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Review Article

Green Functional Nanomaterials:

Synthesis and Applications

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Abstract: Interaction between inorganic molecules and biological species is very fascinating. Green synthesis of metallic nanoparticle using plants and microorganisms is widely preferred over the physical and chemical methods due to their nontoxic, safer, biocompatible, less expensive, environment-friendly nature and greater biomedical applications. Some unicellular and multicellular organisms including plants and bacteria may be involved in biosynthesis as they have the ability to absorb and accumulate inorganic metallic ions. Advantages of using biological entities are that nanoparticles of wide range of shapes, sizes, compositions and physical properties may be synthesized through this. In comparison between microorganisms and plants, approaches involving plants are more advantageous because of their faster and relatively easy scale up for production in large quantities. Biological synthesis of nanoparticles can be considered as a bottoms-up approach where such particles are formed by reduction or oxidation of metallic ions. Bacteria such as Escherichia coli, Lactobacillus spp., Pseudomonas sp. etc. can produce nanoparticles either by extracellular or intracellular processes. Parts of plants such as leaves, fruits, roots etc. can be used for synthesis of nanoparticles due to the presence of phytochemicals which act as reducing and stabilizing agents and quantity, size and morphology of such products can be influenced by the concentration of plant extract, metal salt concentration, temperature, pH of the reaction solution and time of reaction. Biosynthesized nanoparticles have wide applications including cancer treatment, targeted drug delivery, fluorescent labelling, magnetic resonance imaging, in the field of biosensors, environmental remediation, gene therapy etc.

Keywords: Green synthesis; Environment-friendly; Biosynthesized nanoparticles; Plant; Bacteria; Bottoms-up approach.

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1. Introduction

Merging of nanometre-scale technologies and biological technologies has given rise to the new discipline called as nanobiotechnology. This discipline is concerned with the production, manipulation, and application of nanoscale materials. Nanoparticles (NPs) can be controlled by their size, shape, and size distribution, which are determined by their physicochemical, magnetic, and optoelectronic properties. The medicinal potentials of many metals were mentioned in the ancient Indian Ayurvedic medicine text "Charak Samhita". NPs can be classified into four types based on their chemical make-up: composite based (nanotubes, nanofibers of carbon, etc.); bio-organic based (liposomes, micelles, etc.); and metal and metal oxide based (Ag, Cu, etc.) (Pandey et al, 2018). Additionally, NPs can be categorised as organic or inorganic in nature (Yu et al, 2018). While inorganic NPs are based on inorganic materials made of metals and metal oxides like silver oxide, zinc oxide, etc., organic NPs are biodegradable in nature and include polymeric NPs, lipid-based nanocarriers, liposomes, carbon-based nanomaterials, and solid lipid NPs. Two alternative methods, namely (i) the top-down approach and (ii) the bottom-up approach, can be used to synthesise NPs (Thakkar et al, 2010; Das et al, 2017). Various approaches, including physical, chemical, and biological procedures, are used to create NPs. The biological synthesis via nano-biotechnology processes have a significant potential to boost nano-particles production without the use of harsh, toxic, and expensive chemicals commonly used in conventional physical and chemical processes. Green synthesis is necessary to avoid the formation of undesirable or dangerous by-products by developing dependable, sustainable, and environmentally friendly synthesis techniques. Plants and microbes have long exhibited the ability to absorb and accumulate inorganic metallic ions from their surroundings. Many living entities have attractive qualities that make them efficient biological factories capable of greatly decreasing environmental pollution and retrieving metals from industrial waste. Nanoparticles can be made from a wide range of biological entities, including actinomycetes, algae, bacteria, fungi, plants, viruses, and yeast. Each biological organism possesses variable degrees of biochemical processing capability that can be exploited to successfully generate specific metallic or metallic oxide nanoparticles. Numerous nanoparticles of metals and their derivates, such as oxides, hydroxides, sulphides, phosphates, fluorides, and chlorides, have been synthesised over the years and found useful in a variety of fields, including catalysis, microelectronics, semiconductors, sensors, cosmetics and medical sciences. Such materials are appealing due to their exceptional qualities, which include excellent chemical stability, high photo stability, a high electro coupling coefficiency and a broad range of radiation absorption capacity.

2.Biological components of green synthesis

2. (a) Bacteria

Production of nanosized materials by bacterial cell has emerged as a viable technique for the manufacture of metal nanoparticles. Microbial cells are thought to be promising biofactories for the production of gold, silver, and cadmium sulphide NPs. In green nanotechnology, a variety of bacterial species have been used for the synthesis of NPs. Bacteria are thought to be a possible biofactory for the production of NPs such as gold, silver, platinum, palladium, titanium, titanium dioxide, magnetite, cadmium sulphide etc. Magnetotactic bacteria and S-layer bacteria are two well-known examples of bacteria that synthesise inorganic compounds. Bacteria have a remarkable ability to decrease heavy metal ions, making them one of the finest possibilities for nanoparticle manufacturing. Pseudomonas stutzeri and Pseudomonas aeruginosa, for example, may survive and grow in high metal ion concentrations. Others, including Thiobacillus ferrooxidans, T. thiooxidans, and Sulfolobus acidocaldarius, can decrease ferric ion to ferrous state when grown on elemental sulphur as an energy source. Other biomineralization phenomena have been reported, including the formation of tellurium (Te) in Escherichia coli K12, the direct enzymatic reduction of Tc (VII) by resting cells of Shewanella putrefaciens and Geobacter metallireducens and the reduction of selenite to selenium by Enterobacter cloacae, Desulfovibrio desulfuricans and Rhodospirillum rubrum.

2. (b) Plants

Plant functionalised metal nanoparticle has several advantages compared to other non-biological entity. The advantages of using plants are that it avoids formation of inorganic salts, safe to store for having long life time, easy and inexpensive removal from reaction mixture by filtration or centrifugation, has greater selectivity option and cost effective. Plants are thought to reduce metal ions primarily through amino acids (Shao et al, 2004), citric acid (Yehia et al, 2014, flavonoids (Shankar et al, 2003), phenolic compounds (Sivaraman et al, 2009), terpenoids (Thakkar et al, 2010), heterocyclic compounds (Huang et al, 2007), enzymes (Narayanan et al, 2011), peptides (Tan et al, 2010), polysaccharides (Park et al, 2011), saponins (Arunachalam et al, 2013), and tannins (Huang et al, 2011). Several research demonstrating green synthesis of Metallic Nanoparticles (MNPs) utilising plants relied on the reduction of noble metals such as gold (Au), silver (Ag), platinum (Pt), and copper (Cu). The most common MNP shapes reported in green synthesis utilising plants are spheres (Bonatto et al, 2014, Bar et al, 2009, Smitha et al, 2009, Philip, 2010) and triangles (Smitha et al, 2009, Chandran et al, 2006). The hydrodynamic diameter of greenly produced MNP is typically in the region of 15-50 nm (Veeraputhiran, 2013). Biological activity of MNPs generated through green synthesis employing plants include antibacterial (Singh et al, 2010), antifungal (Bonatto et al, 2014), anticancer (Mollick et al, 2014), and larvicidal (Borase et al, 2014) properties.

2c) Other organisms

I. Actinomycetes

According to Ahmad et al., 2003, actinomycetes undergo intracellular reduction of metal ions on the surface of mycelia and the cytoplasmic membrane, resulting in the formation of nanoparticles. The researchers demonstrated the bactericidal efficacy of silver nanoparticles produced by actinomycetes both intracellularly and extracellularly against therapeutically significant infections. Silver nanoparticles produced by actinomycetes inhibited the growth of Proteus mirabilis, P. vulgaris, S. typhimurium, Micrococcus luteus, and Enterococcus faecalis (Sunitha et al, 2014). These nanoparticles were discovered to be potentially active against a wide range of human pathogenic fungi, including Candida tropicalis, Saccharomyces cerevisiae and dermatophytes such as Trichophyton rubrum and T. tonsurans. Silver nanoparticles derived from actinomycetes (Streptomyces sp.) have antiparasitic activity against Rhipicephalus microplus and Haemaphysalis bispinosa (Karthik et al, 2014).

II. Yeast

Yeasts is a good absorber and accumulator of toxic metals from environment (Tian et al, 2008). Various techniques are used by it to produce and stabilise nanoparticles. The synthesis by yeast leads to variations in particle size and location. Dameron et al. in 1989 showed the creation of CdS quantum dots by Candida glabrata and PbS quantum dots by Torulopsis sp. in their experiment. The intracellular synthesis of Au nanoparticles with varying sizes was carried out using Pichia jadinii. Similar studies with Yarrowia lipolytica showed during extracellular and intracellular production that the concentration of Au salt and biomass had an impact on morphology as well as size of the generated particles. Additionally, another yeast strain MKY3 showed production of extracellular Ag spherical nanoparticles with diameters ranging from 2 to 5 nm (Kowshik et al, 2003). There have been reports of different intracellular synthetized nanoparticles such as cadmium sulphide, silver, selenium, titanium, and gold etc. which are being produced by yeast strains Candida glabrata and Saccharomyces pombe.

III. Algae

Algae can produce metallic nanoparticles and experimentally it has been seen that S. wightii produces Au nanoparticles (8 to 12 nm). Kappaphycus alvarezii stain alos have the capacity to produce Au nanoparticles. Castro et al, 2013 showed that Chondrus crispus and Spirogyra insignis can also synthesise Au and Ag nanoparticles. Kappaphycus alvarezii was also reported to produce the extracellular Au nanoparticles by Rajasulochana et al, 2010. Mata et al, 2009 showed the biological reduction of Au utilising Fucus vesiculosus. Intracellular production of Au nanoparticles by Tetraselmis kochinensis was reported by Senapati et al, 2012.

IV. Fungi

Fungi can also biosynthesis nanoparticles which can be both extracellular and intracellular. Aspergillus sp., Fusarium sp., and Penicillium sp., are well known for their biosynthetic ability to produce nanoparticles (Ag and Au) (Gade et al, 2008). Proteins and enzymes produced per unit of biomass gives this organism advantage for increased production of NPs (Narayanan et al, 2010). However, the culture conditions have substantial impact on the biogenesis process. Nanoparticles produced by extracellular process were found to be produced during the stationary biological reduction of Au ions by Trichothecium sp. However, biomass agitation tended to produce intracellular nanoparticles. The reason for this might be the non-agitation stimulated enzyme and protein release while agitation inhibited it (Ahmed et al, 2005). In fluorescence spectroscopy studies, the extracellular production of nanoparticles by fungus is being caused due to the action of bioactive reducing agents that are secreted from cell wall that result in protein-stabilized nanoparticles. Some fungi have the remarkable ability to produce nanoparticles with a broad range of chemical compositions. In intracellular extraction, processes of downstream processing often suffer from low yields, but the extracellular synthesis generates nanoparticles at the cell surface or at the cell's periphery and thus producing nanoparticles can be easily collected in downstream processing (Narayanan et al, 2010).

V. Virus

The use of viruses in the production of nanomaterial is a revolutionary technology and inorganic compounds such as cadmium sulphide (CdS), iron oxide (Fe2O3), silicon dioxide (SiO2) etc. can be successfully obtained. The surface covering of capsid proteins of virus forms a highly reactive surface which is capable of interacting with metallic ions (Makarov et al, 2014). Tobacco Mosaic Virus was mixed into the extracts of Nicotiana benthamiana plant before adding to Ag or Au salts. When compared to non-viral solutions, virus not only reduced the size of the nanoparticles produced, but can significantly increase their number (Love et al, 2014).

Synthesis of nanoparticles by biological entities

3a) Microorganism based mechanism (Bacterial)

Nanoparticle production is done in various ways by various microorganisms. However, nanoparticles are commonly produced by: i) initially stuck on the outside or inside of microbial cells and ii) metal ions are later transformed into nanoparticles in the presence of enzymes. Two distinct ways exist through which microorganisms affect mineral formation. In the first approach, they can alter the solution's chemical structure to make it supersaturated or more supersaturated than before with respect to a certain phase. Whereas, the production of organic polymers by microbes, which can affect nucleation by promoting (or preventing) the stability of the earliest mineral seeds, is a second method. Bacteria are chosen over other microorganisms for the synthesis of NPs due to their inexpensive purifying costs, high yield, and ease of maintenance. The oxidation/reduction of metallic ions by secreted biomolecules by microbial cells, such as sugars, polysaccharides, proteins, etc., results in the formation of NPs during the microbial synthesis process (Prabhu et al, 2012). However, understanding of microbial NP synthesis is still not enough since different types of bacteria use different synthesis pathways. In contrast to fungi, which use nitrate-dependent reductase or carboxylic groups, bacteria mostly use deoxyribonucleic acid (DNA) or proteins containing sulphur to reduce silver for the creation of external and intracellular AgNPs (Sabri et al 2016). Kalishwaralal et al, 2009 showed that nitrate reductase enzyme has role in AgNP production by B. licheniformis. Metallophilic bacteria have evolved genetic and proteomic adaptations to hazardous environments. When it comes to microorganism survival, heavy metal ions like Hg2+, Cd2+, Ag+, Co2+, CrO4 2+, Cu2+, Ni2+, Pb2+, and Zn2+ are detrimental. Microorganisms have a large number of metal resistance gene clusters that enable cell detoxification through a number of mechanisms. Mechanisms like complexation, efflux, or reductive precipitation are important in this aspect. Shewanella oneidensis bacterium was used to produce magnetites (Perez-Gonzalez et al, 2010). First, when bacteria use ferrihydrite as a terminal electron acceptor, active Fe2+ production happens, and the pH around the cells rises likely as a result of bacterial amino acid metabolism. A local increase in the system's supersaturation with regard to magnetite is subsequently caused by the concentrated concentration of Fe2+ and Fe3+ at the net negatively charged cell wall, cell structures, and/or cell debris that causes the magnetite phase to precipitate by a passive mechanism.

Table 1: Some of the bacterial species with their corresponding synthesized NPs

Bacterial species	Morphology	Size of the nanoparticle (nm)	Type of the nanoparticle	Reference
Bacilus cecembensis	Spherical	6-13	Silver	Shivaji et al., 2011
Bacilus subtilis 168	Hexagonal-octahedral	5-50	Gold	Southam et al., 1994
Lactobacilus casei	Spherical	20-50	Silver	Korbekandi et al., 2012
Bacilus cereus	Spherical	20-40	Silver	Sunkar e al., 2012
Bacilus megaterium DO1	Spherical	<25	Gold	Wen et al., 2009
E.Coli DH5a	Spherical	8-25	Gold	Du et al., 2007
Desulfovvibrio desulfuricans	Spherical	20-50	Gold	Deplanche et al., 2008
Rhodopseudomonas capsulate	Triangular	10-20	Gold	He et al.,2007
Aquaspirillum magnetotacticum	Octahedral prism	40-50	Iron oxide	Mann et al., 1984
Rhizopus nigricans	Round	35-40	Silver	Ravindra et al., 2014
Nocardiopsis sp. MBRC-1	Spherical	45	Silver	Manivasagan et. al.,2013
Escherichia coli MC4100	Spherical, Triangular, Hexagonal and Rod Shaped	<50	Silver , Gold	Mahanty et al., 2013

Table 2: Some of the bacteria and their synthesis location of NPs

Bacterial sp.	Location of synthesis	Reference
Pseudomonas spp.	Intracellular	Das et. al.,2014
P. aeruginosa SNT1	Intracellular	Kumar et. al., 2009
Bacillus subtilis 168	Intracellular	Beveridge and Murray, 1980
Corynebacterium spp. SH09	Intracellular	Bai et. al.,2006
Aquaspirillum magnetotacticum	Intracellular	Bazylizinki et. al.,1993
Escherichia coli	Extracellular	Park et. al.,2011
Desulfovvibrio desulfuricans	Extracellular	Cai et. al.,2009
Lactobacillus sp.	Extracellular	Shahverdi et. al.,2007
Enterococcus garvieae	Extracellular	Shahverdi et. al.,2007
Enterococcus faecium	Extracellular	Shahverdi et. al.,2007
Lactococcus garvieae	Extracellular	Shahverdi et. al.,2007

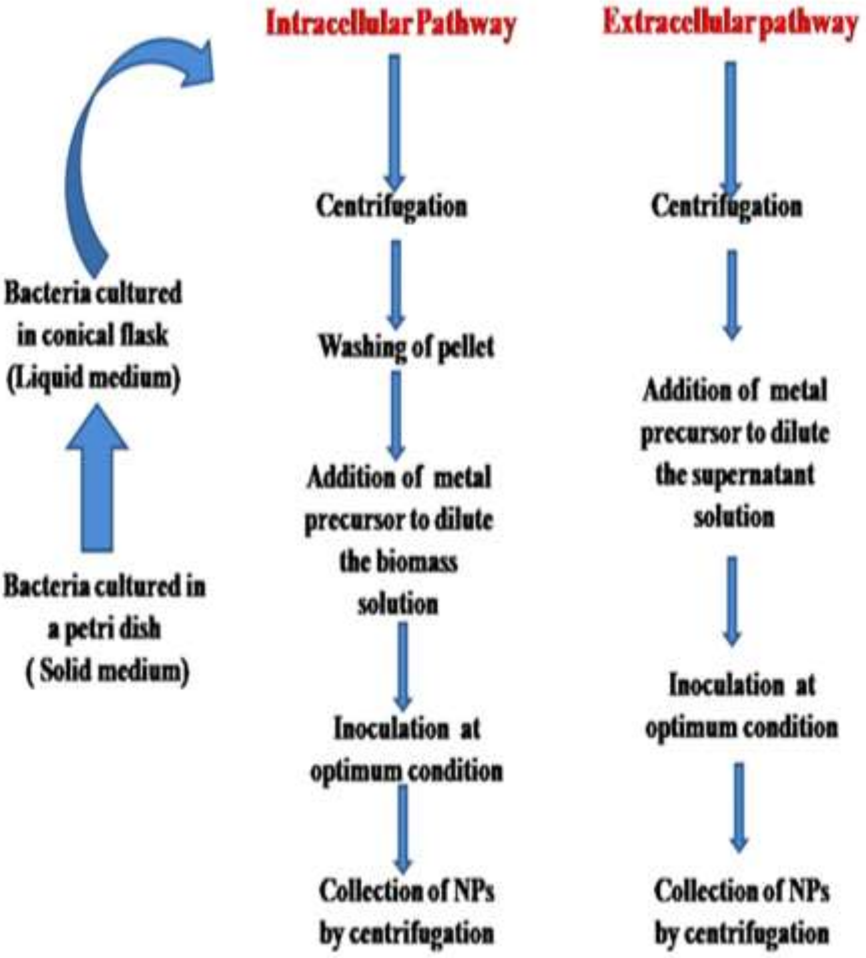

Fig 1: Schematic representation of bacterial NPs synthesis procedure

3. (b) Plant extract based mechanism

Different components of plant such as seed, flower, fruit, bark, tuber, and root as well as leaf extracts are used in the green synthesis of MNPs. Plant extracts may function in the creation of nanoparticles as both reducing and stabilising agents (Kumar and Yadav's, 2009). Mittal et al, 2013 reported the use of biomolecules which is derived from plant extracts by green synthesis process. Biomolecules of plants such as proteins, DNA, and saccharides as well as flavonoids and carotenoids, etc., serve as reducing and capping agents, constitutes the fundamental mechanism of synthesis.

Table 3 : Some of the nano particles with their corresponding Plant extracts

Plants species	Morphology	Size of the nanoparticle (nm)	Type of the nanoparticle	Reference
Medicago sativa (alfalfa sprouts	Mostly spherical	2-20	Silver	Jorge et al,2003
Cinnamomum camphora	Triangular or spherical	55–80	Gold and Silver	Huang et al,2007
Medicago sativa	Spherical	2-5.6 (depending on pH)	Zinc	Canizal et al,2006
Diopyros kaki	Crystalline	15 -19	Platinum	Song et al,2010
Curcuma longa	Spherical	10 -15	Paladium	Sathishkumar et al,2009
Medicago sativa	fcc twinned and icosahedron structure	2-20	Gold	Gamez et al,2000

Fig 2: Pine (Oroxylum indicum) and Broken bones tree (Colocasia esculenta) which were collected from the forest biome of Manas National Park and Kamrup, Assam, India were found to have NP synthesized capacity which were taxonomically identified and authenticated by the Department Of Botany, Pub Kamrup College, Guwahat, Assam.

In the experiment performed by the authors, each of the above plant's 5, 10, 15, and 20 mL of aqueous leaf extract were carefully added to 10 mL of a 1 mM aqueous silver nitrate, coper nitrate, chloroauric acid, and zinc nitrate solution in

250 mL Erlenmeyer flasks at 50 °C. For 2 hours, the mixture was prepared after which the mixture was centrifuged to separate the bigger pieces and avoid agglomeration. The colour of the colloidal solutions had changed which was indicated green synthesis of silver and gold nanoparticles. To produce the product that will be used for further examination, the solid should be washed three times with cold water and dried under vacuum (Manjari et.al., 2017). The amount of copper in the catalyst was estimated using atomic absorption spectroscopy which was found to be 2.26 wt percent in our investigation (analysed in AANALYST 700, Perkin Elmer).

Metal Salts + Biomolecules ⚜ Metal NPs + By-products

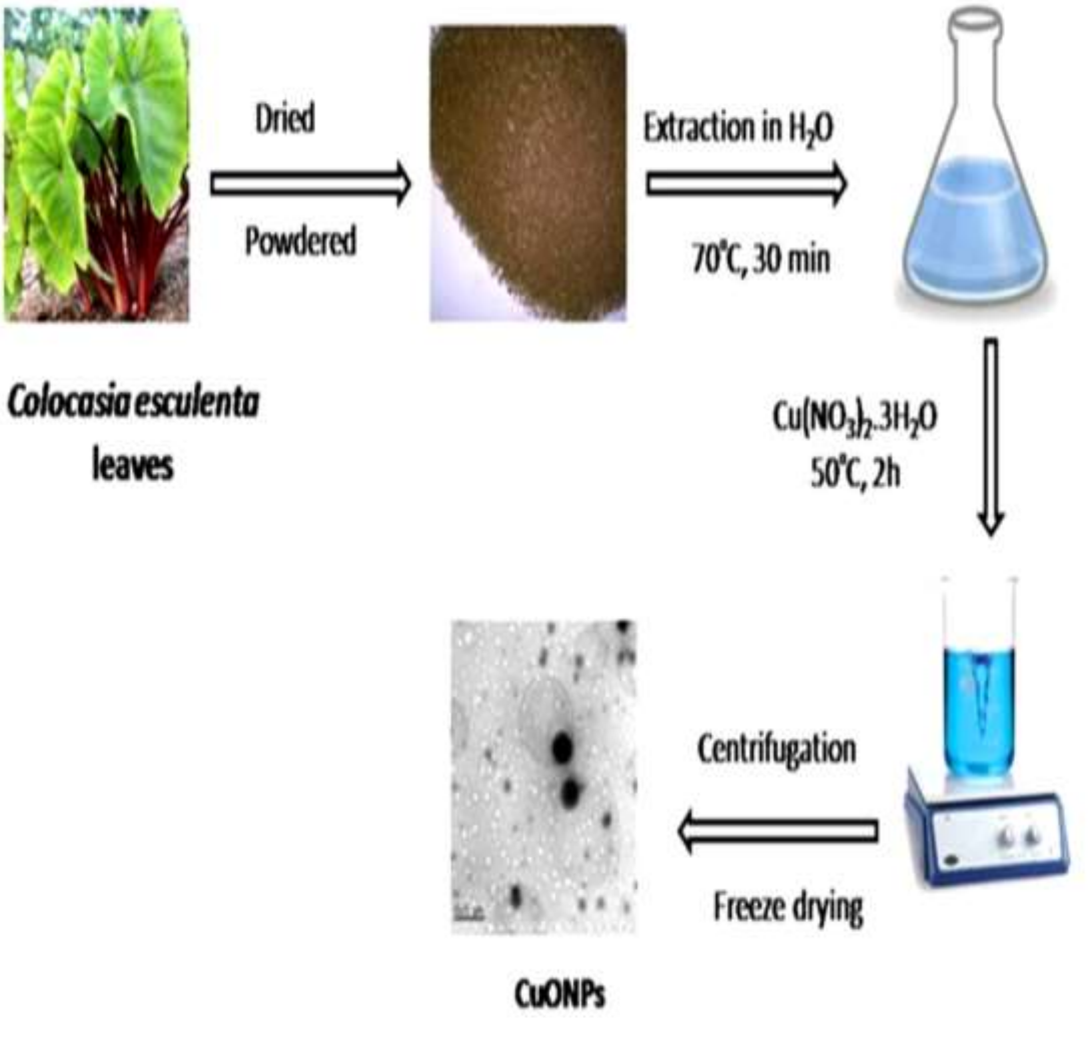

Fig 3 : Schematic presentation of the biosynthesis processes of nanoparticle **(**CuONP**)**

Some of the synthesis procedure of nanoparticles are discussed here:

Copper: Copper nanoparticles are synthesized from plant extracts and the reduction mechanism was proposed by Ramanathan et al, 2013 as :

$$CuSO_4.\ 5H_2O \quad + \quad \text{Plant extract} \quad \longrightarrow \quad \text{CuONPs} \quad + \quad \text{by products}$$

Gold: The proposed reaction for Au+ ions reduction into metallic Auo nanoparticles in the presence of metabolites and redox enzymes (Schröfel et al, 2014) is:

$$\mathrm{HAu^{+}Cl_4.4H_2O} \quad + \quad \text{Plant extract} \quad \longrightarrow \quad \text{AuONPs} \quad + \quad \text{by products}$$

Silver: The biochemical reaction of AgNO3 reacts with plant broth leads to the formation of AgNPs by following reaction (Tripathy et al,2010)

$$\mathrm{Ag^{+}NO_3^{-}} \quad + \quad \text{Plant extract} \quad \longrightarrow \quad \text{AgONPs} \quad + \quad \text{by products}$$

Zinc oxide: The typical procedure employed in ZnO nanoparticles production is given according to Sangeetha et al, 2011

$$\mathrm{Zn(NO_3)_2} \quad + \quad \text{Plant extract} \quad \longrightarrow \quad \text{ZNO} \quad + \quad \text{by products}$$

4.Characteristics of biosynthesized nanoparticles

The characteristics of nanoparticles in general include their size, shape, surface area, and dispersity (Jiang et al, 2009). The most widely used methods for characterization include transmission electron microscopy (TEM), scanning electron microscopy (SEM), powder X-ray diffraction (XRD), fourier transform infrared spectroscopy (FTIR), dynamic light scattering (DLS), and energy dispersive spectroscopy (Feldheimand , 2002; Sepeur, 2008; Shahverdi et al, 2011).

Characterising different metal nanoparticles in the size range of 2 -100 nm often requires light with wavelengths between 300 - 800 nm (Feldheim, 2002). For Ag and Au nanoparticles, spectroscopic absorption measurements are used (wavelength 400–450 nm) (Huang and Yang, 2004) and 500–550 nm (Shankar et al, 2004) respectively. FTIR spectroscopy is used for describing the surface chemistry of the NPs (Chithrani et al, 2006). FTIR can also be used to identify additional surface chemical residues and organic functional groups attached to surface of NPs. The crystal structure of the nanoparticles is characterised and its phase can be identified using XRD (Sun et al, 2000). The surface charge and size distribution of the particles suspended in a liquid are characterised using the dynamic light scattering (Jiang et al, 2009). Another often used method of characterisation is electron microscopy (Cao, 2004). Morphological characterization is carried out at the nanoscale to micrometre scale using transmission electron microscopy and scanning electron microscopy (Schaffer et al, 2009). When compared to scanning electron microscopy, transmission electron microscopy offers a 1000-fold higher resolution (Eppler et al, 2000). Energy dispersive spectroscopy (EDS) is frequently used to determine the elemental composition of metal nanoparticles (Strasser et al, 2010).

5. Factors Affecting Biological Synthesis of Metal Nanoparticles

During biological synthesis of metallic nanoparticles, a number of controlling factors such as pH, reactant concentrations, reaction time, and temperature are considered.

i)Influence of pH

During the creation of nanoparticles, the pH level of the reaction medium is crucial. Particularly, higher the values of pH tend to produce smaller particles while lower produce larger particles. For instance, rod-shaped Au nanoparticles made from biomass of Avena sativa generated at pH 2 were larger (25 to 85 nm) whereas significantly smaller (5 to 20 nm) were formed at pH 3 and 4 in the experiment of Armendariz et al, 2004. In a related work where Cinnamon zeylanicum bark extract was used to synthesise Ag nanoparticles, the quantity of particles produced increased with increasing bark extract concentrations, and at higher pH levels (pH 5 and above) and the morphology of the nanoparticles tended to become spherical (Sathishkumar et al, 2009). On the other hand, there was a small increase in particle size with increasing pH when palladium (Pd) nanoparticles were synthesised using Cinnamon zeylanicum bark extract. The size of the particles varied between 15 and 20 nm when the pH was below 5 and between 20 and 25 nm when the pH was above 5 (Sathishkumar et al, 2009) .

ii) Influence of Reaction Time

According to a study of Ahmad et al, 2012 the reaction time is a crucial element in the production of spherical Ag nanoparticles using Ananas comosus extract. In the experiment, it resulted in a quick colour change within 2 minutes. Within two minutes, nanoparticles began to form from the fast reduction of aqueous Ag(NO)3 in the reaction media. Up until 5 minutes into the reaction, there was only a very tiny change in colour that could be seen. The generated nanoparticles were spherical and sized 12 nm in size. Nanoparticles started to form during the synthesis process in less than 15 minutes and kept doing so for two hours.

iii) Influence of Reaction Temperature

It has been found that temperature also has a significant role in regulating the size, shape, and yield of nanoparticles produced by plant extracts (Satishkumar et al, 2010). For example, the synthesis of Ag nanoparticles using Citrus sinensis peel extract at a reaction temperature of 250 C resulted in particles with an average size of about 35 nm. The average particle size, however, dropped to 10 nm when the reaction temperature was raised to 60 0C (Kaviya et al, 2011).

6. Application of biosynthesized nanoparticles

6. (a) Biomedical research

In vitro antibacterial investigations show that metallic nanoparticles effectively inhibit various microbial species (Dizaj et al, 2014). The use of nanoparticles has been found as one of the most promising techniques for reducing or avoiding microbial drug resistance. Metallic nanoparticles can inhibit or overcome multidrug resistance and biofilm development via a variety of methods. Various nanoparticles use numerous strategies to fight germs at the same time. For example, NO-releasing nanoparticles, and chitosan-containing nanoparticles are found to be effective in this aspect. Silver NPs is used as an effective antibacterial, antifungal, antiviral, and anti-inflammatory agent.

6. (b) Agricultural research

Nanoparticle applications in crop protection and agriculture are growing day by day (Nair et al, 2010; Khot et al, 2012). Changes in germination inhibitors and stimulators could explain the enhanced seed emergence following NPs priming. As a result, biologically derived NPs are emerging as a priming agent having the potential to significantly improve seed performance and seedling growth. Aside from seed priming, NPs such as AgNPs can be directly impregnated into a medium to enhance rice development.

6. (c) Drug delivery

A fundamental concern in the design and development of innovative drug delivery systems is the precise and safe delivery of the pharmaceuticals to their target areas at the appropriate time to have a controlled release and obtain the maximal therapeutic benefit. Nanoparticle drug carriers can get beyond the skin's tight epithelial junctions and the blood-brain barrier, which often prevent the delivery of medications to the intended target site. Secondly, nanocarriers exhibit enhanced pharmacokinetics and biodistribution of therapeutic drugs and hence limit toxicity by preferentially accumulating at the target site due to their high surface area to volume ratio (Vaidyanathan et al, 2009). Moreover, they make a range of medicinal compounds, such as peptides and oligonucleotides which are found to be very stable (Emerich et al, 2006). Gold nanoparticles have emerged as a viable framework for medication and gene delivery that can be used in conjunction with more standard delivery vehicles. Because of their low intrinsic toxicity, high surface area, stability, and function tunability, they have unique properties that should enable innovative delivery tactics.

6. (d) Environmental remediation

A variety of nanoparticles have been found to lower microbial burdens in treated wastewater effluent (Duran et al, 2007). Because of their small size and large proportion of atoms at the surface, NPs have strong adsorption, contact, and reaction capabilities. They can also act as colloids when suspended in aqueous solutions. Because of their small size, these particles conserve energy, which can eventually contribute to cost-effectiveness. NPs have significant advantages for treating water at deep depths and in any region where traditional technologies have failed. Green nanoparticles have a wide range of capabilities for treating contaminated water with hazardous metal ions, organic and inorganic solutes, and pathogenic microbes.

6. (e) Other applications

Nanoparticles can be used in biosensor applications and have intriguing electrical and optical features. Bacillus subtilis has been reported to produce spherical selenium nanoparticles with sizes ranging from 50 to 400 nm (Wang et al, 2010) which are used to develop the HRP (horseradish peroxidase) biosensor because of its high surface-to-volume ratio, strong adhesive properties, and biocompatibility. According to electrochemical experiments, the glassy carbon electrode-based vanillin sensor was able to increase the electrochemical responsiveness of vanillin by at least five times.

7. Conclusion

Nanomedicine is a rising field of study with enormous potential for improving human illness detection and treatment. Although the field of biosynthesized nanoparticles is still in its early stages, researchers have begun to investigate their potential applications in areas such as targeted drug delivery, cancer treatment, gene therapy and DNA analysis, antibacterial agents, biosensors, enhancing reaction rates, separation science etc. The properties of NPs can be managed by optimising essential factors that control organism growth, cellular activities, and enzymatic processes. Mild synthetic conditions and biocompatible substrates endow NPs with desirable features such as excellent performance, stability, and biocompatibility. These natural nanofactories can be utilised to synthesise stable NPs with well-defined sizes, shapes, and compositions by adjusting the reaction conditions and selecting the appropriate bacteria. It is advantageous to synthesis nanoparticles from plant and microbial sources since it is a cost-effective, energy-saving, and low-cost product. It can preserve human health and the environment, eliminating waste and ensuring safe products.

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