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Natural Sources and Bio-assisted Synthesis of Nano Particles: A Short Review

Kazi Sabnam Banu

Department of Chemistry, Netaji Nagar Day College, Kolkata, West Bengal, India

Corresponding Author's Email: kazisabanam80@gmail.com

Abstract:

Nanoamaterials (NMs) are unique chemical compounds characterized by exceptionally high surface areas and external dimensions in the nanoscale range, specifically between 1 and 100 nm. There are different types of nanomaterials, such as inorganic-based nanomaterials, organic-framed NMs, carbon-framed NMs, and composite-framed NMs. The extensive study of nanomaterials spans a vast area of research, including nanotechnology, nanoengineering, and nanoscience. Nanomaterials play a crucial role in various scientific fields, influencing disciplines such as physics, chemistry, microbiology, materials science, biotechnology, biochemistry, and microelectronics. Therefore, there is an urgent need for researchers to focus on synthesizing nanomaterials. Numerous methods for synthesizing nanomaterials have been established, utilizing various substances such as metals, semiconductors, ceramic-based materials, metal oxides, and polymeric materials. The specific synthetic procedures and the origin of the materials are key factors in determining the physicochemical, structural, and morphological characteristics of NMs. Among these methods, biosynthesis—also known as green synthesis or bio-assisted methods—stands out as the most eco-friendly, less toxic, and cost-effective approach. This review aims to provide an overview of the synthesis of nanomaterials using bio-assisted methods. It discusses different types of bio-assisted methods, including (i) living organisms-assisted biosynthesis, (ii) biomolecules (as templates)-assisted biosynthesis, and (iii) plant extracts-assisted biosynthesis of NMs.

Keywords: *Biological Assisted Method; Biomolecules; Enzyme; Green Method; Microorganism; Plant Phytochemicals*

Introduction:

Nanotechnology emerged in the 1980s (Bayda *et al.,* 2019). At the beginning of the 2000s, the commercial and transformative applications of nanomaterials were projected by nanotechnology (Roco, 2011). Today, research in science and technology is highly dependent on nanomaterials (Kostoff, Koytcheff & Lau, 2007). Thus, nanotechnology and nanoscience encompass a broad range of research areas. According to the National Nanotechnology Initiative in the US, nanotechnology involves handling matter with particles sized between 1 and 100 nanometers, with at least one dimension within this range. With the significant reduction of particle size to the nanoscale, statistical mechanical effects and quantum mechanical effects become pronounced, greatly altering the electronic properties of solids. This impacts a wide range of scientific and technological fields (Anthon, Seth & Thakral, 2017). The term "nano," which means "dwarf," comes from the Latin word "nanus" or its ancient Greek etymon "nanos" (Boholm, 2016). Nanomaterials have been utilized in technological development due to their extraordinary properties and enhanced performance compared to their bulk counterparts. Nanotechnology is a multifaceted field, and the application of nanomaterials spans almost all branches of science, including physical science, chemical science, materials science, solid-state science, and biological science (Khan, Saeed & Khan, 2019). Due to their unique features and characteristics, nanomaterials have extensive industrial applications. These include the biomedical industry, food processing industry, biotechnology, environmental remediation, construction, agriculture, communication, defense, security, renewable energy, electronics, and energy storage. The unique nature of nanomaterials is attributed to their excess surface energy, spatial confinement, and higher degree of perfection. The high surface area-to-volume ratio, exceptional penetrability, and quantization of electronic states in nanomaterials make them fundamentally different from their bulk counterparts. Nanoscience focuses on the arrangement of atoms at the nanoscale, while nanotechnology deals with the production and application of various nanomaterials across different fields. Various types of nanomaterials are available, differing in shape and size. Table 1 presents nanoparticles of various shapes. Based on dimensionality (with dimensions less than 100 nm), nanomaterials can be classified as zero-dimensional (e.g., nanoparticles), one-dimensional (e.g., nanorods and nanotubes), two-dimensional (e.g., nanofilms and nanolayers), and three-dimensional (e.g., hollow spheres and quantum dots formed by interacting with two or more nanoparticles).

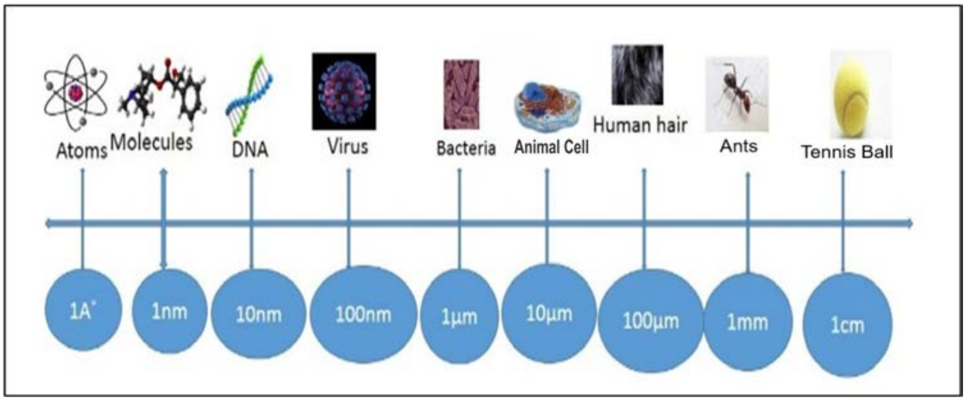

Figure 1: Various Sizes of Nano Materials *(Ealia & Saravanakumar, 2019 and Eaton et al., 2017)*

Nanomaterials are also categorized by morphology, composition, properties, and size into metal nanomaterials, ceramic nanomaterials, lipid-based nanomaterials, polymeric nanomaterials, semiconductor-based nanomaterials, and carbon-based nanomaterials.

Additionally, nanomaterials can be classified as single-phase solids, multi-phase solids, or multilayer solids depending on their phase composition. Due to their vast applications and significant impact on human well-being, researchers are dedicating substantial efforts to the synthesis of novel nanomaterials. Among the various synthesis methods, the most environmentally friendly is the green method, or biological synthesis. This method is non-toxic and environmentally benign, using microbial enzymes or plant phytochemicals. Although substantial progress has been made, there remains considerable scope for further research in this field. Table 1 describes different NMs with various shapes and examples.

Table 1: *Shapes of Different Kinds of Nanoparticles*

Types	Shapes	Materials
0D (amorphous or Crystalline)	Sphere	Carbon, Fullerene
1D (needle like)	Nanorod, nanowire, nanotube	Carbon, Metal oxide, Metal
polygonal of two dimensionality	Square, Triangle, disc, pentagon, hexagon, nano ring	Au, Ag, Pt, Pd, PLA, triacrylate, resin, poly(pyrrole), PEG-diacrylate
polyhedral of three dimensionality	Tetrahedron, cube, icosahedron, decahedron, octahedron, hollow nanocage, bundles of nanowires, nanotubes and multinanolayers.	Au, Ag, Pt, Pd, PLA, poly(pyrrole), PEG-diacrylate
Branched	Monopod, bipod, tripod, tetrapod, octopod, star shaped	Au, CdS, CdSe, CdTe, ZnO, MnS.
Complex	Snowflake, cone, flower, tree, thorn, hemisphere, urchin, worm, filamentous particle, biconcave discoid, dendrite, necklace, chain	Gold, Silver, Cu, Co, Platinum, Iron, Ruthenium, alloys and oxides of Si, metals, Si

Source: Ealia & Saravanakumar, 2019 and Eaton et al., 2017

Discussion

Different kinds of naturally occurring nanoparticles

Despite the various processes that can improve the synthesis of NMs, nature itself is an eminent nanotechnologist, providing a variety of naturally occurring nanoparticles through various processes, including volcanic eruptions, surface water, marine water, iceberg sedimentation, umber, ores, mineral wells, and particulate matter. For example, silicon dioxide (SiO_2) nanoparticles from volcanic eruptions are well documented. Iron oxide (Fe_3O_4) nanoparticles are found in iceberg sediments, and manganese oxide (MnO_2) nanoparticles are present in umber. Calcium carbonate ($CaCO_3$), silicates (SiO_2), and alumina (Al_2O_3) are just a few of the nanoparticles found in natural surface water. Additionally, silver, gold, carbon, and sulphur nanoparticles can be found in saltwater, mineral wells, ores, and particulate matter. Metal titanates ($FeTiO_3$) are obtained from ilmenite sand, alumina (Al_2O_3) nanoparticles from bauxite, TiO_2 nanoparticles from natural ilmenite, and iron oxide nanoparticles (Fe_3O_4) from ironstone. Carbon can be easily collected from ordinary organic biomass in the form of waste, whereas the sources of the previously described nanoparticles are often specialized inorganic wastes, minerals, and sediments. Researchers are continually seeking environmentally friendly alternatives to synthetic polymers. Chitin, a natural polymer found in crustacean shells, insect exoskeletons, and fungal cell walls, provides structural support. Like cellulose, chitin consists of nanoscale structural elements that can be extracted as nanofibers and nanocrystals using various top-down methods aimed at breaking down the natural structure. However, regarding the material properties of nanoscale components, chitin has largely been overtaken by cellulose. As the most abundant natural polymer on the planet, cellulose has received significant attention as a carbon source. It is biodegradable and can be derived from renewable resources such as wood, cotton, bamboo, and microorganisms. Cellulose nanofibrils (CNFs) and cellulose nanocrystals (CNCs) can be obtained from various cellulose materials like spruce dissolving pulp (SDP), bleached eucalyptus pulp (BEP), and cotton-based qualitative filter paper (QFP). Table 2 lists the names and different sources of nanoparticles. Table 2 describes different sources of naturally occurring NMs

Table 2: *Names and Sources of Different types of Natural NMs*

Name of some NMs	Natural Sources
Silica (SiO_2) nanoparticles	Volcanic eruptions
Iron oxide (Fe_3O_4) nanoparticles	Iceberg sediments
Manganese oxide (MnO_2) nanoparticles	Umber
Calcium carbonate ($CaCO_3$), Silicates (SiO_2)	Natural surface water
Silver (Ag), Gold (Au), Carbon (C), and Sulphur (S) nanoparticles	Saltwater, Mineral wells, Ore deposits, and particulate
Metal Titanates ($FeTiO_3$); TiO_2 nanoparticles	Ilmenite sand
Alumina (Al_2O_3) nanoparticles	Bauxite; Natural surface water
Iron oxide nanoparticles (Fe_3O_4)	Ironstone
Carbon	Organic biomass
Chitin	Crustacean shells, Insect exoskeletons, and Fungal cell walls
Cellulose Nano fibrils (CNFs) and Cellulose Nano crystals (CNCs)	Spruce dissolving pulp (SDP), Bleached eucalyptus pulp (BEP), and Cotton based qualitative filter paper (QFP)

Source: Frattini et al., 2021; Jin & Spontak, 2023; Malakar et al., 2021

Incidental Nanomaterials by nature

From the anthropogenic activities incidental nano particles (NPs) are produced. This is the unintended creation of NPs. The common sources of NPs generated incidentally are automobile exhaust, mining waste, industrial waste, corrosion processes, combustion from domestic work, heating of solid fuel, smelting, welding gases and cooking.

Fullerene, an incidental nano particle, is generated from burning candles and biomass. Figure 2 represents some sources of Incidental Nanomaterials.

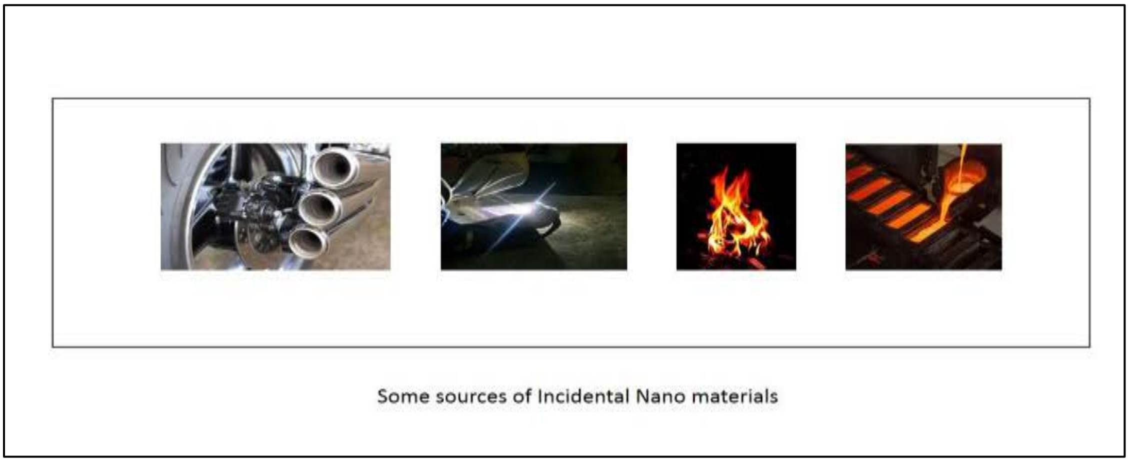

Figure 2: Incidental Nanomaterials ***(****Frattini et al., 2021; Jin & Spontak, 2023; Malakar et al., 2021****)***

These types of accidental nanoparticles are carbon-based, such as carbon soot particles from combustion processes, metal-based nanoparticles from metal oxides, or plastic-based nanoparticles (nanoplastics) from the degradation of plastic materials. In our daily lives, nanoparticles can be found in various places and are absorbed in very small amounts through daily activities. Nanoparticles may be present in health products, household items like utensils, and furniture like drawers. Despite their widespread presence, many are unaware of their existence as they cannot be properly detected without specific conditions and specialized equipment.

It is essential to pay proper attention to the life cycles of both natural and synthetic nanoparticles. For health implications, we must protect our environment from the biogeochemical impacts of nanoparticles on various natural resources. The widespread presence of nanomaterials in drinking water, air, and agricultural soils is alarming. Understanding the potential toxicity of nanoparticles in the environment is crucial for predicting the long-term effects, including impacts on ecosystems and human health. The toxicological implications of the occurrence and exposure of natural, accidental, and artificial nanoparticles remain unclear.

Green synthesis of nano materials

Biological synthesis of nanomaterials, also known as the green method, utilizes microbial enzymes or plant phytochemicals. Enzymes extracted from microorganisms such as bacteria, fungi, algae, and phytochemicals from plant tissues like leaves, stems, roots, and flowers act as reducing agents, capping agents, and stabilizing agents for nanomaterials. Since no harmful chemicals are used in biological synthesis, the produced nanomaterials are eco-friendly and economically viable, as plants and microbes are readily available. This method offers more advantages compared to physical and chemical synthesis methods used for nanomaterials. Moreover, modifying the size, shape, and properties of nanomaterials is easier through adjustments in the cultural medium of microorganisms, such as temperature, pH, and nutrient media. Various biosynthetic nanomaterials are illustrated in Figure 3.

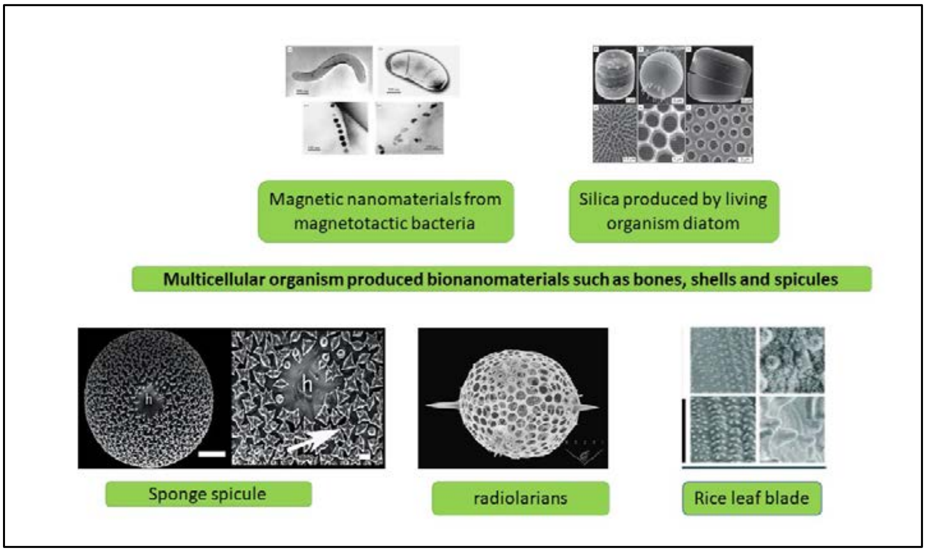

Figure 3: The Different Biosynthetic Nanomaterials (*Kuppusamy et al., 2016)*

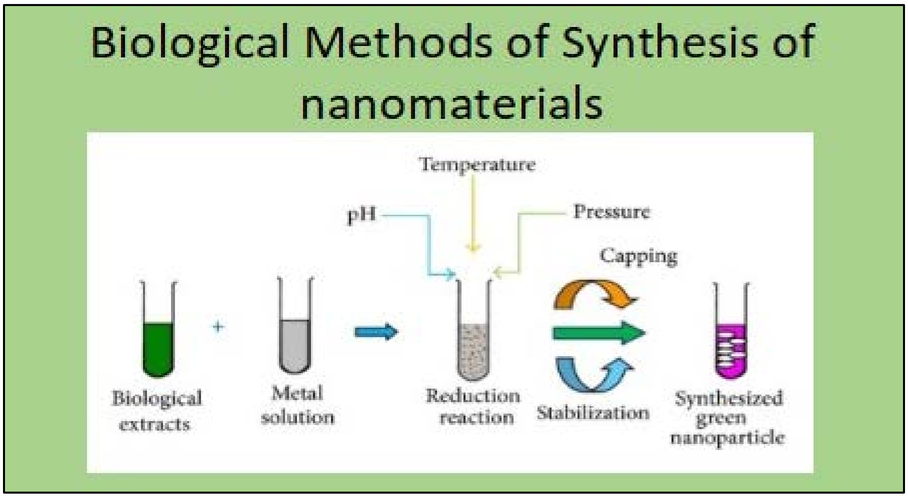

Figure 4: Schematic Representation of Synthesis Nano Materials (*Iravani, 2011*)

Biological methods can be classified into three categories:(i) Biological synthesis of nanomaterials using microorganisms (ii) Biological synthesis of nanomaterials using biomolecules as the templates (iii) Biological synthesis of nanomaterials using plant extracts. Figure 4 represents the schematic representation of biological synthesis of nano materials.

(i) Biogenic synthesis using microorganisms:

Microorganisms capture target metal ions from their environment either extracellularly or intracellularly and then convert these ions into elemental states through enzymes generated by cellular activities. In the intracellular method, metal ions are transported into microbial cells to form nanoparticles (NPs) in the presence of enzymes. Extracellular synthesis of NPs involves trapping metal ions on the surface of cells and reducing them in the presence of enzymes (Zhang *et al.,* 2011). Various anionic functional groups present in bacteria, proteins, enzymes, and reducing sugars in bacterial biomass aid in reducing interacting metal ions. The fungal-assisted green method for NP synthesis offers several advantages, including higher bioaccumulation, economic viability, and scalability due to simple downstream processing and biomass handling. In intracellular processes, aqueous solutions of silver ions are reduced to silver nanoparticles (Ag NPs) upon exposure to fungal biomass. Microscopic investigations have revealed that NP synthesis occurs at the surface of fungal mycelia, mediated by enzymes secreted from

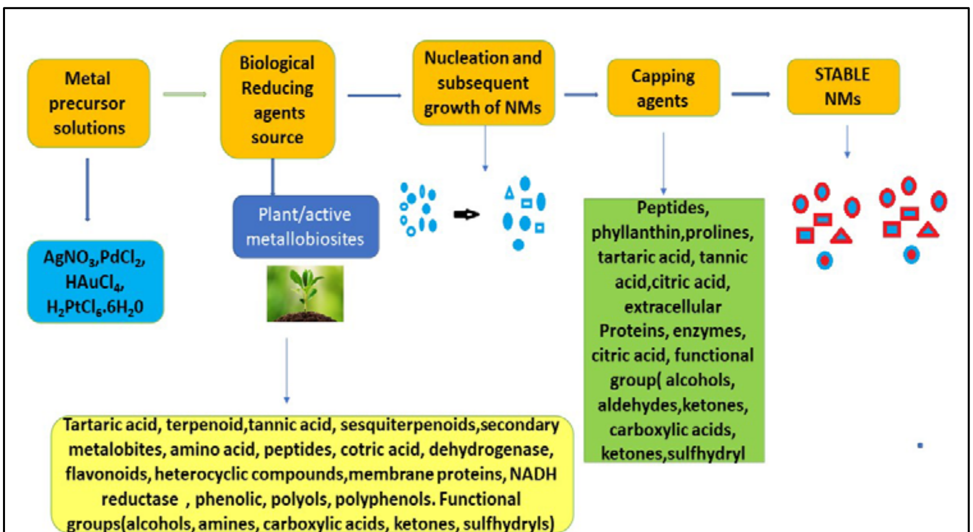

Figure 5: Phytosynthesis of NMs (*Akhtar, Panwar & Yun, 2013*)

the fungal cell wall. In some cases, NMs are produced extracellularly in fungi through NADH-dependent enzyme-catalyzed reactions. Yeasts, eukaryotic microorganisms, and actinomycetes are involved in the biogenic synthesis of NPs. Carboxyl, hydroxyl, and amide groups on the cell surface of yeast may play a role in synthesizing various NMs. Actinomycetes possess numerous enzymes capable of reducing gold salt to gold nanoparticles. For the synthesis of NMs of noble metals, metal oxides, or bimetallic alloys, plant extracts or plant biomass have been utilized. Biogenetic synthesis of NMs using plants is highly cost-effective, environmentally friendly, rapid, and non-toxic compared to other biosynthesis methods. Many metalloproteins in plants can serve as both reducing agents and capping agents in the synthesis of nanomaterials. Figure 5 illustrates the schematic phytosynthesis of metal nanoparticles. Phytosynthesis of nanoparticles exhibits a higher rate compared to other biosynthetic routes. Some nanoparticles are stabilized by peptides and terpenoids present within the latex of plants (Vellora *et al.,* 2013).

The following tables, Table 3, Table 4, Table 5 and Table 6 represent the types of nanomaterials synthesized from bacteria, fungi, east and actinomycetes

Table 3: *Nanomaterials Synthesized from Microorganisms*

Bacteria	Nanoparticle	Size (nm)	Morphology
Aeromonas sp. SH10	Silver	6.4	—
Bacillus cereus	Silver	20–40	Spherical
Bacillus megatherium D01	Gold	1.9 ± 0.8	Spherical
Bacillus subtilis 168	Gold	5–25	Octahedral
Bacillus subtilis	Silver	5–50	Spherical and triangular
Clostridium thermoaceticum	Cadmium sulfide	—	Amorphous
Corynebacterium sp. SH09	Silver	10–15	—
Desulfobacteraceae	Zinc sulfide	2–5	Spherical
Desulfovibrio desulfuricans	Palladium and selenium	—	—
Desulfovibrio vulgaris	Gold, uranium, and chromium	—	—
Desulfovibrio magneticus strain RS-1	Magnetite	Up to 30	Crystalline
Enterobacter cloacae	Silver and selenium	—	—
Escherichia coli	Cadmium sulfide	2–5	Wurtzite crystal
Escherichia coli	Silver	8-9	Spherical
Escherichia coli DH5	Silver	10–100	Spherical
Escherichia coli DH5	Gold	25 ± 8	Spherical, triangular, and quasi-hexagonal
Escherichia coli MC4100	Gold	Less than 10 to 50	Spherical, triangular, hexagonal, and rod shape
Geobacillus sp.	Gold	5–50	Quasi-hexagonal
Geovibrio ferrireducens	Gold	—	—
Klebsiella aerogenes	Cadmium sulfide	20–200	Crystalline
Klebsiella pneumonia	Silver	28.2–122 (average size of 52.2)	Spherical
Lactobacillus strains	Gold	20–50 and above 100	Crystalline, hexagonal, triangular, and cluster
Lactobacillus strains	Silver	15–500	Crystalline, hexagonal, triangular, and cluster
Lactobacillus strains	Silver-gold alloys	100–300	Crystalline and cluster
Lactobacillus strains	Titanium	40–60	Spherical

Lactobacillus casei subsp. *casei*	Silver	25–50	Spherical
Magnetospirillum magnetotacticum	Magnetite	—	Cluster (folded-chain and flux-closure ring)
Nocardiopsis sp. MBRC-1	Silver	~45	Spherical
Plectonema boryanum UTEX 485	Gold	10–25 and ~1–10 and 10 to 6000	Cubic and octahedral Platelet
Pseudomonas aeruginosa	Gold	15–30	—
Pseudomonas aeruginosa	Lanthanum	—	Crystalline and needle-like
Pseudomonas fluorescens	Gold	50–70	Spherical
Pseudomonas putida NCIM 2650	Silver	~70	Spherical
Pseudomonas stutzeri AG259	Silver	35–46 and up to 200	Hexagonal, equilateral triangle, crystalline silver, and monoclinic silver sulfide acanthite
Rhodobacter sphaeroides	Zinc sulfide	Average diameter of 8	Spherical
Rhodopseudomonas capsulate	Gold	10–20	Nanoplate and spherical
Rhodopseudomonas palustris	Cadmium sulfide	8.01 ± 0.25	Crystalline, face-centered cubic
Serratia nematodiphila	Silver	10–31	spherical, and crystalline
Shewanella algae	Platinum	5	Elemental
Shewanella algae strain BRY	Gold	Various sizes changed with pH	—
Shewanella putrefaciens (Gs-15)	Magnetite	10–50	Fine-grained crystal
Thermoanaerobacter ethanolicus TOR-39	Magnetite, cobalt, nickel, and chromium	—	Octahedral

Table 3 describes various NPs with different morphologies with different sizes and examples.

Table 4: *Different nanomaterials synthesis from Fungi*

Fungi	**Types of nanomaterials**	**Size(nm)**
Verticillium.	Silver NPs	25±12
Aspergillus Terreus	Ag NPs	
Pleurotus ostreatus, Aspergillus avus, Bryophilous Rhizoctoni, etc.	Ag NPs	
Candida albicans	Au NPs	20–40 nm
Fusarium oxysporum(from agro based rice husk)	Nanocrystalline silica	2–6 nm
various fungal species. (Fusarium oxysporum)	Magnetite NMs TiO_2 NMs ZrO NMs	20–50nm 6–13 nm 7-8nm

Table 4 represents different kinds of fungi extracted nano materials with different characteristics with examples.

Table 5: *Various Nanomaterials Extracted from Yeast and Actinomycetes*

Yeast & actinomycetes	Types of nanomaterials	Size(nm)
Silver tolerant yeast strain MKY3.	silver NPs	2–5 nm
Hanensula anomala	AuNPs	**14nm**
Yarrowia lipolytica NCIM 3589	AuNPs	**9-23nm**
Candida glabrata and Rhodosporidium	Cd and PbS NPs	**2nm-5nm**
Candida albicans	Au NPs	**20-40nm**
Thermomonospora sp	Au NPs	8–40 nm
Rhodococcus sp.	Au NPs	**5-15nm**

Table 5 describes different nano materials extracted from Yeast and Actinomycetes and their examples

ii) Biomolecules as templates to design nanoparticles

Different biomolecular templates such as DNA, viruses' nucleic acids, membranes and diatoms have been used in the synthesis of NPs. DNA has strong attraction towards transition metal ions and before attached with transition metal ions crosslinked hydrogel could be made as in DNA macromolecules in the synthesis of AuNPs. First Au(III) has reduced to Au metals which eventually converted to metal clusters which form AuNPs on the chain of DNA (Zinchenko *et al.,* 2014). Kundu *et al*. reported the synthesis of different kinds of NPs e.g. stable wire-like clusters of Ag NPs (17±3 nm and inter-particle gap of ~1.7 ±0.2 nm) and their assemblies were using DNA templates and or organic scaffolds (Majumdar *et al*., 2013; Kundu, 2013; Kundu & Liang, 2008; Kundu & Nithiyanantham, 2014; Anantharaj *et al*., 2014; Nithiyanantham *et al*., 2015; Ede *et al*., 2015; Nithiyanantham *et al*., 2014a; Kundu *et al*., 2009; Kundu, Lee & Liang, 2009; Kundu & Liang, 2008a; Kundu & Jayachandran, 2013; Nithiyanantham *et al*. 2014b; Ede *et al*., 2014). They are used as ultrasensitive SERS substrates (Ghorbani, 2013) as well as good catalysts in the reduction of aromatic nitro compounds (Kundu, 2013). Au nanoclusters (10–40 nm) and long nanostructures (diameter: 40–70 nm) exhibit the resistivity like the pure metals when synthesized by electroless, photolytic, DNA-mediated metho (Kundu, Maheshwari & Saraf, 2008). In solar cell applications ZnO NPs with different morphologies (wire-like, ~150±15 nm; flake like, ~80±10 nm; flower like, ~350±50 nm) were reported by using DNA bio template (Nithiyanantham *et al.,* 2014c). Organosols of Os NPs and b-MnO_2 NPs were synthesized by using DNA as supports through the homogenous reduction route and these NPs have shown catalytic activity in hydrogenation and oxidative polymerization of pyrrole and in hydrogenation. Self-assembled $NiWO_4$, $ZnWO_4$ and $MnWO_4$ NPs having different shapes have been reported to synthesized using DNA scaffolds. DNA can be used as reducing and capping agent for the synthesis of electrically conductive nanowires of Au, Pd and CdS and used in functional nanodevices, miniaturized computers, sensors and optoelectronic applications (Kundu & Liang, 2008b). Table 6 represents the synthesis of self-assembled nano clusters by using DNA as bio template or scaffold. Biological membrane can also be used as templates for the synthesis of NPs as it has ultra fine pores. Au NPs were reported to be synthesized from Au(III) solution at 80^0C on the rubber membrane V (*Hevea brasiliensis* trees) which was used as preservative (Santos *et al*, 2019). Viruses having hollow center in their structure could be used as the template for the synthesis of uniform size and morphology of NPs (Pokorski & Steinmetz, 2011). Polycrystalline AgNPs (20 to 25 nm) were reported to be synthesized by extracts from Diatoms (e.g. as Amphora-46) and $AgNO_3$ solution in the presence of a pigment fucoxanthin which reduces Ag ions in the presence of light (Jena *et al*., 2014).

Table 6: *Representation of Various Self-Assembled Nanomaterials with Different Characteristics*

Various Self assembled nano clustures	Shape of nano clustures	particle diameter, ϕ_p	chain diameter ϕ_c	wire diameter (ϕ_w)	chain length (L)	Applications
Ag NPs	Wire like	17 ± 3 nm, (IPD = 1.7 ±0.2 nm)	-	-		As ultrasensitive surface enhanced Raman spectroscopy Substrate
Os NPs	Wire like Honeycomb like	2 ±0.5 nm 1.5 ±0.2 nm,	-	290 ±20 nm 400 nm		Catalysis and surface enhanced Raman spectroscopy
Os NPs (organosol)	Wire like Aggregated wires	2.6 ±0.2 nm, 1.2 ± 0.2 nm,	-	-	0.54 ±0.03 µm 8–10 micron	
ZnO NPs	Wire-like Flower-like Flake-like	150 ±15 nm 350 ±50 nm 80 nm ±10 nm	-	-	1–2 µm	Catalysis and dyesensitized solar cells
b-MnO_2 NPs	Wire-like Flake-like	35 ± 5 nm 25 ±5 nm	-	-	1.9 ±0.2 mm, 275 ±25 nm	Catalysis and supercapacitor
TiO_2 NPs	Wire like cluster (large) Wire like cluster (small)	15 ± 5 nm 10 ±2 nm,	180 ± 20 nm 40 ±5 nm	-	-	Supercapacitor and dye sensitized solar cells
$NiWO_4$ NPs	Chain like (small) Chain like (large)	20 ± 5 nm 26 ± 4 nm	175 ±15 nm 245 ±15 nm,	-	2 ± 0.2 mm 3.4 ± 0.2 mm,	Catalysis and supercapacitor
$ZnWO_4$ NPs	Aggregated, chain like	75 - 5 nm	~75 ±15 nm	-	L = ~3 mm	High performance supercapacitor and catalysis

$MnWO_4$ NPs	Wire-like Flake-like Rice-like	75 - 15 nm 25 - 5 nm	-	-	L ≳700 nm 90-180 nm 90 -10 nm	Magnetic, catalysis and supercapacitor studies

Table 6 represents various self-assembled nanoclusters with different shapes, diameters (chain and wire), chain length and their applications.

iii) Plant extracts for nanoparticles synthesis

Synthesis of NPs like noble metals, metal oxides, bi-metallic alloys, etc. (Iravani, 2011) are carried out by the bio synthesis method using plant extract. It is one of the most important environmentally friendly, non-toxic very quick and effective method. Various plant bio metabolites have been reported to be used as reducing agents and capping agents in this biosynthesis of NPs. Photosynthesis of NPs is given in Figure 5 (Akhtar, Panwar & Yun, 2013). Table 7 represents the various plant extracted NPs.

Table 7: *Various Plant Extracted Nanomaterials*

Plant Extracts	Types of nanomaterials	Size(nm)
lemongrass leaf extract	gold nanotriangles	
leaf extract of plants *(Tamarindus indica, Aloe vera, Emblica officinalis)*	Au NPs.	
various parts of different plants	Pd NPs and Pt NPs	
Azadirachta Indica (leaf extracts), *Emblica officinalis*(fruit extract)	Ag NPs	
Aloe vera, *Capsicum annuum* and *Helianthus annuus* (leaf extract)	Ag NPs	
Aloe vera.	In2O3 NPs	5–50 nm
Sedum alfredii (Zn-hyperaccumulator)	Wurtzite ZnO NPs	53.7 nm
Medicago sativa (alfalfa) Plant	Iron oxide NPs	
Glutathione (an antioxidant tripeptide in plants)	Au NPs(aggregate)	
Curcumin	shape-selective AgNPs	

Table 7 describes different types of nano materials varying in size extracted from various parts of the plants.

Conclusion

Nanomaterials can be synthesized through physical, chemical, and biological methods. However, bio-assisted techniques are also considered a green approach to synthesizing eco-friendly and economically viable nanoparticles. The bio-inspired technique causes much less environmental damage compared to other methods since toxic chemicals are not used. By simply modifying the culture medium, nanoparticles with different morphologies can be synthesized. Microorganisms, biomolecules, and plant extracts are utilized in biological synthesis.

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