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SYNTHESIS, CHARACTERIZATION OF NANOPARTICLES AND THEIR APPLICATIONS IN EVERYDAY LIFE: A REVIEW

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ABSTRACT

Nanoparticles have been extensively studied by researchers because of their unique properties e.g., size and shape depending optical, antimicrobial, and electrical properties. Nanoparticles are certain particulates which have dimension between 1-100 nm. These can be of Gold, Silver, certain compounds such as Silicon monoxide (SiO), Titanium Oxide (TiO), Zinc Oxide (ZnO) etc. Plants, environmental phenomenon, and microorganisms are natural and nontoxic sources of nanoparticle synthesis. Nanoparticles can be synthesized chemically or biologically for commercial and basic research use. Green synthesis involves extracellular or intracellular synthesis of nanoparticles from either microorganisms or plants. Chemical methods have been employed these years however, green synthesis is preferred because of its sustainable nature. They are characterized using various techniques such as UV–visible Spectroscopy, Fourier transform infrared spectroscopy, Scanning electron microscopy, Transmission electron microscopy, Dynamic Light Scattering etc. Nanoparticles have immense applications in disinfectants, agricultural goods, medicine including disease diagnostics, drug delivery systems, tissue engineering, genetic engineering, food packaging materials, electronics, energy etc. and thus nanoparticles have attracted considerable attention in recent years. These nanoparticles can play many important roles in plant growth, increasing the yield of crops and the quality and quantity of the grains. They can be applied at initial stages of plant growth and for different doses. There are different techniques which have been used to characterise the surface, charge, size and various other physical properties of nanoparticles. Some studies have thrown light on multiple ways of nanoparticle synthesis including physical, chemical, and biological methods while some provided knowledge on their applications. This comprehensive review summarises all the recent studies pertaining to various research aspects of nanoparticles.

KEYWORDS: Nanoparticles, nanotechnology, green synthesis, plants, microorganisms, fungi.

INTRODUCTION

Nanotechnology is the branch of science concerned with the production and designing of nano particles. Nanoparticles are the particles that range in size from 1-100 nm and can even reach to 500 nm. Nanoparticles have wide range of shapes including nano cubes, nano prisms, nanoplates, nano discs, nanorods, nanowires, and nanoflowers.[1] This field is now coming to light because there are numerous eco-friendly methods which can be used for producing nanoparticles. Nanoparticles are employed in everyday life because of their small size. However, pharmaceutical, and biological science is where nanoparticles are most useful. The distinct characteristics of nanoparticles, which are largely regulated by their composition, size, and shape, provide us with a wide range of applications in a variety of sectors, accelerating science and technology progress. Nanoparticles created by noble metals such as gold, silver, palladium, and platinum are frequently utilized in consumer goods such as lotions, soaps, toothpastes, shampoos, and shoes in addition to their therapeutic usage.[2] Nanoparticles synthesized from fungi have also been mentioned as having mosquito control potential. ZnO nanoparticles size range from 2 to 7 nm. They can be utilised to boost fungal biomass such as *P. indica*'s.[3] Their surface area is huge, and their catalytic activity is strong. Characterization of nanoparticles entails the examination of many types of nanoparticles, including surface charge, shape, size and structure, which is required for material research in general. This includes investigating both their morphological and chemical features, as well as their toxicity and the techniques by which they are synthesized via inorganic and organic pathways. UV–visible spectroscopy, X-ray diffraction technique (XRD), Fourier transform infrared spectroscopy (FTIR), Atomic force microscopy (AFM), Scanning electron microscopy (SEM), Energy dispersive

X-Ray spectroscopy, etc., are the molecular techniques used for the characterization of nanoparticles.[4] Recent papers disclose green production of nanoparticles by numerous plants and their versatility in terms of applications. But there is only limited knowledge on the efficient and novel techniques used for characterisation of nanoparticles. This review article aims to summarise the present knowledge on the different techniques used for characterization along production and applications of nanoparticles, all collectively.

ROLE OF MICROORGANISMS IN THE SYNTHESIS OF NANOPARTICLES

The use of microorganisms in the manufacturing of nanoparticles successfully connects nanotechnology with microbial biotechnology. Numerous plants and microbes have been able to manufacture nanoparticles using this method. Biogenic synthesis increases biocompatibility in nanoparticle applications by being easy, clean, long-lasting, and cost-effective. Fungi are crucial in the formation of nanoparticles because they convert metals to insoluble compounds in colloidal particle form, such as metal sulphides. Common microbes for nanoparticle synthesis are fungi and bacteria. *Aspergillus niger*, *P. ostreatus* and *A. bisporus* are different fungus used to synthesise gold nanoparticles.[5] Nanoparticles obtained with microorganisms are majorly spherical shape. They are most effective nanoparticles among all and are also frequently utilised in water treatment, textiles, production of cosmetics.[1] *Fusarium oxysporum*, *P. ostreatus* and *G. frondose*, *L. edodes* and *G. lucidum* are certain microorganisms which are employed for production of SiO2 nanoparticles that have a size of 25 nm and are spherical in shape. They have a widespread us in electronic devices and pharmaceuticals.[1]

SOURCES FOR NANOPARTICLE SYNTHESIS

Nanoparticles can be synthesised by using natural sources. For this purpose, various biological organisms like plants and microorganisms are in demand.

Plants

Phyto nanotechnology is an eco-friendly, cost-effective technique of synthesising nanoparticle.[6] Advantages of this method include- biocompatibility, scalability and the applicability of universal solvent, water, which is often used as a reducing medium. Plants prove beneficial, fulfilling and advantageous as they are readily available and nontoxic and their culture preservation is not required. Plants have extreme potential for use in environmental and biomedical fields.[7] Table 1 summarizes various plants as sources of nanoparticle production.

Table 1: Examples of plants as sources of nanoparticle production.

S. no.	Plant name	Nanoparticle synthesised
1.	*Cocos nucifera*	Lead
2.	*Abutilon indicum*	Copper oxide
3.	*Ocimum sanctum*	Silver
4.	*Catharanthus roseus*	Gold

Microorganisms

Microorganisms such as fungi, algae and bacteria are potentially greener substitutes for nanoparticle production. Use of microorganisms has proved to be eco-friendly and non- toxic, for nano production. They can synthesise metal nanoparticles extracellularly and intracellularly. However, extracellular synthesis has received much attention because methods such as sonication, of cell wall, several centrifugation, and washing steps are not required, which are otherwise used for intracellular processes.[6] Table 2 summarizes various microorganisms as sources of nanoparticle production.

Table 2: Examples of microorganisms as sources of nanoparticle production.

S. No.	Microbe	Nanoparticle synthesised
1.	Bacteria a) *Bacillus amyloliquefaciens*	Cadmium sulfide
	b) Pseudomonas stutzeri	Silver
	c) Bhargavaea indica	Silver and gold
	d) Marinobacter pelagius	Gold
2.	Fungi a) *Neurospora crassa*	Silver, gold
	b) Fusarium solani	Gold

SYNTHESIS OF NANOPARTICLES

Numerous methods are employed for nanoparticles production. The choice of method of preparation of nanoparticles is important because it has a strong influence on the morphology including structure and size, stability, and certain other properties.[8]

Bottom-up method

Bottom-up or constructive method is the production of nanomaterials from atoms to tiny clusters of nanoparticles. There are various methods involved such as spinning, pyrolysis, sol-gel, biosynthesis, etc.[9]

Top-down method

Top-down method, often known as destructive method, includes breaking down a bulk material into nanoscale particles. They are simple to carry out, however, they are not ideal for manufacturing nanoparticles of very small size.[9] Examples are Mechanical milling, Nanolithography, Thermal decomposition, Laser ablation.

Chemical synthesis

Chemical reduction

This is the most widely used approach. In this, reduction is mediated by organic and inorganic reducing agents. Examples of reducing agents - Sodium citrate, ascorbate, Sodium borohydride (NaBH4), Poly (ethylene glycol), elemental hydrogen, Polyol process, N, N-dimethylformamide (DMF).[10]

Sol gel method

A colloidal suspension (sol) and gelatin are used to form a network in liquid phase (gel). The most often used silica gel ingredients are Tetramethoxysilane (TMS) and Tetraethoxysilane. The catalyst is then added to a homogenous solution of selected alkoxides. Hydrolysis, condensation, particle growth, and particle agglomeration are the four main processes in the production of a sol-gel.[8]

Tollens method

The principle behind Tollens method is the reduction of Ag $(NH_3)_2$ (as tollens reagent) by aldehyde. It is most commonly used for the synthesis of silver nanoparticles. This process has been somewhat modified in that silver ions are reduced to saccharides in the presence of ammonia, resulting in silver nanoparticles of various shapes. The size of the nanoparticles generated is related to the amount of ammonia present.[10]

Chemical vapor deposition method

In this method, a thin layer of target material is deposited on the surface. The production of this film is the outcome of a chemical reaction between atoms in a gaseous molecule. The target material is released as a volatile molecule that acts as a precursor, and a sequence of chemical interactions occur between the precursor fragment, the precursor, and the substrate surface to form a thin layer.[8]

Green synthesis

Since the chemical methods used are too expensive, eco-unfriendly, and incorporate the use of toxic chemicals which are harmful for use and environment, the need for biosynthesis came up. The biosynthetic path is a very safe, relatively cheap, and environment-friendly green approach which uses plants and microorganisms for nano production.[7]

Synthesis of nanoparticles from microorganisms

Extracellular synthesis

Microorganisms are first cultured in a rotating shaker under optimum conditions (including pH, temperature, medium components, etc.). Then after culturing, the culture is centrifuged. Then the resultant supernatant is used to synthesize nanoparticles by addition of metal salt solution which is incubated. Then the colour change of the culture medium is observed. Different colours are observed which are different for different metals like, for silver nanoparticles, the colour changes to deep brown, for gold nanoparticles, the colour changes from ruby red to a deep purple colour. After incubation, the reaction mixture is again centrifuged at different speeds to remove any large particles. The final stage involves the isolation of nanoparticles in which the nanoparticles are centrifuged at high speed. After centrifugation, the supernatant is discarded, and the pellet is washed thoroughly in water/solvent (ethanol/methanol) and collected in the form of a pellet.[6]

Intracellular synthesis

Here also microorganisms are first cultured and then collected by centrifugation and then washed with water. Then metal salt solution is added, and the reaction mixture is incubated. The reaction mixture is interpretated by a colour change.[6] The mixture is removed by ultrasonication, washing and centrifugation. This is done to break down the cell wall so that the nanoparticles are released. The mixture is then centrifuged, washed, and collected.

Synthesis of nanoparticles from plants

Many plant parts such as leaves, fruits, roots, stem, and seeds are employed in the production of different nanoparticles due to the presence of phytochemicals such as alkaloids which act as reducing agent. The process begins with a thorough cleaning of the plant parts with distilled water. They are then chopped into little pieces and are boiled for extraction. Following this step, purification occurs. Filtration and centrifugation are used to purify the plant extracts. The essential elements for nanoparticle synthesis are plant extracts, metal salt solution, and water. All ingredients are incubated until a colour change is noticed. The reduction of metal salt is the mechanism through which plants produce nanoparticles, it is similar to that of isolation of nanoparticles from microorganisms. The nanoparticles are centrifuged at high speed. After centrifugation, the pellet is washed thoroughly in water/solvent (ethanol/methanol) and collected in the form of a pellet.[6]

NANOPARTICLE CHARACTERIZATION APPROACHES

Nanomaterials, according to Liu et al., have a unique structure and size, and are likely to have a variety of biological roles. The discovery of novel materials, processes, and phenomena at the micro- and nanoscale will open new avenues for the fabrication of novel nano systems and nanostructures. Molecular techniques such as UV–visible Spectroscopy, Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy (SEM), Dynamic Light Scattering (DLS), and others are used to characterise metal nanoparticles. The next sections go into the specifics of these strategies.[11]

UV-Visible Spectroscopy

Generally, it is also used to monitor the production and stability of Ag nanoparticles and is a very reliable and effective approach for the main characterisation of produced nanoparticles. Because noble metal nanoparticles have a vivid hue that can be seen with the naked eye, UV–visible spectroscopy is a valuable tool for characterising them. The surface plasmon resonance of these nanoparticles is size and shape dependant and they have a high extinction coefficient. As a result, this approach can provide qualitative information on nanoparticles. Beers law is used to determine absorption. The absorption value (A) is primarily determined by the nanoparticle concentration, measuring the cell path length (l) and nanoparticle extinction coefficient (ε).

$A = \varepsilon c l$

The absorption bandwidth decreases as the size of the nanoparticle decreases in the intrinsic size zone and grows as the size of the nanoparticle increases in the extrinsic size region. The SPR exhibits a red shift in the extrinsic area as the particle size rises. The colour of gold nanoparticles changes as their size increases, from ruby red to purple and finally blue. Metal nanoparticles have optical features that can be exploited to construct sensors. Furthermore, UV–Vis spectroscopy is quick, straightforward, simple, and sensitive for various types of nanoparticles, requires just a brief measurement time, and does not require calibration for particle characterization of colloidal suspensions.[11]

Fourier transform infrared spectroscopy (FTIR)

FTIR is a useful technique since it has a number of advantages over traditional IR spectroscopy. FTIR identifies the functional groups bonded to the metal nanoparticles surface and presents a different identical absorption pattern than that of free groups, providing information about the surface chemistry of nanoparticles.[11]

Scanning electron microscopy (SEM)

Nanoscience and nanotechnology have now enabled very high-resolution microscopy ways to explore and illustrate nanomaterials in great detail using a ray of high-energy electrons. SEM is essentially a surface imaging technique capable of resolving a wide range of particle sizes, size distributions, nanomaterial forms, and particle surface topology at the micro- and nanoscale. The image of a specimen's surface is created in a scanning electron microscope by scanning the surface with an accelerated voltage electron beam. The detector collects backscattered and secondary electrons, which are then processed to produce pictures or images.[11]

Dynamic Light Scattering (DLS)

The most frequent method for analysing hydrodynamic particle size and distribution over a range of sizes is dynamic light scattering. The Stokes-Einstein equation is used to evaluate light interference based on the Brownian motion of nanoparticles in the suspension and a correlation of their velocity (diffusion coefficient) with their size. The polydispersity index (PDI), which is an output of the autocorrelation function, depicts the particle size distribution. PDI values range from 0 to 1, with 1 denoting a highly heterogeneous population and 0 denoting a relatively homogeneous population of nanoparticles. Non-spherical particles, like rods can also be analysed by this technique, using multiangle DLS.[12]

APPLICATIONS OF NANOPARTICLES

Nanoparticles are employed in everyday life because of their unique features. Nanoparticles have been discovered to be employed in optical product forms, disinfectants, fabric cleansers, food packaging materials, biosensors and diagnostics, biology and medicine, cosmetics, textiles, electronics, opticals, composites and energy, agricultural goods and other fields. However, pharmaceutical and biological science is where nanoparticles are most useful. In addition to their applications in medicinal products, nanoparticles generated by noble metals such as gold, silver, palladium, and platinum are frequently utilised in consumer goods such as lotions, soaps, toothpastes, shampoos and shoes. Silver zeolites are useful for disinfection, food preservation, and product decontamination. Because of their eco-friendliness, nanoparticles are also utilised as excellent biofertilizers and biopesticides to control plant diseases in crops.[11]

Drug Delivery

The most important consideration when designing and developing novel medication delivery systems is the precise and secure delivery of pharmaceuticals to their target locations at the appropriate time. The reasons for this are to achieve a regulated release and the greatest therapeutic impact. Targeted Nano conveyors must pass through blood tissue obstacles to reach the target cells. Furthermore, to reach targeted cells, targeted nano carriers must contact cytoplasmic targets via particular endocytotic and transcytotic transfer pathways. Magnetic nanoparticles such as Fe_3O_4 (magnetite) and Fe_2O_3 (maghemite) are known to be biocompatible. They've been researched dynamically for a variety of reasons, including target cancer therapy (magnetic hyperthermia), stem cell categorization and manipulation, trained drug delivery, gene treatment, and DNA examination and MRI. Silver nanoparticles have been widely used as new therapeutic components, with their use expanding to include antibacterial, antifungal, antiviral, and anti-inflammatory properties. Kalishwaralal et al. Studied silver nanoparticles with antiangiogenic properties produced by *Bacillus licheniformis* in this regard.[13]

Antibacterial Agents

With the recent breakout and escalation of microorganism resistance to a variety of antibiotics, there has been a focus on silver-based antiseptics. The production of silver nanoparticles was achieved using the fungus *Trichoderma viride*. When exposed to a *T. viride* filtrate, aqueous silver ions in solution were reduced, resulting in the creation of extremely stable Ag-NPs with a size range of 5–40 nm. In addition, the nanoparticles were tested for their enhanced antibacterial properties against Gram-positive and Gram-negative bacteria using a variety of antibiotics.[13]

Biosensor

Nanoparticles can be used in biosensor applications because of their appealing optical and electrical properties. Zheng et al. discovered that the manufacture of Au-Ag alloy nanoparticles by yeast cells was used to fabricate a sensitive electrically chemical vanillin sensor. Furthermore, electrochemical investigations revealed that a vanillin sensor based on Au-Ag alloy nanoparticles-modified glassy carbon electrode may boost the electrochemical response of vanillin by at least five times. Under optimal operating conditions, the oxidation climax flow of vanillin at the sensor increased linearly with its condensation in the size range of 0.2–50 M with a tiny detection limit of 40 nM. This vanillin sensor was used to determine the amount of vanillin in a vanilla bean and a sample of vanilla tea. It is possible that it could be useful in vanillin-controlling systems. AuNP-based glucose oxidase (GOx) biosensors were developed in a separate study based on observations revealing the enhancement of GOx enzyme activity by AuNPs. The glucose biosensor has a linear response range of 20 mM to 0.80 mM glucose and a detection limit of 17 mM (S/N = 3). This type of biosensor was used to determine the glucose content of business glucose injections.[13]

Agriculture

Elgorban et al. (2016) used the fungus *Aspergillus versicolor* to make silver nanoparticles and studied their impact on *Sclerotinia sclerotiorum* and *Botrytis cinerea* in strawberry plants. The nanoparticles had concentration-dependent action against both pests, with *B. cinerea* having the largest effect.[14]

Pest Control

Gherbawy et al. (2013) used *Trichoderma harzianum* to make silver nanoparticles, which they combined with triclabendazole to suppress the parasite Fasciola sp., which affects sheep and cattle. When tested on the larvae and pupae of the dengue vector mosquito *Aedes aegypti*, Sundaravadivelan and Padmanabhan (2014) produced silver nanoparticles from *Trichoderma harzianum* filtrate and observed concentration-dependent death.[14]

PROSPECTS

The use of fungi to make nanoparticles has been shown to be quite useful in a variety of fields. The development of a smart delivery system for medications to a specific location will aid disease diagnostics. The development of smart biosensors and detecting systems will aid in the protection of agricultural crops from insects and pathogens. In a nutshell, myco-nanotechnology is still in the works. The use of nanoparticles will continue to expand, but more research into their toxicity, environmental build-up, and impact on human and animal health is still needed. There is also a new optimism that nanoparticles may be employed to treat a variety of serious ailments, perhaps opening a new scientific profession. To reach various milestones in the fields of medicine, agriculture, cosmetics, electronics, and the environment, additional research is needed to explain and elaborate the knowledge and functions of nanomaterials. Despite the numerous advantages of fungal-mediated metal nanoparticle manufacturing, it still has several limits and problems to overcome before it can be employed in practise.

In addition, more research is needed to optimise the various reaction conditions to get better control over the nanoparticles' size, shape, and mono-dispersity. Furthermore, nanoparticle stability is a crucial factor to consider. All these restrictions must be overcome by targeted research and the creation of innovative tactics in this field. The exact mechanics of fungus-based nanoparticle manufacturing have yet to be fully explored. As a result, more research and testing are required to elucidate the specific mechanism and identify the biomolecules responsible for nanoparticle reduction and stability. In this sense, low-cost recovery solutions must be developed for the production process to be commercially viable.[11]

CONCLUSION

Nanotechnology is the molecular approach to build effective metal particulates which are generally stable. In the near future, it is assumed that nanotechnology will have a revolutionary impact on the production of various needful things. Nanoparticles such as gold, silver are having increasing demands in various fields such as medicine, agriculture, cosmetics, energy, etc. due to their efficacy and extremely small size. The use of plants or microorganisms for green synthesis of nanoparticles is still developing, which has immense beneficial effects on the environment. Despite having benefits, there is a concern regarding the development of nanoscience which is the long-term result for mankind due to the accumulation of nanoparticles, because after all nanoparticles are nothing but metals, so this concern must be resolved in the future for sustainable mankind. If the research on nanoscience is continued at the current rate in the future as well, then in no time nanotechnology will be widely accepted and will prove beneficial to mankind. Microbes have a lot of potential for making metal nanoparticles, which has a lot of applications. Mycogenesis of nanoparticles has sparked a lot of interest in this area in recent years. It has been discovered to be an efficient and acceptable method for the synthesis of numerous types of nanoparticles with substantial potential and applications in industries such as agriculture, food, textiles, medicine, cosmetics, optics and electronics. The use of fungi to make nanoparticles has the benefit of being simple to handle and process later. Nanoparticles of varied compositions have been restricted to metals, some metal sulphides, and very few oxides in recent years. As a result, a methodology for noble synthesis of nanostructures of various metal oxides, nitrides, carbides, and other materials is needed.

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