. Green nanotechnology is synthesizing the nanoparticles or nanomaterials using biological routes, as shown in **Fig. 1,** such as microorganisms, plants, viruses, or their by-products such as proteins and lipids. Nanoparticles produced by green technology are far superior to those manufactured with physical and chemical methods based on it eliminates the use of

QUICK RESPONSE CODE

DOI:
10.13040/IJPSR.0975-8232.12(11).5624-33

This article can be accessed online on www.ijpsr.com

DOI link: http://dx.doi.org/10.13040/IJPSR.0975-8232.12(11).5624-33

expensive Chemicals, consumes less energy and generates environmental friendly by-products [7].

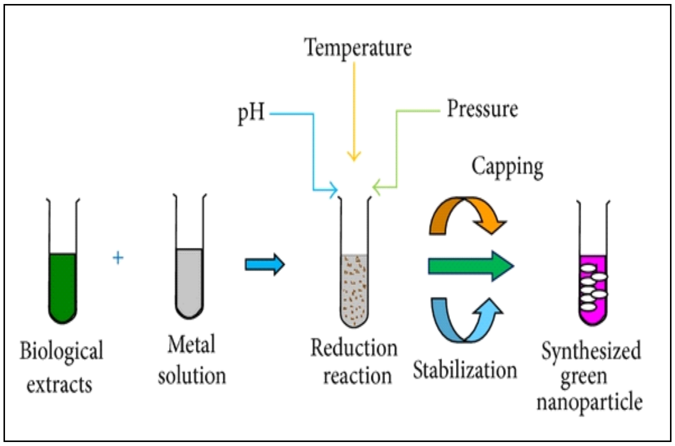

FIG. 1: BIOLOGICAL SYNTHESIS OF METAL NANOPARTICLES

Approaches for the Synthesis of Nanoparticles: Metal particle synthesis typically takes place in one of two ways: top-down or bottom-up, as shown in **Fig. 2**. The top-down approach uses an external force to pressure bulk materials, eventually causing these materials to break down into smaller components by means of mechanical, chemical, or some other energy sources. A bottom-up approach takes place in a reverse tactic, growing precursor particle size by using chemical reactions to combine atomic or molecular species. It should be noted that the top-down approach is considered to be a physical method while the bottom-up approach is chemical, although both approaches can be applied in a range of states, including liquid, solid, gas, supercritical fluids, or vacuum [8].

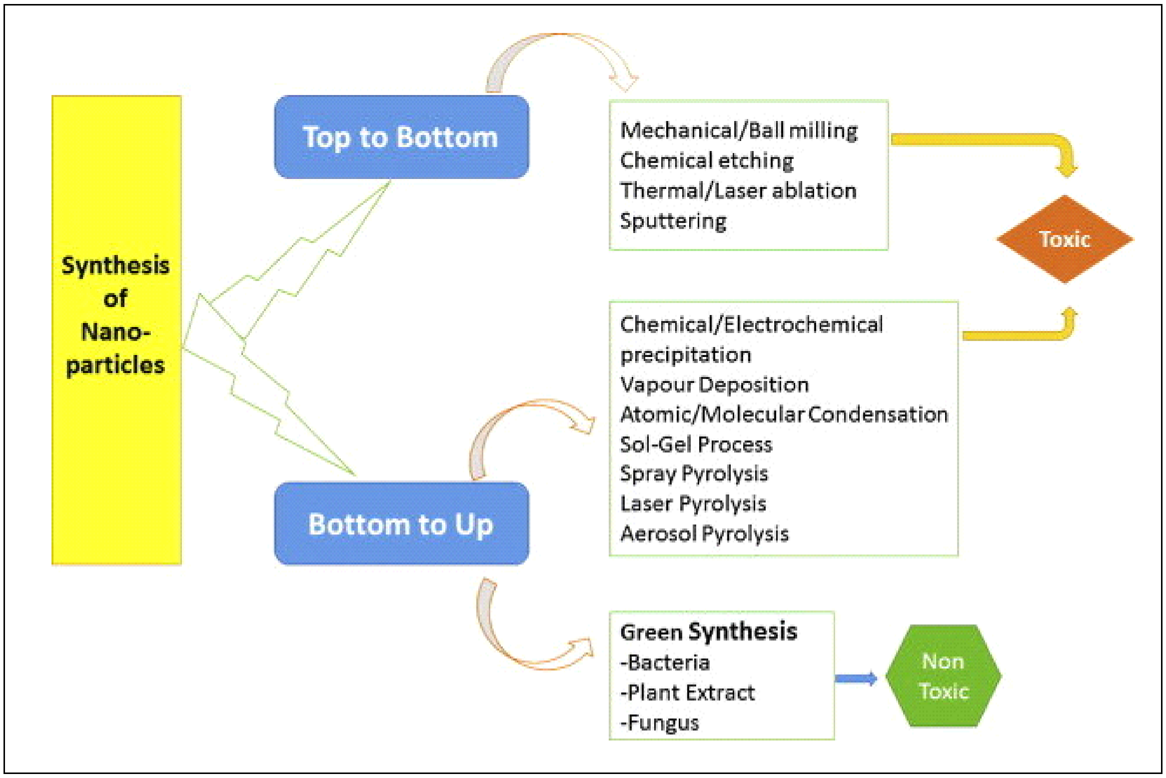

FIG. 2: DIFFERENT APPROACHES FOR SYNTHESIS OF METAL NANOPARTICLES

Green Synthesis of Metal Nanoparticles:

1. Micro-organisms Based Mechanism: There are different mechanisms for the formation of nanoparticles using different microorganisms. First metallic ions are captured on the surface or inside the microbial cells, and then these arrested metal ions are reduced into metal nanoparticles by the action of enzymes. The two key aspects in the biosynthesis of nanoparticles are NADH (Nicotinamide Adenine Dinucleotide) and NADH-dependent nitrate reductase. Nonetheless, The bioreduction mechanisms associated with the production of metal salts and the resulting metal nanoparticles formed by microorganisms remain unexplored [9].

- **Bacteria:** Bacterial species have been widely utilized for commercial biotechnological applications such as bioremediation, genetic engineering, and bioleaching. Bacteria possess the ability to reduce metal ions and are momentous candidates in nanoparticles preparation.

For the preparation of metallic and other novel nano-particles, a variety of bacterial species are utilized. Prokaryotic bacteria and action mycetes have been broadly employed for synthesizing metal/metal oxide nanoparticles. The bacterial synthesis of nanoparticles has been adopted due to the relative ease of manipulating the bacteria. Some examples of bacterial strains that have been extensively exploited for the synthesis of bio-reduced silver nanoparticles with distinct size / shape morphologies include: *Escherichia coli*, Lactobacillus casei, *Bacillus cereus*, Aeromonas sp. SH10 *Phaeocystis a*ntarctica, *Pseudomonas proteolytica*, *Bacillus amyloliquefaciens*, *Bacillus indicus*, *Bacillus cecembensis*, Enterobacter cloacae, Geobacter spp., *Arthrobacter gangotriensis*, Corynebacterium sp. SH09, and *Shewanella oneidensis*. Likewise, for the preparation of gold nanoparticles, several bacterial species (such as *Bacillus megaterium* D01, *Desulfovibrio desulfuricans*, *E. coli* DH5a, *Bacillus subtilis* 168, *Shewanella alga*, Rhodopseudomonas capsulate and Plectonema boryanum UTEX 485) have been extensively used. Information on the size, morphology, and applications of various nano-particles is summarized in **Table 1**.

TABLE 1: SYNTHESIS OF METALLIC NPS FROM VAR

S. no.	Species	Nanoparticles	Size (nm)	Morphology	Application	Reference
1	*Bacillus cereus*	Silver	20-40	Spherical	Anti- bacterial activity	10
2	*Pseudomonas proteolytica, Bacillus cecembensis*	silver	6-13	Spherical	Anti -bacterial activity	11
3	*Lactobacillus casei*	Silver	20-50	Spherical	Drug delivery, cancer treatment, bio labeling	12
4	*Klebsiella pneumonia, Escherichia coli, Enterobacter cloacae*	Silver	28-122	Spherical	Optic receptors, anti -microbial agent	13
5	*Bacillus indicus*	Silver	-	-	Anti -microbial agent	14
6	*Plectonema boryanum UTEX 485*	Gold	10-25	Cubic, octahedral	-	15
7	*Bacillus subtilis 168*	Gold	5-50	Hexagonal, octahedral	-	16
8	*Bacillus megaterium D01*	Gold	<25	Spherical	Catalysis, bio-sensing	17
9	*Shewanella alga*	Gold	10-20	Triangular	-	18
10	*E. coli DH 5α*	Gold	8-25	Spherical	Direct electrochemistry of hemoglobin	19
11	*Desulfovvibrio desulfuricans*	Gold	20-50	Spherical	Catalysis	20
12	*Rhodopseudomonas capsulate*	Gold	10-20	Triangular	Cancer hyperthermia	21
13	Magnetospirillum magneto-Tactium	Iron oxide	47	-	-	22
14	*Aquaspirillum magnetotacti- Cum*	Iron oxide	40-50	Octahedral prism	-	23
15	*Shewanella oneidensis*	Uranium oxide	1-5	-	-	24
16	*Klebsiella aerogenes*	Cadmium sulphide	20-200	-	-	25
17	*E. coli*	Cadmium sulphide	2-5	Wurtzite structure	Fluorescent labels	26
18	*Rhizopus nigricans*	Silver	35-40	Round	Bactericidal, catalysis	27
19	*Aspergillus niger*	Silver	20	Spherical	Anti-bacterial agent	28
20	*Verticillium luteoalbum*	Gold	<10	Triangular, hexagonal	Optics, sensor, coatings	29
21	*Aspergillus terreus*	Zinc oxide	8	Spherical	Catalysis, bio-sensing, drug delivery, diagnostics	30
22	*Aspergillus flavus* TFR7	Titanium dioxide	12-15	Spherical	Plant nutrient fertilizer	31
23	MKY3	Silver	2-5	Hexagonal	Coatings for solar energy absorption	32
24	*Saccharimyces cerevisae*	Gold, silver	4-15	spherical	Catalysis	33

- **Fungi:** Fungi-mediated biosynthesis of metal/metal oxide nanoparticles is also a very efficient process for the generation of mono-dispersed nanoparticles with well-defined morphologies. They act as better biological agents for the preparation of metal and metal oxide nanoparticles, due to the presence of a variety of intracellular enzyme. Competent fungi can synthesize larger amounts of nanoparticles compared to bacteria. Moreover, fungi have many merits over other organisms due to the presence of enzymes/proteins/reducing components on their cell surfaces. The probable mechanism for the formation of the metallic nanoparticles is enzymatic reduction (reductase) in the cell wall or inside the fungal cell. Many fungal species are used to synthesize metal/metal oxide nanoparticles like silver, gold, titanium dioxide and zinc oxide, as discussed in **Table 1**.

2. Plant Extract Based Mechanism: For a long time, it has been known that plants have the potential for biological reduction of metallic ions and hyper-accumulation. Because of such remarkable properties, plants have been considered a more environmentally friendly biological method for synthesis of metallic nanoparticles, and also useful for detoxification applications. Plant extracts contain various bioactive, such as alkaloids, proteins, phenolic acids, sugars, terpenoids and polyphenols, which have been found to have an important role in first reducing and then stabilizing the metallic ions, as shown in **Fig. 3**.

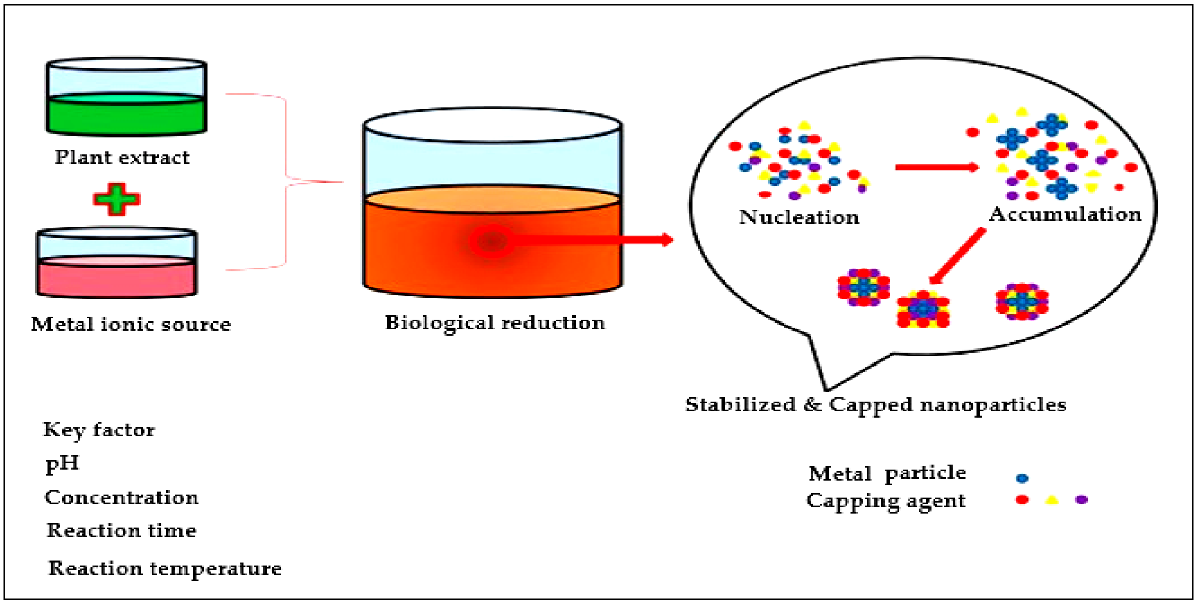

FIG. 3: BIOSYNTHESIS OF NANOPARTICLES USING PLANT EXTRACT

The shape and size of nanoparticles mainly depend on the variation in composition and concentration of active biomolecules of different plants, and their interaction with the aqueous metal ions. Especially in the chemical and biological synthesis of nano-particles, the aqueous metal ion precursors from metal salts are reduced, which results in a colour change of the reaction mixture and provides a quantitative indication of nanoparticle formation. More importantly, the nanoparticles synthesized from reducing agents may show general toxicity, engendering serious concern for developing environmentally friendly processes. The process of the formation of nanoparticles begins by mixing a metal–salt solution with a sample of plant extract. During the synthesis of nanoparticles, biochemical reduction of the salt solution starts immediately and the change in colour of the reaction mixture indicates the formation of nanoparticles.

During synthesis, initially there is an activation period process in which metal ions are converted to zero-valent state from their mono or divalent oxidation states, so that the nucleation of such reduced metal atoms takes place. Furthermore, the process of nanoparticle synthesis is followed by the integration of smaller neighboring particles to form larger nanoparticles, which are thermodynamically stable, and, subsequently, the metal ions are reduced biologically.

In this way, growth progresses and nanoparticles aggregate to form a variety of shapes such as spheres, cubes, triangles, rods, wires, hexagons, and pentagons. In the final stage of the process, the ability of plant extract to stabilize the nanoparticle finally determines its stable morphology. Significantly, the quality, size, and morphology of the nanoparticles are influenced by properties of the plant extracts; mainly its concentration, reaction time, metal salt concen-tration, reaction solution pH, and temperature [3].

Applications:

1. Anti-microbial Activity: Various studies have been carried out to ameliorate antimicrobial functions because of the growing microbial resistance towards common antiseptic and antibiotics. According to in vitro antimicrobial studies, the metallic nanoparticles effectively obstruct several microbial species. The antimicrobial effectiveness of the metallic nanoparticles depends upon two important parameters like material employed for the synthesis of the nanoparticles and the particle size of the metal nanoparticle. Silver nanoparticles are the most admired inorganic nanoparticles, and they are utilized as efficient antimicrobial, antifungal, antiviral and anti-inflammatory agents. The antimicrobial potential of silver nanoparticles can be described in the following ways:

a) Denaturation of the bacterial outer membrane.

b) Generation of pits/gaps in the bacterial membrane leading to fragmentation of the cell membrane.

c) Interactions between silver nanoparticles and disulphide or sulfhydryl groups of enzymes which disrupt the metabolic processes and leads to death [9].

TABLE 2: GREEN SYNTHESIS OF METALLIC NPS FROM VARIOUS PLANT EXTRACTS

S. no.	Species	Nanoparticle	Size (nm)	Morphology	Applications	Reference
1	*Aloe barbadensis* Miller (Aloe vera)	Gold & silver	10-30	Spherical, triangular	Cancer hyperthermia	35
2	*Aloe barbadensis* Miller (Aloe vera)	Indium oxide	5-50	Spherical	Solar cells, gas sensors	36
3	*Acalypha indica*	silver	20-30	Spherical	Anti-bacterial activity	37
4	Apiinextracted from henna leaves	Silver & gold	39	Spherical, triangular	Cancer hyperthermia, IR-absorbing optic coating	38
5	*Avena sativa* (oat)	gold	5-20	Rod-shaped	-	39
6	*Azadirachta indica* (neem)	Gold, Silver & silver-gold alloys	5-35, 50-100	Spherical, triangular, hexagonal	Remediation of toxic metals	40
7	*Camellia sinensis* (black tea leaf extracts)	Gold & silver	20	Spherical, prism	Catalyst, sensors	41
8	*Brassica juncea* (mustard)	Silver	2-35	Spherical	-	42
9	*Cinnamomum camphora* (camphor tree)	Gold & silver	55-80	Triangular, spherical	-	43
10	*Carica papaya* (papaya)	Silver	60-80	Spherical	-	44
11	*Citrus limon* (lemon)	Silver	<50	Spherical	-	45
12	*Coriandrum sativum* (coriander)	Gold	6.75-57.91	Spherical, triangular, decahedral	Drug delivery, tissue/tumor imaging	46
13	*Cymbopogon flexuosus* (lemongrass)	Gold	200-500	Spherical, triangular	IR-absorbing optics coating	47
14	*Cycas sp.* (cycas)	Silver	2-6	Spherical	-	48
15	*Diospyros kaki* (persimmon)	Bimetallic gold & silver	50-500	Cubic	-	49
16	*Emblica officinalis* (Indian Gooseberry)	Gold & silver	10-20 & 15-15	-	-	50
17	*Eucalyptus citriodora* (neelagiri)	Silver	20	Spherical	Anti-bacterial activity	51
18	*Eucalyptus hybrid*	Silver	50-150	Crystalline,	-	52

				spherical		
19	*Garcinia mangostana* (mangosteen)	Silver	35	Spherical	Anti-microbial agent	53
20	*Gardenia jasminoides Ellis* (gardenia)	palladium	3-5	-	Nano catalyst	54
21	*Medicago sativa* (alfalfa)	Iron oxide	2-10	crystalline	Cancer hyperthermia, drug delivery	55
22	*Sedum alfredii* Hance	Zinc oxide	53.7	Hexagonal, wurtzite	Nano electronics	56
23	*Ocimum sanctum* (tulsi; leaf extract)	Gold & silver	30& 10-20	Crystalline, hexagonal, triangular & spherical	Bio-labeling & bio-sensors	57
24	*Pear fruit extract*	Gold	200-500	Triangular, hexagonal	Catalyst, bio-sensors	58
25	*Terminalia catappa* (almond)	Gold	10-35	Spherical	Biomedical field	59

2. Catalytic Activity: Metal nanoparticles play a notable role in catalysis application. Specifically, metal nanoparticles with high surface area and more active sites promote faster reactions and increase product yield. These particles can be broadly divided into two main groups: noble-metal (Au, Pt, Ag, etc.) - supported metal nanoparticles and non-noble-metal (Fe, Cu, Ni, Co, *etc.*)-based nanoparticles **Table 3**.

TABLE 3: VARIOUS METAL NANOPARTICLES SYNTHESIZED AND THEIR CATALYTIC PROPERTIES [60-88]

S. no.	Metal Nanoparticles	Catalysts
1	Molybdenum–Bismuth Bimetallic Chalcogenide Nanoparticles	CO_2 to Methanol
2	Platinum–Antimony Tin Oxide Nanoparticles	Cathode catalysis for direct methanol fuel cells via an oxygen reduction reaction (ORR)
3	Cobalt Oxide Nanocrystals	Cobalt Oxide Nanocrystals with CoO nanocrystals coupled with carbon nanotubes as catalysts for chlor–alkali electrolysis systems
4	Iron Oxide Magnetic Nanoparticles	Catalytic oxidation of phenolic and aniline chemical compounds (Fe_3O_4)
5	Zirconia Nanoparticles	Catalysts for sol–gel synthesis, aqueous precipitation, thermal decomposition, and hydrothermal synthesis
6	Tin Oxide Nanoparticles	Catalysts for the reduction and photo degradation of organic compounds
7	Silver Nano flakes	Silver Nano flakes on molybdenum sulfide (MoS_2) films for the catalytic oxidation of tryptophan
8	Tungsten Oxide Nanoparticles	Hetero-nanostructured photo electrodes synthesized via the atomic layer decomposition of tungsten oxide (WO_3) combined with an oxygen evolving catalyst
9	Cuprous Oxide Nanoparticles	Cuprous oxide nanoparticles on reduced graphene oxide (RGO) for usage as an efficient electro catalyst in ORR
10	Titanium Dioxide Nanoparticles	Carbon modified titanium dioxide (TiO_2) can be used in daylight photo catalysis. TiO_2 nanoparticles and photo catalytic performance measured under a medium-pressure mercury UV lamp.
11	Iridium Oxide Nanoparticles	Ligand-free iridium oxide nanoparticles for high electro catalytic activity. Reusable catalyst in 1-n-butyl-3-methylimidazolium hexafluorophosphate room-temperature ionic liquid for the biphasic hydrogenation of olefins under mild reaction conditions.
12	Palladium Nanoparticles	Catalytic formic acid oxidation can take place through the oleylamine-mediated synthesis of palladium nanoparticles
13	Gold Nanoparticles	Gold nanoparticles help to create an active catalyst for the reduction of nitroarenes in an aqueous medium when placed on top of nanocrystalline magnesium oxide. Catalytic CO oxidation can occur under the presence of gold nanoparticles

14	Elemental Sulfur Nanoparticles	Catalysis occurred when elemental sulfur nanoparticles were placed on chromium (VI) with a sulfide reaction
15	Silica Titanium Oxide Nanoparticles	Exhibit catalytic properties that can be tested for the oxidation of saturated and unsaturated hydrocarbons
16	Silica Vanadium Oxide Nanoparticles	Exhibit catalytic properties that can be tested for the oxidation of saturated and unsaturated hydrocarbons
17	Dendrimer-Encapsulated Metal Nanoparticles	Dendrimer can be used to control the placement and other properties of metal nanoparticles for their usage as catalysts
18	Imidazolium Metal Nanoparticles	Metal nanoparticles immersed in imidazolium ionic liquids exhibit unique catalytic properties
19	Zinc Oxide Nanoparticles	Semiconducting zinc oxide nanowires made from nanoparticles can be tested for photoluminescence properties through catalytic growth
20	Silver Nanoparticles	Silver nanoparticles can be used as chemically stable nanoparticles with no environmentally harmful effects on microbes under anaerobic conditions
21	Magnesium Oxide Nanoparticles	EXAFS spectroscopy shows that magnesium oxide is a precursor of a type of mononuclear complex of gold that can catalyze ethane hydrogenation
22	Calcium Oxide Nanoparticles	Calcium oxide nanoparticles can be catalyzed with pyridines in an aqueous ethanol medium
23	Strontium-Doped Zinc Oxide Nanoparticles	Can be created with the sol–gel method, and tests showed successful photo catalytic activity of these nanoparticles when removing methylene blue (MB)
24	Titanium Carbide Nanoparticles	Such nanoparticles can support platinum catalysts for methanol electro oxidation in acidic mediums
25	Cerium Oxide Nanoparticles	These nanoparticles with their catalytic properties can be used for a variety of biomedical applications
26	Antimony–Vanadium Oxide Catalysts	Catalysts prepared are selective for acrylonitrile formation
27	Metal Nanoparticles at Mesoporous N-doped Carbons and Carbon Nitrides	Metal nanoparticles at Mesoporous N-doped carbons and carbon nitrides held in Mott–Schottky heterojunctions can function as efficient catalysts
28	Metal Nanoparticles	Catalytic properties of metal nanoparticles can be used in the synthesis of single-walled carbon nanotubes

3. Removal of Pollutant Dyes: Cationic and anionic dyes are a main class of organic pollutants used in various applications. Organic dyes play a very imperative role due to their gigantic demand in paper mills, textiles, plastic, leather, food, printing, and pharmaceutical industries. In textile industries, about 60% of dyes are consumed in the manufacturing process after which 15% of dyes are wasted and are discharged into the hydrosphere, they represent significant source of pollution. Dyes produce undesirable turbidity in the water, which will reduce sunlight penetration and leads to the resistance of photochemical synthesis and biological attacks to marine and aquatic life [9]. The need for hygienic and safe drinking water is increasing day by day. Considering this fact, the use of metal and metal oxide semiconductor nanoparticles for oxidizing toxic pollutants has become of great interest in recent material research fields.

4. Heavy Metal Ion Sensing: Heavy metals (like Ni, Cu, Fe, Cr, Zn, Co, Cd, Pb, Hg) are well known for being pollutants in air, soil and water. There are innumerable sources of heavy metal pollution such as mining waste, vehicle emissions, natural gas, paper, plastic, coal, and dye industries. Some metals (like lead, copper, cadmium, and mercury ions) show enhanced toxicity potential even at the traces of ppm levels. Therefore, identifying toxic metals in the biological and aquatic environment has become a vital need for proper remedial processes. Due to the tunable size and distance-dependent optical properties of metallic nanoparticles, they have been preferably employed for the detection of heavy metal ions in polluted water systems [89-90]. The advantages of using metal nanoparticles as colorimetric sensors for heavy metal ions in environmental systems/samples include simplicity, cost, effectiveness and high sensitivity at sub-ppm levels.

CONCLUSION: Green synthesis of metal and metal oxide nanoparticles has been a highly attractive research area over the last decade. The use of nanoparticles in the medical, food, pharmaceutical and agricultural industries has garnered a great deal of interest, with a focus on development of more convenient methods using green biotechnology tools for production of eco-friendly, non-toxic, and environmentally benign nanoparticles. Numerous kinds of natural resources like plants, bacteria, fungi, yeast and plant extracts have been employed in the synthesis of metallic nanoparticles. Among them, plant extract has been proven to possess high efficiency as stabilizing agent and reducing agent for the synthesis of controlled materials.

ACKNOWLEDGEMENT: Authors are thankful for the management, St. Pauls College of Pharmacy for their constant encouragement and moral support for writing this review.

CONFLICTS OF INTEREST: The authors declare no conflict of interest.

REFERENCE:

1. Mohanpuria P, Rana NK and Yadav SK: Biosynthesis of nanoparticles: technological concepts and future applications. Journal of Nanoparticle Research 2008; 10: 507-17.
2. Tiwari DK, Behari J and Sen P: Time and dose-dependent antimicrobial potential of Ag nanoparticles synthesized by top- down approach. Current Science 2008; 95(5): 647–55.
3. Luechinger NA, Grass RN, Athanassiou EK and Stark WJ: Bottom-up fabrication of metal/metal nanocomposites from nanoparticles of immiscible metals. Chemistry of Materials 2010; 22(1): 155-60.
4. Parashar UK, Saxena PS and Srivastava A: Bioinspired syn- thesis of silver nanoparticles. Digest Journal of Nanomaterials and Biostructures 2009; 4(1): 159-66.
5. Daniel MC and Astruc D: Gold nanoparticles: assembly, supramolecular chemistry, quantum-size-related properties, and applications toward biology, catalysis, and nanotechnology. Chemical Reviews 2004; 104(1): 293-46.
6. Li X, Xu H, Chen ZS and Chen G: Biosynthesis of nanoparticles by microorganisms and their applications. Journal of Nanomaterials 2011; 16
7. Kharissova OV, Dias HVR, Kharisov BI, Perez BO and Perez VMJ: The greener synthesis of nanoparticles. Trends in Biotechnology 2013; 31(4): 240-48.
8. Alshammari A, Kalevaru VN and Martin A: Metal Nanoparticles as Emerging Green Catalysts 2016; http://dx.doi.org/10.5772/63314
9. Singh: J Nanobiotechnol 2018; 16: 84.
10. Sunkar S and Nachiyar CV: Biogenesis of antibacterial silver nanoparticles using the endophytic bacterium Bacillus cereus isolated from *Garcinia xanthochymus*. Asian Pacific Journal of Tropical Biomedicine 2012; 2: 953-59.
11. Shivaji S, Madhu S and Singh S: Extracellular synthesis of antibacterial silver nanoparticles using psychrophilic bacteria. Process Biochemistry 2011; 46: 1800-07.
12. Korbekandi H, Iravani S and Abbasi S: Optimization of biological synthesis of silver nanoparticles using *Lactobacillus casei* subsp. casei. Journal of Chemical Technology & Biotechnology 2012; 87: 932-37.
13. Ahmad N, Sharma S and Alam MK: Rapid synthesis of silver nanoparticles using dried medicinal plant of basil. Colloids Surf B Biointerfaces 2010; 81: 81–86.
14. Fu M, Li Q and Sun D: Rapid preparation process of silver nanoparticles by bio reduction and their characterizations. Chinese Journal of Chemical Engineering 2006; 14: 114-17.
15. Lengke MF, Fleet ME and Southam G: Morphology of gold nanoparticles synthesized by filamentous cyano-bacteria from gold(I)− thiosulfate and gold(III)− chloride complexes. Langmuir 2006; 22(6): 2780-87.
16. Southam G and Beveridge TJ: The in vitro formation of placer gold by bacteria. Geochimica Cosmochim Acta 1994; 58: 4527-30.
17. Wen L, Lin Z and Gu P: Extracellular biosynthesis of monodispersed gold nanoparticles by a SAM capping route. Journal of Nanoparticle Research 2009; 11:279–288.
18. Konishi Y, Tsukiyama T and Tachimi T: Microbial deposition of gold nanoparticles by the metal‐reducing bacterium Shewanella algae. Electrochim Acta 2007; 53: 186-92.
19. Du L, Jiang H, Liu X and Wang E: Biosynthesis of gold nanoparticles assisted by Escherichia coli DH5α and its application on direct electrochemistry of hemoglobin. Electrochemistry Communications 2007; 9: 1165-70.
20. Deplanche K and Macaskie LE: Biorecovery of gold by *Escherichia coli* and *Desulfovvibrio desulfuricans*. Biotechnology Bioengineering 2008; 99: 1055-64.
21. He S, Guo Z and Zhang Y: Biosynthesis of gold nanoparticles using the bacteria Rhodopseudomonas capsulate. Mater Lett 2007; 61: 3984-87.
22. Philipse AP and Maas D: Magnetic colloids from magneto tactic bacteria: chain formation and colloidal stability. Langmuir 2002; 18: 9977-84.
23. Mann S, Frankel RB and Blakemore RP: Structure, morphology and crystal growth of bacterial magnetite. Nature 1984; 310: 405-07.
24. Marshall MJ, Beliaev AS, Dohnalkova AC et al: c‐Type cytochrome‐ dependent formation of U(IV) nanoparticles by Shewanella oneidensis. PLOS Biology 2006; 4:1324–1333.
25. Holmes JD, Smith PR and Richardson DJ: Energy‐dispersive X‐ray analysis of the extracellular cadmium sulfide crystallites of Klebsiella aerogenes. Arch Microbiology 1995; 163: 143-47.
26. Chen YL, Tuan HY and Tien CW: Augmented biosynthesis of cadmium sulfide nanoparticles by genetically engineered *Escherichia coli*. Biotechnology Progress 2009; 25: 1260-66.
27. Ravindra BK and Rajasab AH: A comparative study on biosynthesis of silver nanoparticles using four different fungal species. International Journal of Pharmacy and Pharmaceutical Sciences 2014; 6(1): 372-76.
28. Gade AK, Bonde P and Ingle AP: Exploitation of Aspergillus niger for synthesis of silver nanoparticles. Journal of Biobased Materials and Bioenergy 2008; 2: 243-47.
29. Gericke M and Pinches A: Microbial production of gold nanoparticles. Gold Bull 2006; 39: 22-28.
30. Raliya R and Tarafdar JC: Biosynthesis and characterization of zinc, magnesium and titanium nanoparticles: an eco‐friendly approach. International Nano Letters 2014; 4: 93.
31. Raliya R, Biswas P and Tarafdar JC: TiO2 nanoparticle biosynthesis and its physiological effect on mung bean (*Vigna radiata* L.). Biotechnology Report 2015; 5: 22–6.

32. Kowshik M, Vogel W and Urban J: Microbial synthesis of semiconductor PbS nanocrystallites. Adv Mater 2002; 14: 815-18.
33. Mourato A, Gadanho M, Lino AR and Tenreiro R: Biosynthesis of crystalline silver and gold nanoparticles by extremophilic yeasts. Bioinorganic Chemistry and Applications 2011; 1: 1.
34. Verma A, Gautam SP, Bansal KK, N Prabhakar and Rosenholm JM: Green Nanotechnology: Advancement in Phytoformulation Research; Medicines 2019, 6: 39.
35. Chandran SP, Chaudhary M, Pasricha R, Ahmad A and Sastry M: Synthesis of gold nanotriangles and silver nanoparticles using Aloe vera plant extract. Biotechnology Progress 2006; 22(2): 577-83.
36. Maensiri S, Laokul P and Klinkaewnarong J: Indium oxide (in 2O3) nanoparticles using *Aloe vera* plant extract: synthesis and optical properties. Journal of Optoelectronics and Advanced Materials 2008; 10: 161-65.
37. Krishnaraj C, Jagan EG and Rajasekar S: Synthesis of silver nanoparticles using *Acalypha indica* leaf extracts and its antibacterial activity against water borne pathogens. Colloids Surf B Biointerfaces 2010; 1: 1.
38. Kasthuri J, Veerapandian S and Rajendiran N: Biological synthesis of silver and gold nanoparticles using apiin as reducing agent. Colloids Surf B Biointerfaces 2009; 68: 55-60.
39. Armendariz V, Herrera I and Peralta VJR: Size controlled gold nanoparticle formation by Avena sativa biomass: use of plants in Nano biotechnology. Journal of Nanoparticle Research 2004; 6: 377-82.
40. Shankar SS, Rai A, Ahmad A and Sastry M: Rapid synthesis of Au, Ag, and bimetallic Au core Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. Journal Colloid Interface Science 2004; 1: 1.
41. Mondal S, Roy N and Laskar RA: Biogenic synthesis of Ag, Au and bimetallic Au/Ag alloy nanoparticles using aqueous extract of mahogani (*Swietenia mahogani* JACQ.) leaves. Colloids Surfaces B Biointer‐ faces 2011; 82: 497-04.
42. Haverkamp RG and Marshall AT: The mechanism of metal nanoparticle formation in plants: limits on accumulation. Journal of Nanoparticle Research 2009; 11: 1453-63.
43. Huang Q, Li D and Sun Y: Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnamomum camphora* leaf. Nanotechnology 2007; 1: 1.
44. Mude N, Ingle A, Gade A and Rai M: Synthesis of silver nanoparticles using callus extract of *Carica papaya*—a first report. Journal of Plant Biochemistry Biotechnology 2009; 18: 83-86.
45. Prathna TC, Chandrasekaran N, Raichur AM and Mukherjee A: Biomimetic synthesis of silver nanoparticles by *Citrus limon* (lemon) aqueous extract and theoretical prediction of particle size. Colloids Surf B Biointerfaces 2011; 82: 152-59.
46. Narayanan KB and Sakthivel N: Coriander leaf mediated biosynthesis of gold nanoparticles. Mater Lett 2008; 62: 4588-90.
47. Shankar SS, Rai A, Ahmad A and Sastry M: Controlling the optical properties of lemongrass extract synthesized gold nanotriangles and potential application in infrared‐absorbing optical coatings. Chemistry of Materials 2005; 17: 566-72.
48. Jha AK and Prasad K: Green synthesis of silver nanoparticles using cycas leaf. International Journal of Green Nanotechno Physics and Chemistry 2010; 1: 110-7.
49. Song JY and Kim BS: Biological synthesis of bimetallic Au/Ag nanoparticles using Persimmon (*Diospyros kaki*) leaf extract. Korean Journal of Chemical Engineering 2008; 25: 808-11.
50. Ankamwar B, Chaudhary M and Sastry M: Gold nanotriangles biologically synthesized using tamarind leaf extract and potential application in vapor sensing. Synthesis and Reactivity in Inorganic Metal-Org and Nano‐Metal Chemistry 2005; 35: 19-26.
51. Ravindra S, Murali MY, Reddy NN and Raju MK: Fabrication of antibacterial cotton fibers loaded with silver nanoparticles *via* “green approach”. Colloids Surf A Physicochem and Engineering Aspects 2010; 367: 31- 40.
52. Dubey M, Bhadauria S and Kushwah BS: Green synthesis of nanosilver particles from extract of *Eucalyptus hybrida* (Safeda) leaf. Digest Journal of Nanomaterials and Biostructures 2009; 4: 537-43.
53. Veerasamy R, Xin TZ and Gunasagaran S: Biosynthesis of silver nano- particles using mangosteen leaf extract and evaluation of their anti-microbial activities. Journal of Saudi Chemical Society 2011; 15(2): 113-20.
54. Jia L, Zhang Q, Li Q and Song H: The biosynthesis of palladium nanoparticles by antioxidants in Gardenia jasminoides Ellis: long lifetime nanocatalysts for p-nitrotoluene hydrogenation. Nanotechnology 2009; 20(38): 385601.
55. Herrera-Becerra R, Zorrilla C, Rius JL and Ascencio JA: Electron microscopy characterization of biosynthesized iron oxide nanoparticles. Applied Physics A Materials Science and Processing 2008; 91:241–246.
56. Qu J, Luo C and Hou J: Synthesis of ZnO nanoparticles from Zn‐hyper‐ accumulator (*Sedum alfredii* Hance) plants. IET Micro and Nano Letters 2011; 6:174–176.
57. Philip D and Unni C: Extracellular biosynthesis of gold and silver nanoparticles using Krishna tulsi (*Ocimum sanctum*) leaf. Physica E Low-Dimensional Systems and Nanostructures 2011; 43: 1318-22.
58. Ghodake GS, Deshpande NG, Lee YP and Jin ES: Pear fruit extract‐assisted room‐temperature biosynthesis of gold nanoplates. Colloids Surf B Biointerfaces 2010; 75: 584-89.
59. Ankamwar B: Biosynthesis of gold nanoparticles (green‐gold) using leaf extract of *Terminalia catappa*. Journal of Chemistry 2010; 7: 1334-39.
60. Sun X, Zhu Q, Kang X, Liu H, Qian Q, Zhang Z and Han B: Molybdenum-bismuth bimetallic chalcogenide nano sheets for highly efficient electro catalytic reduction of carbon dioxide to methanol. Angewandte Chemie International Edition 2016; 55: 6771-75.
61. You DJ, Kwon K, Pak C and Chang H: Platinum-Antimony Tin Oxide Nanoparticle as Cathode Catalyst for Direct Methanol Fuel Cell. Catalysis Today 2009; 146: 15–19.
62. Liang Y, Wang H, Diao P, Chang W, Hong G, Li Y, Gong M, Xie L, Zhou J and Wang J: Oxygen Reduction Electrocatalyst Based on Strongly Coupled Cobalt Oxide Nanocrystals and Carbon Nanotubes. Journal of American Chemical Society 2012; 134: 15849-57.
63. Zhang S, Zhao X, Niu H, Shi Y, Cai Y and Jiang G: Super paramagnetic Fe3O4 Nanoparticles as Catalysts for the Catalytic Oxidation of Phenolic and Aniline Compounds. Journal of Hazardous Materials 2009; 167: 560-66.
64. Bansal V, Rautaray D, Ahmad A and Sastry M: Biosynthesis of Zirconia Nanoparticles Using the Fungus *Fusarium oxysporum*. Journal of Materials Chemistry 2004; 14: 3303.

65. Seabra AB and Durán N: Nanotoxicology of Metal Oxide Nanoparticles. Metals 2015; 5: 934-75.
66. Xia X, Zheng Z, Zhang Y, Zhao X and Wang C: Synthesis of Ag-MoS2/chitosan nanocomposites and its application for catalytic oxidation of tryptophan. Sensors and Actuators B Chemical 2014; 192: 42–50.
67. Liu R, Lin Y, Chou LY, Sheehan SW, He W, Zhang F, Hou HJM and Wang D: Water splitting by tungsten oxide prepared by atomic layer deposition and decorated with an oxygen-evolving catalyst. Angewandte Chemie International Edition 2011; 50: 499-02.
68. Yan XY, Tong XL, Zhang YF, Han XD, Wang YY, Jin GQ, Qin Y and Guo XY: Cuprous oxide nanoparticles dispersed on reduced graphene oxide as an efficient electrocatalyst for oxygen reduction reaction. Chem. Journal of Communication 2012; 48: 1892-94.
69. Sakthivel S and Kisch H: Daylight photocatalysis by carbon-modified titanium dioxide. Angewandte Chemie International Edition 2003; 42: 4908-11.
70. Pipelzadeh E, Babaluo AA, Haghighi M, Tavakoli A, Derakhshan MV and Behnami AK: Silver Doping on TiO2 nanoparticles using a sacrificial acid and its photocatalytic performance under medium pressure mercury UV lamp. Chemical Engineering Journal 2009; 155: 660-65.
71. Zhao Y, Hernandez-Pagan EA, Vargas-Barbosa NM, Dysart JL and Mallouk TE: A high yield synthesis of ligand-free iridium oxide nanoparticles with high electrocatalytic activity. Journal of Physics Chemistry Letters 2011; 2: 402-06.
72. Dupont J, Fonseca GS, Umpierre AP, Fichtner PFP and Teixeira SR: Transition-metal nanoparticles in imidazolium ionic liquids: recycable catalysts for biphasic hydrogenation reactions. JACS 2002; 124: 4228-29.
73. Mazumder V and Sun S: Oleylamine-Mediated Synthesis of Pd Nanoparticles for Catalytic Formic Acid Oxidation. Journal of American Chemi Society 2009; 131: 4588-89.
74. Layek K, Kantam ML, Shirai M, Nishio-Hamane D, Sasaki T and Maheswaran, H: Gold nanoparticles stabilized on nanocrystalline magnesium oxide as an active catalyst for reduction of nitroarenes in aqueous medium at room Temperature. Green Chemistry 2012; 14: 3164-74.
75. Lopez N and Norskov JK: Catalytic CO oxidation by a gold nanoparticle: a density functional study. Journal of American Chemical Society 2002; 124: 11262-63.
76. Lan Y, Deng B, Kim C, Thornton EC and Xu H: Catalysis of Elemental Sulfur Nanoparticles on Chromium(VI) Reduction by Sulfide under Anaerobic Conditions. Environ. Science Technology 2005; 39: 2087-94.
77. Mendez MS, Henriquez Y, Dominguez O, DOrnelas L and Krentzien H: Catalytic properties of silica supported titanium, vanadium and niobium oxide nanoparticles towards the oxidation of saturated and unsaturated hydrocarbons. J of Mole Catal A Chem 2006; 252: 226-34.
78. Migowski P and Dupont J: Catalytic Applications of Metal Nanoparticles in Imidazolium Ionic Liquids. Chemistry- A European Journal 2007; 13: 32–39.
79. Wang YW, Zhang LD, Wang GZ, Peng XS, Chu ZQ and Liang CH: Catalytic growth of semiconducting zinc oxide nanowires and their photoluminescence Properties. Journal of Crystal Growth 2002; 234: 171-75.
80. Yang Y, Zhang C and Hu Z: Impact of metallic and metal oxide nanoparticles on wastewater treatment and anaerobic digestion. Environmental Science Process 2013; 15: 39–48.
81. Guzman J and Gates BC: Structure and reactivity of a mononuclear gold-complex catalyst supported on magnesium oxide. Angewandte Chemie International Edition 2003; 42: 690-93.
82. Safaei GJ, Ghasemzadeh MA and Mehrabi M: Calcium Oxide Nanoparticles Catalyzed One-Step Multicomponent Synthesis of Highly Substituted Pyridines in Aqueous Ethanol Media. Iranian Journal of Science and Technology 2013; 20: 549-54.
83. Yousefi R, Jamali SF, Cheraghizade M, Khosravi GS, Saaedi A, Huang NM, Basirun WJ and Azarang M: Enhanced visible-light photocatalytic activity of strontium-doped zinc oxide nanoparticles. Materials Science Semiconductor Processing 2013; 32: 152-59.
84. Ou Y, Cui X, Zhang X and Jiang Z: Titanium Carbide Nanoparticles Supported Pt Catalysts for Methanol Electrooxidation in Acidic Media. Journal of Power Sources 2010; 195:1365–1369.
85. Walkey C, Das S, Seal S, Erlichman J, Heckman K, Ghibelli L, Traversa E, McGinnis JF and Self WT: Catalytic properties and biomedical applications of cerium oxide nanoparticles. Enviro Science Nano 2015; 2: 33–53.
86. Nilsson R, Lindblad T and Anderson A: Ammoxidation of propene over antimony-vanadium-oxide catalysts. Catalysis Letters 1994; 29: 409-20.
87. Li XH and Antonietti M: Metal nanoparticles at mesoporous n-doped carbons and carbon nitrides: functional mott–schottky heterojunctions for catalysis. Chemical Society Reviews 2013; 42: 6593.
88. Moisala A, Nasibulin AG and Kauppinen EI: The role of metal nanoparticles in the catalytic production of single-walled carbon nanotubes—a review. Journal of Physics Condensed Matter 2003; 15:S3011–S3035.
89. Annadhasan M, Muthukumarasamyvel T, Sankar Babu VR and Rajendiran N: Green synthesized silver and gold nanoparticles for colorimetric detection of Hg^{2+}, Pb^{2+} and Mn^{2+} in aqueous medium. ACS Sustain Chemical Engineering 2014; 2: 887-96.
90. Maiti S, Gadadhar B and Laha JK: Detection of heavy metals (Cu^{+2}, Hg^{+2}) by biosynthesized silver nanoparticles. Applied Nanoscience 2016; 6: 529–38

How to cite this article:
Kumari H and Mandava K: Green nanotechnology and nanoparticles: an eco-friendly approach. Int J Pharm Sci & Res 2021; 12(11): 5624-33. doi: 10.13040/IJPSR.0975-8232.12(11).5624-33.