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Biogenic Nanoparticles: A Comprehensive Review of Synthesis Approaches and Emerging Applications

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Abstract
The study of biologically generated nanoparticless made from plant derivatives has become one of the most well-known areas of study in the world of material sciences and the investigation of their application. The focused research being done on nanocatalysts is focused on the range of green catalysts' applications, including their anti-oxidant and anti-microbial properties. The enormous plant diversity is the cause for this dearth of investigation, and the potential that plants offer for synthesizing these NPs has largely gone untapped. This overview begins with a discussion of the categorization of nanoparticles and the several ways they may be made before moving on to the biogenic synthesis of Pt, Pd, Fe, Ag, Au, Cu, TiO2, ZnO, and CdS nanoparticles. The authors' goal was to present broad information regarding green NPs synthesis and their uses in many areas. The aim is to decrease the negative effects of synthetic processes, the chemicals used in conjunction with them, and the derivative products. This research will focus on the utilization of natural resources like algae, bacteria, fungi, and plants in the creation of energy-efficient, environmentally friendly and cost-effective metallic NPs that are free from toxicity.

Keywords: Biogenic synthesis, catalysis, green chemistry, metal nanoparticles, biochemistry

Introduction

In recent times, The fundamental goal of this merger of biologically based technologies, environmentally friendly chemical processes, and nanotechnology is to develop ingenious materials and industrial methods that lessen the use of risky materials [1].

Nanotechnology has brought about significant advancements in human history, and the production of nanomaterials with precise structures and exceptional properties has become a prominent area of nanomaterial research[2]. This exceptional technology, which enables the manipulation of matter at the molecular level, has enticed significant consideration from researchers due to its numerous potential applications in area such as electronics, magnetics, agriculture, chemistry, geology, biomedicine, optics and more.

Recent decades, scientists have dedicated their efforts to developing and studying distinctive nanostructural forms like nanowires, NPs, nanotubes, and nanospheres. These structures have shown promising applications in advanced materials. Amidst the wide range of nanomaterials that have surfaced, NPs are considered the elemental foundation of Nanotechnology. Nanomaterials exhibit distinct properties when compared to their bulk counterparts, and these attributes can be customized to achieve novel and altered functionalities. Due to their

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exceedingly tiny size, form, and size distribution, they possess these outstanding qualities. Nanomaterials relate molecular structures to bulk-scale materials because of their extremely small size [3].

Nanomaterials are categorized into two groups based on their chemical composition: organic and inorganic. In contrast to organic nanostructures, which are made of carbon and contain noble metals like Au, Pt, and Ag, inorganic nanoparticles include semiconductors like TiO2 and ZnO as well as magnetic elements like iron oxide (Fe3O4). Metal/metal oxide nanoparticles are currently widely used in various disciplines, such as medical science, catalytic activity, anti-microbial uses and cancer research[4].

Classification of nanoparticles

NPs are categorized into various groups depending on their morphology, size, and shape[5].

A) Organic nanoparticles

Organic nanoparticles, also referred to as polymeric nanoparticles, are highly suitable for drug delivery due to their desirable characteristics. The utilization of these nanoparticles in targeted drug delivery applications is widespread. The predominant shape of organic nanoparticles is the nanosphere which are small spherical particles or nanocapsule which are hollow NPs with core-shell structure such as micelles and liposomes [6]. One of the notable advantages of organic nanoparticles is their non-toxic nature, as well as their biodegradability. In the case of matrix particles, it has solid mass, and on the outer surface of the spherical boundary, additional molecules are adsorbed. Conversely, the particles encapsulate a solid mass.

B) Inorganic nanoparticles

Compared to organic materials, inorganic nanoparticles exhibit non-toxicity, hydrophilicity, biocompatibility, and exceptional stability. The advancement of novel materials enhanced the development of drug delivery systems aimed at enhancing drug effectiveness and minimizing adverse effects. Inorganic NPs can be diversified into two main groups: metal nanoparticles and metal oxide NPs.

1. Metal nanoparticles

Metal nanoparticles composed of Al, Au, Fe, Ag, Zn, Co, Cu, and Cd have gained widespread acceptance. Their unique properties stem from their size which ranges from 10-100 nm, which influences characteristics like ratio of surface area to volume, amorphous structure, size of pores, , surface charge ,crystalline, surface charge density and diverse shapes (including irregular, spherical, hexagonal rod-like, tetragonal, and cylindrical), color, and response to natural factors like sunlight, moisture, air, and heat.

2. Nanoparticles of metal oxides

Due to the possible technological uses of these substances, nanoparticles made of metal oxide represent a subject of materials chemistry that is of great interest. The effects of these materials on industries including catalysis, energy storage, medicine, information technology, and sensing have spurred extensive study into creating synthetic routes to such nanostructures. To alter the characteristics of appropriate metal NPs, metal oxide NPs are made. For instance, oxidation can

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change iron nanoparticles into iron oxide nanoparticles. Iron oxide nanoparticles are more reactive than iron nanoparticles in terms of surface area. An increase in the metal oxide's reactivity and efficacy causes the production of metal oxide nanoparticles.

C) Bionanoparticles

Bionanomaterials are the best substitute for hazardous conventional nanoparticles in biomedical applications, it has been discovered. Bionanomaterials are produced using biomolecules or that encapsulate or immobilize another form of nanomaterial using a biomolecule. Biomolecules are taken out of bacteria, plants, waste from agriculture, insect species, aquatic organisms, and certain animal species to make bionanomaterials. These bionanomaterials showed increased biocompatibility, bioavailability, and bioreactivity in addition to having zero or very low toxicity towards humans, other living things, and the environment [7].

D) Ceramic nanoparticles

The majority of ceramic nanoparticles are made up of the oxides, phosphates, carbonates and carbides of different metalloids and metals, including Si, Ti, Ca and others. These NPs are extremely adaptable as they have multiple advantageous characteristics, which include strong heat resistance and chemical inertness. Among their many applications, ceramic NPs have been extensively studied in medical field. In the biomedical domain, ceramic nanoparticles are highly regarded as exceptional carriers for medications, genes, proteins, and imaging agents, offering superior performance in these applications, etc.[8].

Green Chemistry Principles

Green chemistry and nano engineering work to lessen risks to health of human and the nature while enhancing the efficiency of products in the chemical supply chain. Green chemistry's measurements and guiding principles can have an impact on a chemical's entire life cycle, from creation to disposal. The 12 guiding green chemistry principles offer a framework that is accepted by designers, policymakers, and chemists as well They were first published in 1998[59].

Green chemistry encourages the creation of goods that are eco-friendly throughout their whole lifespan. This entails minimizing the environmental effect at each stage of the product lifetime, from raw material extraction through disposal. Green chemists work to develop products that are sustainable and contribute to a healthy environment by placing a high priority on recyclability, biodegradability, and decreased resource use.

Waste reduction, the use of safer chemicals, energy efficiency, renewable feedstocks, and environmentally friendly product design are the core tenets of green chemistry. Chemists may take important steps towards a more sustainable and environmentally sensitive approach to chemical research and production by using these concepts.

Green chemistry uses a range of techniques to encourage ecologically responsible and sustainable chemical practices. One such technique is the idea of "atom economy," which aims to maximize chemical processes' efficiency by using all the atoms available in the reactants to produce desired products, hence generating the fewest amount of waste possible. Another useful tool is catalysis, which uses catalysts to speed up processes, spend less energy, and provide softer

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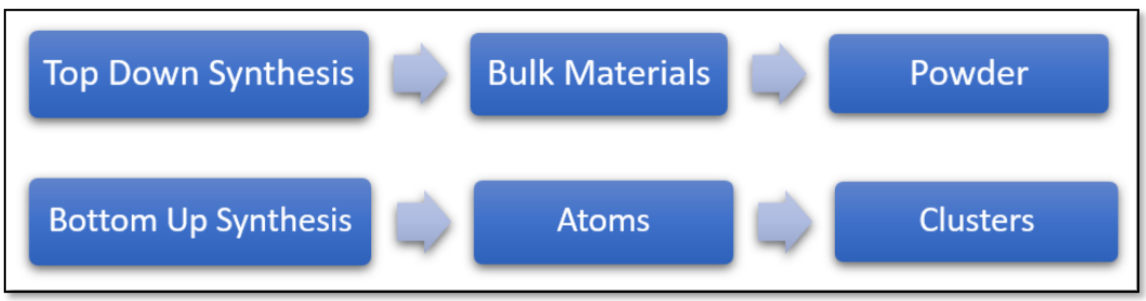
reaction conditions. Green chemistry supports sustainability by using sustainable feedstocks such biomass and agricultural waste, which decreases dependency on non-renewable resources. Another strategy utilized in green chemistry is the use of cleaner solvents, which are less hazardous and more readily recyclable. A fundamental strategy known as "design for degradation" makes ensuring that substances are created that degrade safely in the environment, reducing their negative effects on ecosystems. Energy effectiveness is important, and green chemistry encourages techniques including enhancing reaction conditions and making use of alternative energy sources. Last but not least, life cycle assessment (LCA) enables informed decisions and increases sustainability by evaluating the environmental effect of items or activities from extraction to disposal. These techniques are used by green chemistry in an effort to develop a more ecologically responsible and sustainable chemical industry.

Synthesis of nanoparticles

Green Synthesis:

Combining several common techniques has been used to create nanoparticles. These conventional methods have several downsides, including the cost, the generation of dangerous lethal chemicals, and others. As a result, researchers have been working to develop safe, environmentally friendly alternative methods for synthesising nanoparticles. Among these methods, biological systems have been targeted and used as an ecofriendly approach for nanoparticle synthesis. Unquestionably, biological systems have a special capacity for producing precise shape and controlled structures. The processes known as "Top-down" and "Bottom-up" can be used to broadly categorise the techniques used to create nanoparticles [58].



Top-Down Synthesis Method:

The formation of nanoparticles frequently involves a number of processes, including, nanolithography, mechanical milling, sputtering, thermal breakdown and laser ablation. These techniques use a top-down or destructive strategy to break up huge materials into minute pieces.

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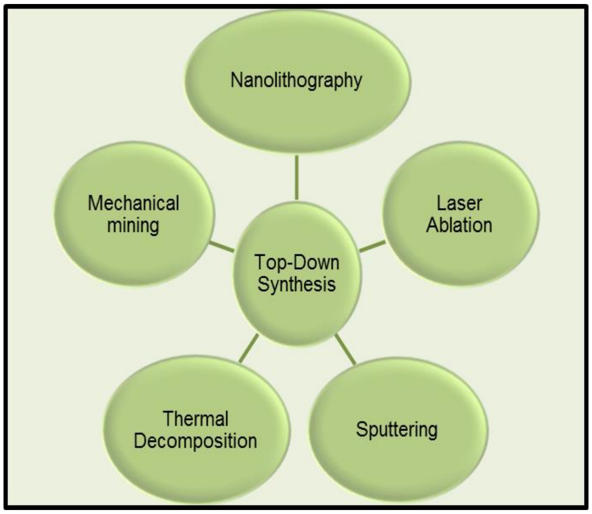


1. Nanolithography: The study of producing structures at the nanoscale scale having only one dimension and size ranging 1 and 100 nm, is known as nanolithography. Nanolithographic techniques come in a variety of forms, such asscanning probe lithography, optical, multiphoton electron-beam and nanoimprint [60]. Lithography, in its widest meaning, refers to a technique that involves embossing a desired structure into a material which is sensitive to beam of light. It accomplishes this by carefully choosing which material to remove, so forming the required shape. The fundamental advantage of nanolithography is its capacity to produce any item with the required form and size, from a single nanoparticle to a cluster. The cost for specialised equipment are the downsides. [61].

2. Laser Ablation:To produce nanoparticles from various solvents, the Laser Ablation Synthesis in Solution (LASiS) method is frequently utilised. A plasma plume condenses and nanoparticles are produced when a metal is subjected to a laser beam while immersed in a liquid solution [62]. It provides a different method for creating metal-based nanoparticles. Because LASiS enables stable nanoparticle synthesis in both organic solvents and water, eliminating the need for any chemical additives or stabilising agents, it is a "green" technique.

3. Sputtering: Sputtering is a process wherein particles are expelled upon colliding with ions, resulting in the deposition of nanoparticles onto a surface [63]. Sputtering can be succinctly characterized as the deposition of a thin layer of nanoparticles, which is subsequently followed by annealing. The substrate type, annealing temperature, annealing time, layer thickness, and other factors affect the structure and size of the nanoparticles [64].

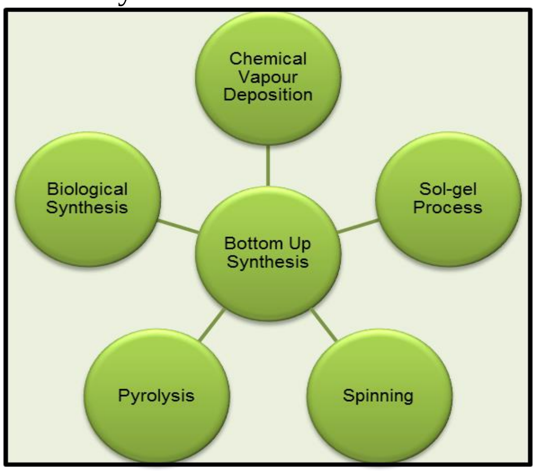
4.Thermal Decomposition:
When heat breaks down a compound's chemical bonds, an endothermic reaction takes place, which is known as thermal decomposition [65]. When material begins to break down chemically, the temperature is known as decomposition temperature. Nanoparticles are created by submitting a metal to a chemical reaction that creates by products at a certain temperature.

5.Mechanical Mining
Among the different techniques available, mechanical milling is widely recognized as the leading top-down approach for producing extensive range of NPs. This process involves milling various

components in an inert environment and employed for the synthesis of nanoparticles, followed by post-annealing [66]. In mechanical milling, the size and shape of particles are influenced by processes such as cold welding, fracture, and plastic deformation, which collectively determine their final characteristics.

Bottom- Up Synthesis Method:

The bottom-up approach to comprehending material structure revolves around the interactions among atoms, clusters, and nanoparticles. Various techniques fall under the bottom-up category, which are employed to produce nanoparticles. These include chemical vapor deposition (CVD), sol-gel, pyrolysis, spinning, and biosynthesis.



Chemical Vapour Deposition:

The process involves depositing a fine layer of gaseous reactants onto a substrate using a technique known as chemical vapour deposition. At ambient temperature when gas molecules combine, they lead to a process of deposition. Upon heating, the combined gas contacts the substrate, initiating chemical reactions [67]. As a consequence of these reactions, a thin film of the product is formed on the substrate surface. This film can be retrieved and reused for subsequent purposes. The substrate temperature is a determining factor in CVD. This method creates uniform, hard and highly pure NPs. Having to use specialised equipment and producing highly toxic gaseous byproducts are two drawbacks of CVD [68].

Sol- gel Process:

A colloidal suspension of solids in a liquid phase is commonly called as a sol. When a macromolecule of solid is immersed in a solvent, it forms a gel. Sol-gel is a widely embraced bottom-up technique that stands out for its simplicity and its capacity to generate a diverse array of NPs. This wet chemical process involves, a chemical solution acting as the initial stage, giving rise to the creation of distinct particles within a unified system. Metal oxides and chlorides are among the most commonly employed precursors in the sol-gel process [69]. These precursors are mixed, stirred, or sonicated into a host liquid to establish a system containing both liquid and solid phases. Several techniques, including centrifugation, filtration, and sedimentation, are used to recover the nanoparticles [70].

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Spinning:

Through the use of a spinning disc reactor (SDR), nanoparticles are spun up. It comprises of a rotating disc that is put within reactor where physical factors, including temperature, may be adjusted. Nitrogen or another inert gas is frequently pumped into the reactor to halt chemical reactions [71]. Water and precursor are fed into the spinning disc through pumps operating at different speeds. The rotational motion brings the molecules into closer proximity, leading to their precipitation, aggregation, and subsequent drying. [72].Several operational parameters, such as disc rotation speed, liquid flow rate, feed location, liquid/precursor ratio, disc surface, and others, have an impact on the properties of nanoparticles produced through SDR.

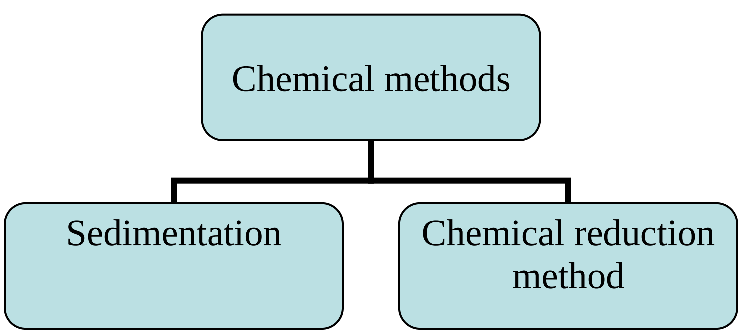
Pyrolysis:

In the industry, pyrolysis is predominant method used for the large-scale synthesis of NPs. The technique involves burning a precursor using flame. A minute aperture in the furnace is utilized to introduce the precursor, which may exist as a liquid or a vapor. Subsequently, it undergoes combustion under high pressure. [73]. The combustion gases are subjected to air classification in order to retrieve NPs. Certain furnaces utilize laser and plasma technology to achieve high temperatures for evaporation, instead of relying on conventional flames. [74]. The advantages of pyrolysis include being affordable,efficient, simple, continuous process with a high yield.

Biological Synthesis: Biosynthesis is an environmentally friendly, non-toxic approach to manufacturing biodegradable NPs. Biosynthesis creates NPs utilising bacteria, algae, plant extracts, fungus, and other precursors rather than using traditional chemicals for bio reduction and capping [75].

Chemical methods

Sedimentation and chemical reduction processes can be utilized to chemically create NPs. Hydrothermal, sol-gel, co-precipitation, and alkaline precipitation techniques are used in the sedimentation process, while polyol, organic acids, sodium borohydride, and sugar are used in the chemical reduction process[76].



Disadvantage of using chemical methods

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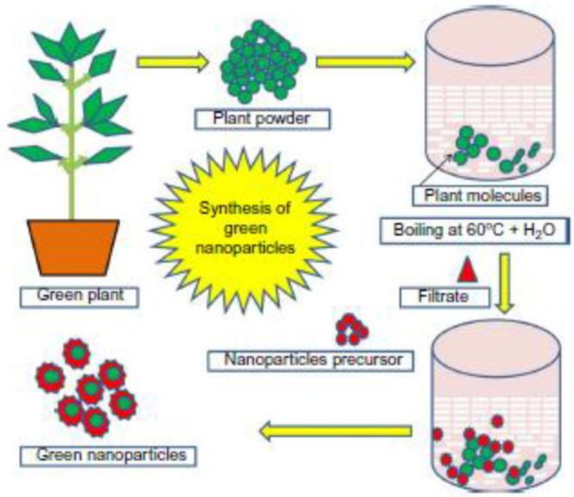
- High cost of equipment
- Large-scale manufacturing is challenging
- The need for chemical purification of nanoparticles
- Use of organic solutions that can be toxic
- The lack stability of intermediates and complexes of elements

Green Synthesis of Nanoparticles:



Plant-derived nanomaterials with tenable physio-chemical characteristics have recently received much interest as they have extensive range of uses in numerous industries. To overcome the drawbacks of the physical and chemical techniques, researchers are now employing the biological synthesis methodology. Utilising plant extracts for the biosynthesis of nanomaterials is beneficial, inexpensive, and ecologically friendly because it doesn't need the use of risky chemicals or a lot of energy[77].Exploration and innovation in the realm of herbal and medicinal plant biology are actively underway in order to converge with nanotechnology thanks to advancements in science and technology. One such interference is the synthesis of NPs using plants. Growing interest in the potential of using plants to synthesise nanoparticles on purpose as a dependable and environmentally responsible method of producing and characterising metallic nanoparticles. Since ancient times, people have used a variety of beneficial substances found in plants as traditional medicines. Plants are constantly being studied for a variety of uses in the medical, agricultural, industrial, etc. sectors due to their enormous diversity.These advantages include being easily accessible, safe to handle, and readily available.

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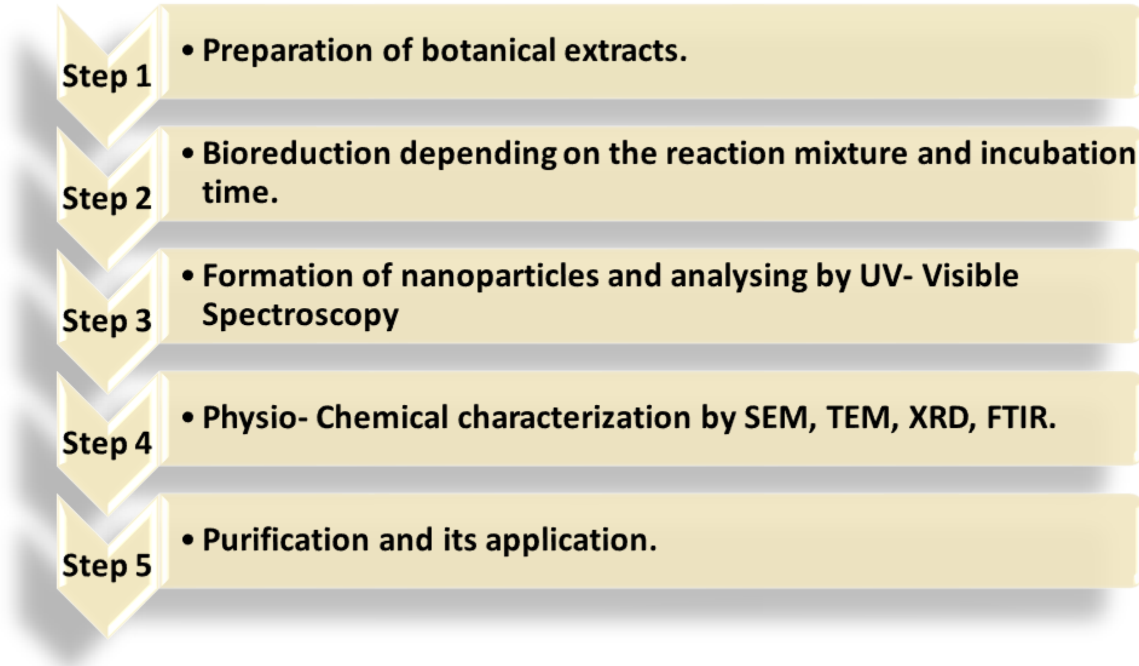
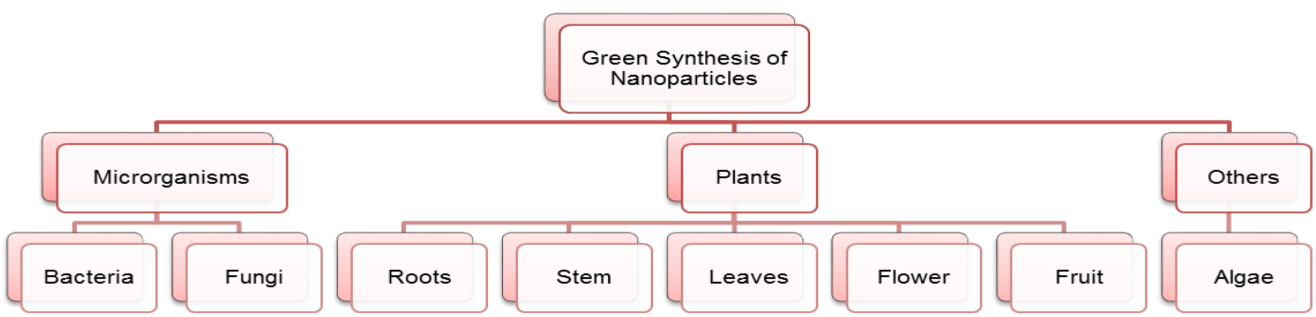


Researchers have adapted biomimetic nanostructures from viruses, bacteria, fungi, algae, and proteins for a variety of applications. The ability to build a variety of highly ordered hierarchical structures in a variety of sizes is possessed by plants. Biomolecules possess specialised recognition abilities or catalytic activity, for example. Biological elements may self-assemble into distinctive superstructures with unique forms based on these identification abilities. They can be used to build nanomachines because they can respond to a variety of physical, chemical, or biological stimuli [78]. The term "biosynthesis of nanoparticles" refers to the process of producing NPs having biomedical applications using microorganisms and plants. This approach is economical, biocompatible, safe, secure, and green. "Green synthesis" is the term used to describe synthesis that involves plants, bacteria, fungi, algae, etc. NPs made using a biomimetic technique may exhibit increased catalytic activity while using fewer expensive and hazardous chemicals. These plant extracts create specific phytochemicals that have stabilising, reducing, and capping properties [79].



As the extract from plant components such asleaves, roots, seeds, stems, and fruits is rich in phytochemicals with anti-oxidant and stabilising characteristics, these portions of plants have

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also been employed to create NPs.[80-86]. According to a common definition, By using biological processes including bacteria, plants, viruses, or their byproducts, "green nano-biotechnology" refers to the application of various biotechnological approaches in the manufacture of NPs. Due to a variety of factors, nanoparticles made utilising green technology have a number of benefits over those made physically and chemically.Green techniques, for example, produce environmentally-friendly products and byproducts. while consuming less energy and expensive chemicals. In order to produce less hazardous chemical products and by-products, academics, researchers, chemical technologists, and chemists adhere to the principles of green chemistry, which consist of twelve guidelines.When synthesizing nanoparticles using a biological system, three crucial steps come into play. These comprise selecting an appropriate solvent medium, opting for a safe and eco-friendly reducing agent, and identifying a non-toxic chemical to serve as a capping agent for stabilizing the nanoparticles produced. [87].

Properties of nanoparticle

Physical Properties:

Nanoparticles possess distinct physical properties that arise from their small size and large surface area-to-volume ratio. Due to quantum confinement effects, nanoparticles exhibit size-dependent optical properties, with their absorption and emission of light varying based on their size. Additionally, nanoparticles can have enhanced mechanical properties, such as increased strength and hardness, due to the presence of surface defects and dislocations. Their small size can also result in lower melting points and unique phase transition behaviors. Magnetic nanoparticles display special magnetic properties and find applications in various fields. Nanoparticles can exhibit different electrical conductivities compared to bulk materials, with semiconducting nanoparticles showing altered conductive behavior due to quantum confinement. Metallic nanoparticles may showcase surface plasmon resonance, which is valuable for sensing and optoelectronic applications. These diverse physical properties make nanoparticles highly versatile and attractive for numerous scientific and technological applications.

Chemical Properties:

Nanoparticles exhibit distinctions from bulk materials in that they have unique chemical characteristics. Since they have a high surface area to volume ratio, nanoparticles are good catalysts with improved catalytic activity. In order to interact with other substances, nanoparticles' surface chemistry might be different from that of the bulk material. Nanoparticle characteristics can be modified by surface functionalization for particular purposes. As a result of their ability to adsorb or absorb substances on their surface or inside of their porous structure, nanoparticles are useful for processes that rely on adsorption. Additionally, nanoparticles can display distinctive redox characteristics and take part in electrochemical processes, making them appropriate for energy storage applications. The surface plasmon resonance that some metallic nanoparticles show increases their potential for use in optoelectronics and sensing.

Biogenic synthesis of nanoparticles

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Platinum Nanoparticles

Platinum NPs can be produced through a method that is both inexpensive and good for the environment. Platinum NPs have been created using a variety of plant extracts. Song et al.[9] successfully synthesized platinum nanoparticles using the leaf extract of *Diospyros kaki*. The average size of the synthesized nanoparticles varied from 2 to 12 nm, and they claimed that at 95°C and 10% leaf biomass concentration, more than 90% of the Pt ions were converted into NPs. In one-pot Pt and PdNP synthesis, lignin isolated from red pine (*Pinus resinos*) was used, according to Coccia et al. [10]. Numerous human health issues have been traditionally treated with the Croton caudatus Geisel.In various parts of Asia, it is applied as a poultice to treat fever and sprains. Due to these potent medicinal qualities, Croton Caudatus Geisel Leaf extract was used in the investigation of a novel platinum nanoparticle synthesis, and their early biological activity was examined[11].

Neem leaf extracts were used to create the Nobel Prize-winning platinum nanoparticles (NPs) in 2016. This demonstrated that neem extract has the ability to convert platinum ions into NPs and has an advantage over other leaf extracts due to neem's widespread availability in India[12]. Using a variety of techniques, including TEM, SEM, XRD, and UV-VIS techniques, the Pt NPs were successfully biosynthesized from *Punica granatum* crust extracts in 2017[13].*P. granatum* contains anti-inflammatory, antioxidant, and anti-HIV ingredients and exhibits anti-inflammatory, antibacterial, and anti-diabetic activity. The ecologically friendly production of monodisperse Pt NPs from P. granatum crusts utilizing an ethanol/water extraction process under ultrasonic

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conditions was investigated, as well as the cytotoxic effects of the Pt NPs against the MCF-7 cell line in vitro.

The healing herb *Ocimum sanctum* (also known as tulsi) is widely distributed and grown in India, Malaysia, Australia, West Africa, and some Arab nations [14]. Traditional medicine has employed tulsi leaves to treat a variety of infections. According to reports, the antibacterial activity is a result of the eugenols, which make up the majority of essential oil components. To combine the inherent antimicrobial properties of platinum metal and Tulsi extract for increased antimicrobial activity, the researchers synthesised platinum nanoparticles from the aqueous extract of Tulsi leaves[15]. In the green synthesis of Pt nanoparticles for studying their effects on different cancer cells, an extract solution derived from Saudi dates and a biodegradable surfactant are utilized. The aqueous extract solution obtained from popular dates like Ajwa and Barni is employed as a stabilizing and reducing agent in the production of Pt nanoparticles under ambient conditions. This approach is favored due to its simplicity, long-term stability, and cost-effectiveness [16]. *Jatropa gossypifolia* and *Jatropa glandulifera*, two Indian medicinal herbs, are used as effective reducing and capping agents in an environmentally friendly method for the formation of platinum nanoparticles. A fantastic pathway for the conversion of platinum ions into platinum nanoparticles was achieved by using an extract made from the leaves of Jatropa gossypifolia and Jatropa glandulifera at a reaction temperature of 100 °C. Ultraviolet-Visible spectroscopy was used to successfully characterise platinum nanoparticles that were bio-synthesised. The existence of amine and amide was verified by FTIR analyses. It was discovered that the reduction of platinum metal to platinum nanoparticles was susceptible to the -SO2 functional group. [17].

Palladium Nanoparticles

Palladium nanoparticles (NPs) have drawn particular interest because of their versatility in a range of industries, including biosensors, catalysis, and medicine. Palladium nanoparticles were created using a green synthesis technique. In the creation of palladium (Pd) from palladium chloride, a straightforward and environmentally friendly approach was adopted, utilizing Anogeissus latifolia, a renewable plant polymer. This non-toxic plant polymer served as both the reducing agent and the stabilizing agent in the process.The appearance of dense brown color and broad continuous absorption spectra in the UV Vis region [18] provided evidence that Pd NPs had formed. The same year, 2015, *Hippophae rhamnoides* Linn leaf extract was used to reduce and stabilize Pd NPs during their synthesis. It was an intriguing, quick, and clean synthetic route for producing Pd NPs on a large scale [19].

For the first time, it has been demonstrated that the alga Chlorella vulgaris can serve as a reducing and capping agent, enabling the production of stable nano-scale palladium particles. This unique and ecologically safe technique proves to be simple, highly cost-effective, and does not require specific parameters such as energy, temperature, hazardous chemicals, or high pressure to successfully generate stable Pd nanoparticles.A study resulted in the development of a straightforward bioprocess for the production of palladium nanoparticles for the first time.[20].It is well known that *Origanum vulgare L.* is a rich source of phenolic compounds; this property was successfully used in the synthesis of Pd NPs, using different concentrations of plant extracts. Furthermore, according to several characterization techniques, the phytomolecules in

OV extract not only contribute to the reduction and development of nanoparticles but also serve as stabilizers. Pd NPs have been successfully used as catalysts for the selective oxidation of alcohols after being examined using UV-Vis, XRD(fig.1.), TEM, FT-IR and thermal gravimetric analysis (TGA)[21].

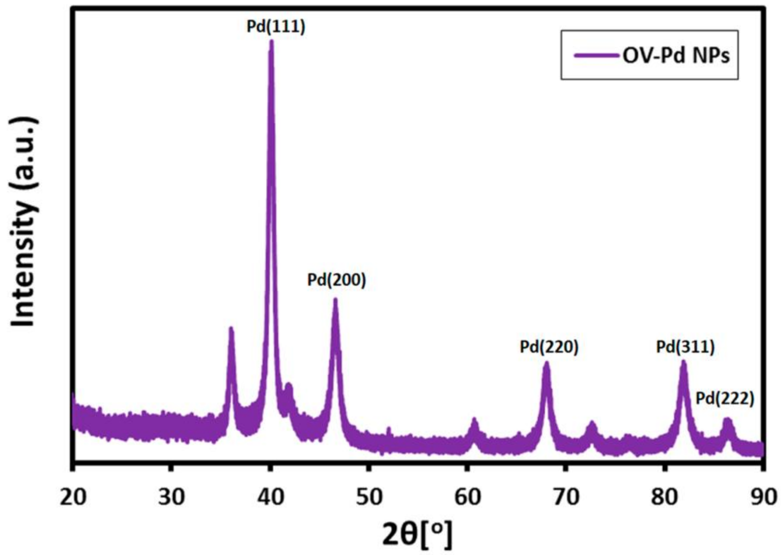

Fig.1. XRD pattern of the synthesized Pd NPs

Prunus dulcis, the scientific name for almonds, is a member of the Rosaceae family and is grown in a variety of climates and subtropical nations. Nonpareil almond hull and shell are agricultural waste that are abundant but have no significant industrial use. Almond shell mostly includes cellulose, hemicellulose, and lignin [22, 23] which is appropriate for support. The antioxidants, phenolic acids, and flavonoids found in almond hull extract are mostly conjugated with other polyols or sugars via O-glycosidic or ester linkages [24, 25]. This substance was employed in the environmentally friendly production of Pd nanoparticles [26].Despite the fact that green wastes have a large number of functional groups, their surfaces are fairly homogeneous, and nanoparticles will collect on them and reduce catalytic activity. In order to solve this issue, the surface was chemically altered using the medication captopril. The outcomes demonstrated that the modified nanocatalyst had extremely high catalytic activity and that there was no discernible decrease in that activity during recycling and reuse. The alkaloid-rich fraction of *Peganum harmala* seed extract was utilised to create Pd NPs in an easy and environmentally friendly way. The alkaloids -carboline and quinazoline, together known as harmala alkaloids, are abundant in *P. harmala* seed and have medicinal properties [27]. Additionally, the seed of P. harmala includes polysaccharides, anthraquinones, flavonoids, and oxygenated monoterpenes (such eugenol), which are essential for the bioreduction of various metal ions [27,28]. P. harmala seeds contain a wide range of biological compounds with antibacterial, antioxidant, and anticancer properties [27,29]. The research has been revealed that Pd NPs made through the green synthesis method using Urtica plant along with characterization was carried out by various spectroscopic instruments including UV-vis, FT-IR, TEM, and X-ray diffraction (XRD) analyses, and their antimicrobial, antioxidant, and DNA-cleaving activities were studied.

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Iron Nanoparticles

Numerous industries, including environmental cleanup and medical biology, use iron-based nanoparticles on a regular basis. Their use in biomedicine includes targeted medication delivery, MRI contrast enhancement, and the tagging and magnetic separation of biomolecules. Environmental cleanup of heavy metals including mercury, nickel, cadmium, lead, and chromium has also made use of iron and its oxide nanoparticles (NPs). The physical and chemical characteristics of iron, which are governed by its size, shape, composition, crystallinity, and structure, have drawn particular interest in nanometer-sized metallic nanoparticles [31]. Utilizing the leaf extract of the plants *Lawsonia inermis* and *Gardenia jasminoides*, iron nanoparticles (FeNPs) were produced in 2015, which was a relatively affordable and straightforward conventional heating approach.Thermal gravimetric analysis (TGA), Fourier transform infrared spectroscopy (FT-IR), scanning electron microscopy (SEM), atomic force microscopy (AFM), and X-ray diffraction (XRD) were used to characterize the iron nanoparticles. Using the well-diffusion technique, the antibacterial activity was investigated against *Escherichia coli, Salmonella enterica, Proteus mirabilis,* and *Staphylococcus aureus*[32]. Iron nanoparticles (Fe NPs) have mostly been biosynthesized utilizing extract of green tea, a readily available, affordable resource. Green tea extract from *Camellia sinensis*, which contains a variety of polyphenols, Hoag et al. [33] synthesized it. Fruit peels were thrown away as necessary byproducts of making fruit juice. *Citrus maxima* peel extracts were used to create iron nanoparticles and lower the amount ofFe(III) in an aqueous solution. By using XPS, EDS, FTIR, TEM, DLS, and Zeta potential procedures, the nanoparticles were identified. 15 asymmetric iron nanoparticles with diameters of 10–100 nm were successfully synthesised [34] based on the characterisation results. The production of iron nanoparticles in 2018 included the utilisation of nephrolepis, spinach leaves, and rosemary plant extract [36]. *Plumeria obtuse* leaf extract was used in the green synthesis of FeNPs, which was likewise a simple, effective, economical, and environmentally beneficial method. To clarify the functionality, stability, and size of the green synthesised FeNPs, several microscopic and spectroscopic methods were used to characterise the NPs. The spherical and crystalline FeNPs were produced at the nanoscale(fig.2.) [38].

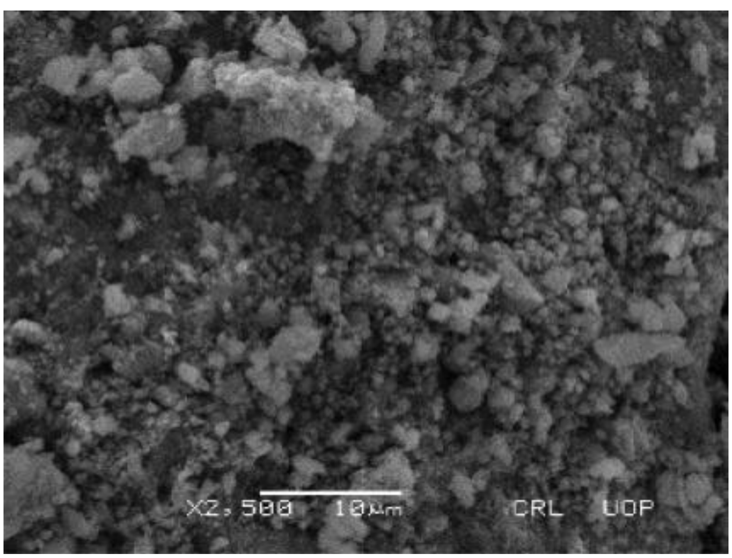

Fig.2. SEM analysis of FeNPs synthesized using *P. obtusa* extract.

In order to assist the reductive synthesis of metals from a metal salt solution, the green synthesis technique just employs extracts of various plant parts as a natural source of material. With the help of several different plants, including *Punica granatum*[39], strawberry leaf extract, eucalyptus leaf extract [40], and orange extract, FeNPs of diverse sizes and morphologies have been effectively synthesised. Red peanut skin extract was also used to create iron nanoparticles [43]. Such plant extracts are a rich source of biomolecules, such as amines and phenols, which may operate as metal reductants and are particularly effective in reducing Fe^{+2} or Fe^{+3} to Fe^{0} in aqueous solution after causing an electron to lose its bound state.[41,42]

Silver nanoparticles

Silver (Ag) metal nanoparticles have drawn a lot of interest recently due to their outstanding properties, which include chemical stability, excellent electrical conductivity, catalytic activity, and antibacterial properties [34]. Utilising plants for the production of AgNPs has garnered interest due to its quickness, environmental friendliness, non-pathogenicity, low cost, single-step biosynthetic process, and presence of significant phytochemicals used as reducing agents for AgNP synthesis.

Croton sparsiflorus leaf extract was used to make spherical, 22–52 nm-sized Ag NPs that were effective against *S. aureus*, *E. coli*, and *B. subtilis*[88]. The strain B. methylotrophicus DC3 was discovered from the soil. AgNPs are produced by this strain. The AgNPs' maximum absorbance was measured using ultraviolet-visible spectroscopy at 416 nm (UV-vis). According to the FE-TEM findings,The size of the particles ranged from 10 to 30 nm, and they were spherical. Another technique used to characterise the result was energy EDX, which showed a peak matching to the Ag nanocrystal [89].

Silver ions and peach gum polysaccharide (PG) were successfully combined to produce silver nanoparticles (Ag NPs).The fcc crystal structure of the it,resulted particles that were on average 23.5677 nm in size..The various synthesis routes were made clear by FTIR [90]. *Azadirachta indica* was utilized to swiftly and readily make silver nanoparticles.The plant's extract serves as a capping and reducing agent. The compounds that are in charge of reducing silver ions were identified by utilising FTIR to analyse the functional groups present in plant extract. A UV-Visible spectrophotometer revealed an absorbance peak between 436 and 446 nm [91].

The production of Ag is easy to perform biogenically as ions of Ag are quickly reduced by plant chemicals in ambient condition.Phytochemicals may change Ag+ into Ag°, which can subsequently be biocapped and biostabilized to form evenly dispersed Ag nanoparticles. The majority of Ag nanoparticles are synthesized at room temperature or under gentle heating conditions (ranging from 30 to 90 °C).Ag nanoparticles were created from green tea leaves by Prema in 2022 using a volume ratio of 5 mL/100 mL for the extract and metallic salt solution. Therefore, it was found that the average size of the produced Ag nanoparticles was between 63 and 69 nm synthesised silver nanoparticles using a ratio of 5 mL/50 mL of orange berry fruit extract at the same AgNO3 salt concentration. Ag particle sizes were significantly smaller (20

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nm), according to the scientists. In a separate investigation, Subramaniam increased the ratio to 50 mL of F. asafoetida extract and 50 mL of 1 mM AgNO3 to synthesize Ag nanoparticles. This led to a particle size range of 5.60–8.66 nm. The observed outcomes were attributed to a more robust capping effect of Ag nanoparticles, which was facilitated by the higher volume of the extract used. [92-95].

The medicinal plant *S. alternifolium*, which is widespread to the Eastern Ghats, produces an aqueous fruit extract that is used in the biosynthesis of stable silver nanoparticles (SNPs). The generated nanoparticles were characterised.The transition from a brown hue to a grey shade signifies the successful formation of nanoparticles, and the SNP status of the newly formed particles is further confirmed by UV-VIS and SPR spectroscopy at 442 nm. In addition, antibacterial experiments on synthetic SNPs indicate significant toxicity towards a number of types of bacteria and fungi. It was the first investigation into the generation of silver nanoparticles from *S. alternifolium* fruit [96].The first demonstration of *Salvia spinosa* plant extract's capacity to biosynthesize silver nanoparticles (Ag NPs) under in vitro conditions. The production of Ag NPs was verified by the surface plasmon resonance seen at 450 nm. Additionally, FESEM pictures demonstrated the spherical form of the nanoparticles. Furthermore, XRD examination verified the particles' crystalline composition[97].

Pomegranate (*Punica granatum*) leaves grown in Egypt have a polyphenol profile that is described in a study, and it shows how these polyphenols are used to create a green synthesis method for AgNPs.Through the application of spectroscopic analysis techniques, the primary phenolic constituent, ellagic acid, was separated and extracted from the polyphenols-rich fraction of the PL aqueous alcohol extract, specifically the ethyl acetate fraction.[98].

Gold Nanoparticles

A number of plant extracts have been used to create gold nanoparticles (NPs). Gold nanoparticles with extremely narrow size ranges between 5 and 20 nm and a spherical form were created using stevia rebaudiana leaf extract [99]. The aqueous extract for this investigation was made from stevia leaves. Numerous conventional and spectroscopic methods have been used to study gold nanoparticles. These nanoparticles are spherical, evenly dispersed, and range in size from 5 to 20 nm, according to TEM examinations.FT-IR spectroscopy revealed that biomolecules containing groups such as -NH2, -OH groups ,carbonyl groups, , and other stabilising functional groups were used to functionalize gold nanoparticles [102].

It has been shown that kokum fruit extract can be utilized to produce photoluminescent AuNPs possessing catalytic and antioxidant properties. The biogenic AuNPs were examined by SEM, TEM, FT-IR, XRD and UV visible spectroscopy. The excitation spectrum exhibits a broad band with a peak excitation at 311 nm, while the emission spectrum shows a band with a maximum emission at 455 nm,were detected during the photoluminescence research. Notably, it was shown that the fluorescence emitted by AuNPs depended on excitation[101].
The application of Cibotium barometz root extract in the environmentally friendly manufacture

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of gold and silver nanoparticles, which had spherical crystals of size range 6 nm 23 nm, was also emphasized[103].

A green technique has been developed to produce AuNPs from papaya leaf extract usingHAuCl4. The leaf extract has stabilising and reducing effects. The generated AuNPs were investigated utilising TEM, FTIR, XRD, Zeta potential, and UV-visible spectrophotometer techniques. The results demonstrated that the generated nanoparticles had diameter in the range of 15nm to 20 nm, were spherical in shape, crystalline, stable, and well diffused[104]. One-pot green biosynthesis of gold nanoparticles (AuNPs) using Croton Caudatus Geisel extract is revealed by reducing chloroauric acid (HAuCl4) with it[105].

Using fruit extract of *Olea europaea* and husk extract of *Acacia nilotica*, AuNP were sythsized.[106], *Lawsonia inermis* leaf extract[107],*Myristica fragrans* leaves[108],*R. roseus* extract[109],*T. terrestris* floral extract[110] were also reported.

Copper Nanoparticles

In several industries, including electronics, catalysis, and biomedicine, copper and its compounds play a crucial role. Since copper has strong electrical conductivity, it is frequently used in contemporary electronic circuits. The catalytic and optoelectronic characteristics of copper nanoparticles make them of tremendous technological relevance. The leaf extract of tulsi is an excellent green source for producing NPs by reduction and stabilising them through encapsulation. Copper nanoparticles were produced by Patel et al. using a CuSO4 solution and a methanolic leaf extract of Tulsi. And the NPs that emerged had diameter of 122.7 nm and were extremely stable[112].

Agarwal and others in 2016, presented a unique biological method for the production of copper nanoflowers using *Ficus beghalensis* leaf extracts. Copper nanoflowers were produced using copper sulphate pentahydrate ($CuSO_4.5H_2O$) solution, and they were then agitated for 15 minutes at 60 °C. Copper nanoflowers were produced as a result of an ion reduction caused by the addition of the leaf extract. The average size of nanoflowers was approximately 500 nm, while nanopetals were 25 nm in size. One nanoflower seems to have three to four nanopetals in SEM micrographs, however they are all joined together to form a 500 nm diameter. The nanopetals are around 150 nm long in fig.3. [113]

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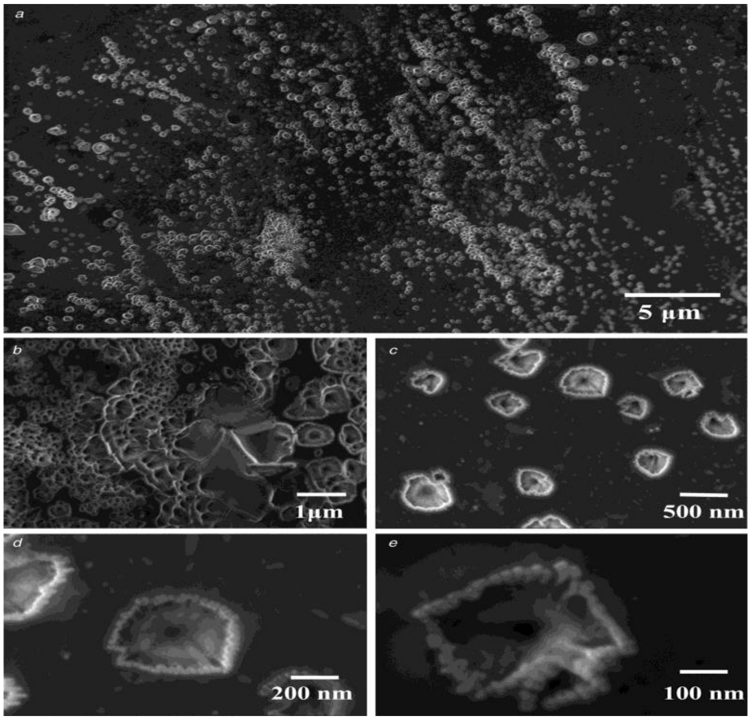

Fig. 3. SEM analysis of CuNPs synthesized

Using *Piper nigrum* seed extract, stable copper nanoparticles were created in an environmentally friendly manner. The plant-based components included in the seed extract are perfectly suited for the production of nanoparticles due to their tightly controlled assembly. Utilising a UV-visible spectrophotometer (XRD) and X-ray diffraction investigation, these eco-friendly copper nanoparticles were identified. Observations show that the Piper nigrum seed extract may transform copper ions into copper nanoparticles in between two and five minutes[114].

A UV-Vis spectrophotometer was used to identify the biogenic copper nanoparticles, which showed a typical resonance (SPR) for CuNPs at about 631 nm. With the use of XRD, the nature of nanoparticles were found FCC with size of 20 nm, was identified [111].

CuO nanoparticles of size range 70.1-99.3 nm with spherical and rod morphologies were produced by C. roseus extract at 45 °C, according to Verma and Bharadvaja (2021). Singh et al. (2021) isolated spherical CuO nanoparticles from A. squamosa that were smaller in size (39.8 nm) at a higher temperature (60 °C). In an effort to minimise CuO, Vasantharaj et al. (2021) conducted the tests using the same extract but at a higher temperature. The result was that they were able to produce CuO with a notably tiny size (10–15 nm) at a reaction temperature of 70 °C. [115,116,117].

TiO_2 (Titanium dioxide)

Titanium is an excellent material since it resists corrosion and is strong and shiny. Its most common component is titanium dioxide (TiO2). In the manufacturing of ceramics, colourants,

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plastics, paper, ink, rubber, textiles, and cosmetics, TiO2 is employed. Green synthesis methods, such as the utilization of *Jatropha curcas* and Aloe Vera plant extracts, were successfully used to produce TiO2 nanoparticles [44, 47]. The creation of the pure TiO2 nanoparticles has also been done for the first time using a simple, green method that makes use of cinnamon powder extract. The capping agent in the reaction is cinnamic acid, a component of cinnamon. X-ray diffraction (XRD) was employed to better comprehend TiO2 nanoparticles.The particles have spherical shapes, are uniformly dispersed throughout the surface, and are between 70 and 150 nm in size, according to micrographs taken using scanning electron microscopy (SEM) [45]. Additionally, using titanium trichloride (TiCl3) solution and an extract from Cucurbita pepo seeds [46]. In 2019, titanium tetra chloride was utilised to make TiO2 nanoparticles from orange peel extract. Several techniques were employed, including powder XRD, FE-SEM, and FT-IR, to study the phase purity, crystallinity, shape, and bonding nature of the generated nanoparticles. UV-Visible and photoluminescence (PL) spectra were assumed to be able to distinguish the optical properties of the nanoparticles [48].

Extending the range Papaya carica leaves are also used to make TiO2 and to use it in photocatalysis[49].Hesperidin flavanol, which is present in hydrolyzed extract of lemon peel, releases aglycone to serve as a capping and reducing agent during the production of these nanocomposites· [50].The leaf extracts of *Piper betel, Ocimum tenuiflorum, Moringa oleifera, Coriandrun sativum* were used as reducing agents to synthesize TiO_2 from Titanium tetraisopropoxide [51].

<u>ZnO (Zinc oxide)</u>

Zinc oxide (ZnO) nanostructures have also gained interest because to their wide band gap (3.37 eV) and strong electron-hole binding energy (60 meV). ZnO NPs have been employed in a variety of applications, including photocatalysis equipment, solar cells, optical devices, and biosensors. *Agathosma betulina* plant extract was used as an efficient chelating agent in the first-ever green production of ZnO nanoparticles, which resulted in their major physical characteristics [52]. When zinc oxide nanoparticles were created using an aqueous leaf extract of Azadirachta indica, they displayed intriguing antibacterial activity against both gramme positive and gramme negative bacteria as well as yeast at micromolar concentration [53].

Both the fruit extract of Opumtia humifusa [55] and the leaf extract of Parthenium hysterophorus [54] were used to create ZnO nanoparticles in a single step. The plant Dysphania ambrosioides, sometimes referred to as "epazote" in Mexico, was used in the environmentally friendly synthesis of ZnO-NPs since it is abundant in terpenes and flavonoids and has historically been used as a dewormer by indigenous people. The results demonstrated that ZnO-NPs were synthesised in the size range of 5–30 nm. ZnO crystalline phase was confirmed by XRD measurements and high resolution transmission electron microscopy HRTEM. Sizes of commercial ZnO-NPs varied from 15 to 35 nm [56].SS

It is easier to utilise the leaf extract to deposit green nanoparticles. It is non-toxic and doesn't spread disease to the surrounding area. As a result, coffee leaf extraction was used to successfully prepare nanoparticle synthesis. Numerous researchers support the use of these preparation procedures since they are cheap, straightforward, and have no negative effects on the environment while being used [57].

CdS(Cadmium sulphide)

Due to the numerous potential uses of semiconducting NPs, including fluorescent medical probes, solar cells, and cadmium sulphide (CdS) nanostructures, attention has been drawn to their biosynthesis. M. Divya Rao and Gautam Pennathura present a simple, "green" approach for producing cadmium sulphide (CdS) from Chlamydomonas reinhardtii. Electron microscopy morphological examination identified the existence of spherical particles with a diameter of around 5 nm. XRD and FT-IR structural investigation verified the existence of cubic CdS NPs coated by algal proteins [118].In 2018, Kavitha Shivaji presented a biogenic synthesis technique for the production of CdS quantum dots (QDs) with 2–5 nm particle size using extract of Camellia sinensis as a toxic-free particle stabiliser. In a number of situations, including (a) activity against bacteria, (b) biological imaging, and (c) lung tumour cell death, they have looked into the biological impacts of these CdS QDs[119].

Termitomyces heimii mushroom extract is used to characterise the physical properties of green synthesised CdS nanoparticles. The acquired CdS samples are of the wurtzite type. The particle size depends on how much extract is used during the synthesis. The protein presence and the CdS formation were both verified by FT-IR spectra. The UV-Vis spectra showed a hypsochromic absorption maxima dependent on particle size. According to the findings of the SEM and TEM tests, the nanocrystallites' estimated sizes from the XRD and UV-Vis studies were in the 3-5 nm range. The predicted electronic polarizability of the CdS samples[120].

The other plants were used for synthesis of CdS NPs are [121]. Cadmium chloride and sodium sulphide were used as metal precursors to produce crystalline morphological CdS NPs from the leaves of *Asparagus racemosus*, *Mimosa pudica*, and *Artabotrys hexapetalus* [125, 128, 124]. Using the same metal precursor; leaf extract of *Annona muricata*, Aloe veraand *Camellia sinensis*, root extract of*Rhaphanus sativus L* were used to synthesize NPs of CdS. They showed spherical morphology [122,123,133, 132]. Employing Cadmium nitrate, sodium sulphide as metal precursors in Banana Peel, *Murraya koenigii*, *Maqui* leaf extract, Papaya peel and *Panicum sarmentosum*, nanoparticles were obtained [126,127,129,131,135]. CdS NPs in the form of hexagons were produced using watermelon peel [134]. Additionally, *N. tabacum L. cv.* plant cells are employed to produce nanoparticles with quantum dot morphologies [130].

Applications of nanoparticles

Antimicrobial

For each Nanocatalyst, recyclability and reusability are two important considerations, particularly for commercial and industrial applications. The potential and applications of metal nanoparticles in several domains are generating considerable interest. There are a wide variety of methods for creating metal nanoparticles; however, environmental considerations, cost-effectiveness, and sustainability favour the green biological method, which uses a variety of plant and microbial sources. The manufacture of metal nanoparticles using extracts and solutions from plants, bacteria, fungi, and templates like viruses is explored. Silver and gold nanoparticles are the most researched and offer the most promise for use in medicine since biosynthesized nanoparticles have been shown to contain antibacterial, antifungal, and even antiviral characteristics[136].

Numerous case studies showed that nanoparticles can provide answers to the present raw material difficulties in the biomedical and healthcare industries. Spherical, nanorod, nanotube, nanosheet, nanofiber, nanomaterials can be created from a variety of raw materials, and their newly developed uses include bioimaging, biosensing, drug delivery, tissue engineering, antimicrobials, and agro-foods. Nanomaterials canemployed as membranes, films, additives, moisturisers, and formulation modifiers depending on their morphology. Since sizes and morphologies affect toxicological evaluation, strict control is required for the testing of effective nanomaterial doses [137].

The biosynthesized Ag NP has shown a variety of antibacterial, antifungal and antiviral, other types of activity [138]. The antibacterial ability of biosynthesized silver nanoparticles has been demonstrated in several investigations against Gramme positive bacteria such B. subtilis, B. cereus, Enterococcus hirae, S. aureus, S. epidermis, and S. pyogenes [139]. According to reports, silver nanoparticles' antibacterial activity is primarily caused by their interaction with cell membranes, which interferes with membrane permeability, respiration, denaturation of ribosomes, and replication inhibition by binding to DNA [140]. Additionally, particle size and concentration have been reported to have a significant impact on the antibacterial activity of silver nanoparticles [141]. AgNP's distinctive cytotoxic capabilities have been primarily credited with their antibacterial potential, which results from their

1) Adhesion to the microbial membrane resulting membrane permeability, cellular content leaking, and transport system impairment;
2) Interaction with DNA and intracellular penetration to destabilise and denature proteins
3) Production of free radicals, reactive oxygen species, and cellular toxicity that cause proteins and lipids to oxidise
4) Genotoxicity, which includes DNA base damage, strand breaks and mutations, as well as transcription and replication inhibition. [142-144]

Photovoltaic (solar energy conversion)

Nanoparticles play a central role in advancing photovoltaic technologies for harnessing solar energy, presenting a variety of groundbreaking uses:

Quantum dots, which are tiny semiconductor materials on the nanoscale, extend the range of light absorption in solar cells, potentially enhancing their effectiveness. Metallic nanoparticles enhance light absorption by leveraging surface plasmon resonance, focusing light within the layers of solar cells to improve their efficiency. One-dimensional nanowires enhance the conveyance of electric charge and reduce unwanted recombination losses in various types of solar cells. These nanoparticles, frequently composed of titanium dioxide, are imbued with dyes to efficiently capture photons and generate electrical current. Thin films incorporating perovskite nanocrystals provide economical, adaptable, and promising materials for solar cells. Coatings reliant on nanoparticles diminish reflection losses, ultimately boosting the efficiency of solar cells. Moreover, nanoparticles serve as protective shields for the surfaces of solar cells,

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amplifying their resilience and durability.

These diverse applications of nanoparticles are driving progress in photovoltaics, rendering solar energy more effective, versatile, and within reach. Researchers are actively exploring these breakthroughs as they contribute to the evolution of a sustainable energy landscape**.**

Drug delivery

NPs assume a crucial role in drug delivery within the medical field, providing innovative solutions to significant challenges. They enhance the solubility of drugs, enable controlled release, and deliver medications precisely to particular cells or tissues, thus minimizing undesirable side effects. Functionalized nanoparticles possess the ability to identify and attach to specific receptors, rendering them precise carriers for drugs. They also safeguard fragile medications from degradation, take advantage of the enhanced permeability and retention effect to target tumors, and permit combination therapy. Furthermore, nanoparticles facilitate vaccine administration, traverse the blood-brain barrier for treating neurological conditions, and enhance drug delivery for respiratory, ocular, and topical applications. This technology holds tremendous potential for transforming the landscape of medicine, offering more effective, personalized, and patient-specific treatments for a diverse array of diseases and medical conditions.

Catalysis by nanoparticles

The main goal of nanoscience is to identify the characteristics that arise from the preparation and stabilisation of tiny particles with nanometric dimensions. The capacity of nanoparticles to catalyse reactions by interacting with substrate and reagents is one of the most illustrative instances of particular characteristics of nanoparticles.

The bioinspired Pt NPs catalytic property was assessed in light of the potential efficiency of NPs as catalysts, and promising efficiency was found. To synthesise PtNPs and investigate their capacity to create hydrogen, O. Sanctum leaf extract was used to reduce chloroplatinic acid [145]. The catalytic activity of the Pt modified TiO2 aided by C. specious leaf extract was also assisted. When compared to pure TiO2, PtNPs modified TiO2 composites exhibit more activity [146]. The reduction of an aromatic nitro compound, which was created using powdered dry leaf material from A. occidentale, is catalysed by the PtNPs with high efficiency[147].

In addition to all of this, nanoparticles are employed as an alcohol oxidation catalyst. The oxidation of alcohols is a process with significant industrial impact, as it produces a number of chemicals of significant commercial value. Whether the alcohol is primary, secondary, or tertiary affects the character of the products. Aldehyde and ketones produced by oxidizing alcohols, found their uses in the dye, polymer, cosmetic, and other sectors. Numerous types of inorganic oxidants can be used to carry out this oxidation process [148].

In 2009, few authors published a study in the Green Chemistry journal describing the oxidation of alcohols using a transition metal nanocatalyst [149]. The potency of this substance as a catalyst for the oxidation of alcohols in water was investigated in this study. Pt nanoparticles were created for the oxidation of a range of primary and secondary alcohols, they used that catalyst and produced high turnover numbers and selectivities.

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In 2016, researchers published a paper in Journal of Nanoparticles Research in which they prepared Cobalt nanoparticles made from cobalt sulphate and tetrabutyl ammonium bromide at room temperature were discovered to be an efficient oxidation catalyst for alcohols. [150].

The green production of nanoparticles and its catalytic activity was the subject of a 2012 publication by S Aswathy Aromal and Daisy Phillip [151]. Their research described the environmentally friendly production of Au NPs using fenugreek aqueous extract. Gold nanoparticles made by synthetic means shown good catalytic activity in the conversion of 4-nitrophenol to 4-aminophenol when $NaBH_4$ was used in excess.

At the moment, environmentally friendly methods for the selective conversion of alcohols mostly use oxygen or ambient air as "green" oxidants. Silver functions as an active component of supported heterogeneous catalysts because oxygen has a strong affinity for it [152].

A research found that using $CuFe_2O_4$ nanoparticles at 40^0C with oxone, the oxidant and acetonitrile as the solvent efficiently catalysed the selective oxidation of alcohols. Alcohols from primary and secondary alcohols provided the necessary chemicals in good yields. Additionally, the catalyst may be quickly recovered and reused several times with almost little activity loss [153].

Other benefits of using nanoparticles as an oxidation catalyst include the stability of the oxidation system, ease of use, speedy reaction times, high product yields, and benign reaction conditions. The catalyst could then be used again. Currently, research is being done to use metal nanoparticles that are synthesised from plant sources to measure the rate of oxidation of various aliphatic and cyclic alcohols. By measuring the unreacted oxidant iodometrically at regular intervals, the oxidation's progress was tracked. The log (unreacted oxidant) vs time graphs were used to calculate the rate constant (k). The outcomes are being monitored.

Conclusion and future perspective

This study centers on the fabrication of diverse nanomaterials through environmentally friendly processes and their potential for environmental contaminant removal. We particularly underscore the use of environmentally friendly agents in nanoparticle creation, such as bacteria, fungi, and plant extracts. Additionally, we focus on the challenges associated with synthesis and characterization. Plant materials, due to their ecologically benign nature and substantial economic value as an alternative to large-scale nanoparticle manufacturing, emerge as increasingly viable agents for nanomaterial creation.

Our emphasis extends to the future prospects of metallic nanoparticles, with a compelling plea for the adaptation of secure biocompatible practices in developing metal nanoparticles. We advocate for exploring regional and readily available resources for a streamlined, single-step process in nanomaterial production. Local resource utilization is recommended to optimize cost efficiency. Subsequent research, delving deeper into biomolecules and their impact on nanoparticle production, is expected to offer a more comprehensive understanding. The objective is to expedite synthesis, enhance nanoparticle stability, and scrutinize nanoparticle application in catalysis, especially in alcohol oxidation, a crucial process yielding aldehyde and ketone—essential raw materials for the chemical industry.

Existing studies indicate that biologically produced nanoparticles pose fewer risks than their synthetic counterparts. Nevertheless, various key areas present both opportunities and challenges for

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researchers. A prominent challenge involves the conversion of salt to ions, necessitating innovative solutions. The specific role of plant molecules as reducing and stabilizing agents in nanoparticles warrants clarification for a more nuanced understanding.

Additionally, researchers may perceive an opportunity in the transfer of technical procedures that must be used to create nanoparticles from the laboratory to the industrial level. Therefore, novel green nanoparticle synthesis techniques will keep developing as the market has enormous potential for a variety of applications.

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