Sustainable Nanoparticle Synthesis from Plant Sources: Methods, Characterization, and Applications

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ABSTRACT:

Green and Sustainable Chemistry is a rapidly evolving field that focuses on the development of environmentally friendly chemical processes and materials. Nano materials, which are materials, have gained significant attention in recent years due to their unique properties and potential applications in various industries. Several research studies have been conducted on the intersection of green and sustainable chemistry with Nano materials, aiming to explore eco-friendly synthesis routes, efficient energy utilization, and safe disposal of Nanomaterial's. Here is a review of key areas of research and techniques related to Nano materials in the context of green and Sustainable Chemistry. Green synthesis of Nano materials: Researchers are actively investigating environmentally benign methods for synthesizing Nano materials, such as using plant extracts, microorganisms, or renewable resources as starting materials. Some Crucial approaches, which minimize the use of hazardous chemicals, reduce energy consumption, and offer scalability, are discussed in this review.

Keywords: Nano materials, Nano particles, Green synthesis, Sustainable Chemistry, Plant based metals.

INTRODUCTION:

Nanotechnology represents a specialized field of technology that focuses on comprehending and manipulating matter at an incredibly minuscule scale, specifically between 1 and 100 nanometers. This range is chosen due to the unique phenomena and properties that emerge within this dimension, allowing for the development of novel and innovative applications. The term "Nano" originates from the Greek word "Nano's," which translates to "dwarf" and signifies the extraordinarily small scale associated with this discipline. Nano refers to materials that possess dimensions of approximately 10-9 meters, which equates to one billionth of a meter, denoted by the prefix "Nano" and symbolized by "n."

Nanotechnology encompasses a broad spectrum of activities, including design, modeling, measurement, production, characterization, and application of systems, structures, and devices.[1] These activities revolve around the precise manipulation and control of size and shape at the nanometer scale. The goal is to engineer systems, structures, and devices that exhibit at least one unique or superior property or characteristic. Through meticulous control over matter at the Nano scale, researchers and engineers can unlock extraordinary properties and behaviors that are absent in bulk materials or larger-scale counterparts. This scientific discipline entails a comprehensive understanding of the behavior of materials at the Nano scale, the manipulation of individual atoms and molecules, and the construction of complex structures with Nano scale precision. It enables the development of cutting-edge technologies and applications in various fields such as electronics, medicine, energy, materials science, and more[2].By leveraging nanotechnology, scientists and engineers can create materials with enhanced strength, increased conductivity, improved chemical reactivity, and other advantageous features. Nano scale devices and structures exhibit exceptional properties, including quantum effects, surface plasmon resonance, and quantum confinement, which can be harnessed for a range of applications. The ability to engineer materials and devices at the Nano scale opens up new possibilities for advancements in electronics, medicine, environmental remediation, energy production, and many other areas.

These materials possess the remarkable ability to overcome various systemic barriers, making them highly desirable for numerous applications. NPs serve as a crucial link between atomic or molecular structures and bulk materials, thus generating significant scientific interest. The key distinction between bulk materials and NPs lies in their size-independent and size-dependent properties. Unlike bulk materials, NPs exhibit distinct properties that vary depending on the particle size.The properties of NPs are intricately linked to their size, meaning that altering the size of NPs can lead to changes in their characteristics. As the particle size decreases, the fraction or percentage of NPs on the material's surface increases. Consequently, the properties of NPs exhibit significant variation in conjunction with their size. Additionally, the shape of NPs plays a pivotal role in determining their unique properties. It is noteworthy that even slight changes in the shape of NPs can result in substantial differences in their properties. This remarkable phenomenon confers diverse and distinctive properties upon NPs.The manipulation of NPs' size and shape grants scientists and engineers the ability to tailor their properties to specific requirements. By precisely controlling these parameters, researchers can design NPs with desired characteristics such as enhanced reactivity, improved electrical conductivity, superior mechanical strength, and unique optical properties. These features make NPs highly versatile and valuable for a wide range of applications. [1-8]

METHODS:

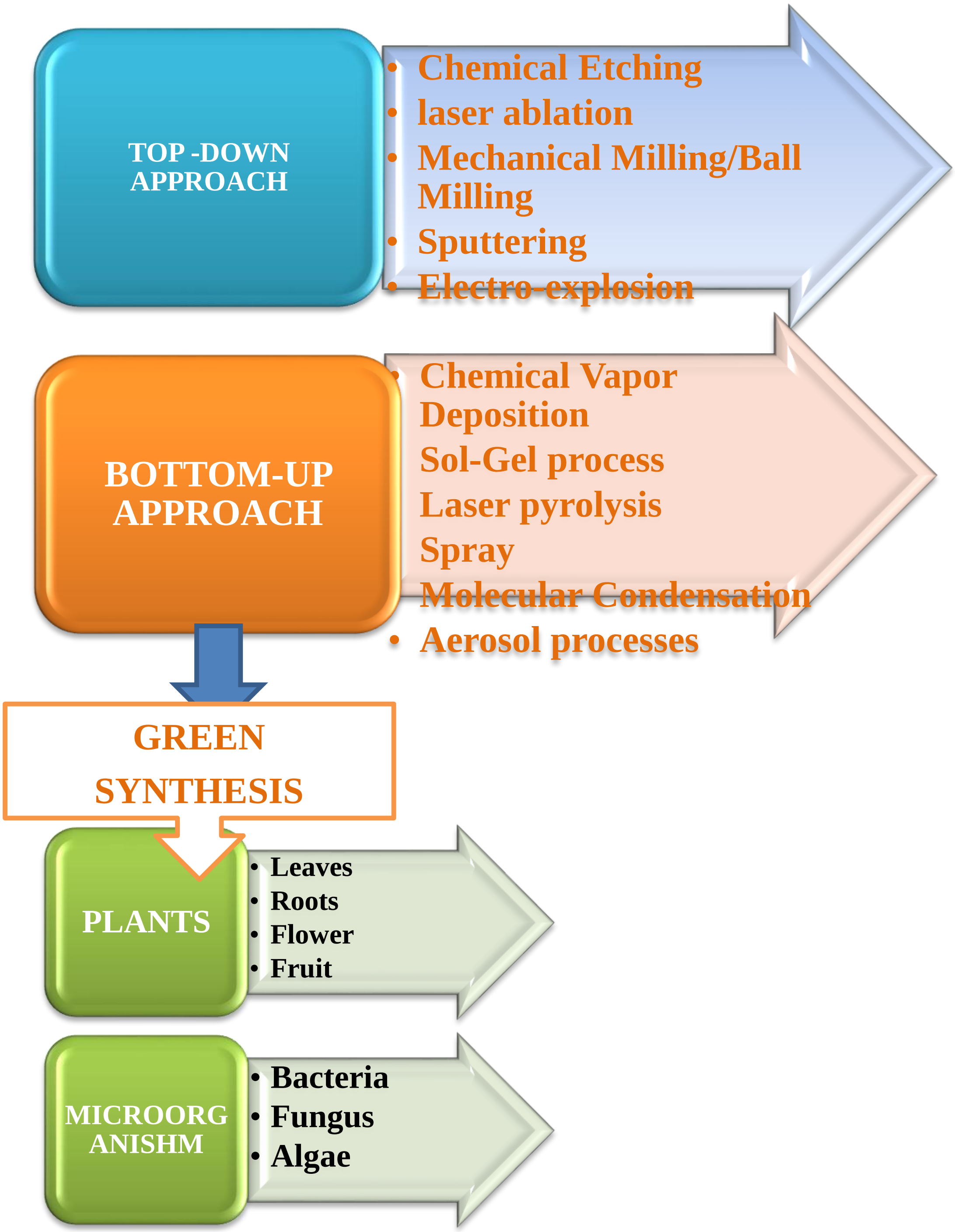

Figure 1: Representation of Nano particles synthesis

The synthesis of nanoparticles (NPs) can be broadly categorized into two approaches: the top-down approach and the bottom-up approach [1-6]. Figure 1 provides a visual representation of the different methods used in NPs synthesis.

The top-down approach:

Top-down approach involves the synthesis of NPs by breaking down larger materials to obtain particles of the desired size. This method relies on the controlled reduction of bulk materials, typically through mechanical, chemical, or physical means. By selectively modifying and manipulating larger structures, NPs with specific sizes and properties can be obtained. This approach is particularly useful when dealing with materials that can be easily fragmented or when precise control over particle size is essential. On the other hand, the bottom-up approach involves the construction of larger nanostructures by assembling individual molecules or atoms. This method entails the controlled growth and aggregation of Nano scale building blocks to form desired structures. Bottom-up synthesis techniques include chemical vapor deposition, sol-gel methods, and molecular self-assembly. By carefully manipulating the interactions between atoms or molecules, it is possible to fabricate larger nanostructures with well-defined properties and structures.

Both approaches have their advantages and are suited for different applications. The top-down approach allows for precise control over the size and shape of NPs and is often used in the production of nanoparticles with uniform characteristics. In contrast, the bottom-up approach enables the creation of complex nanostructures with tailored properties by assembling individual building blocks. This method is particularly valuable for designing nanomaterial with specific functionalities and intricate architectures.

In summary, the synthesis of nanoparticles involves two main approaches: the top-down and bottom-up approaches. The top-down approach focuses on breaking down larger materials to obtain nanoparticles of the desired size, while the bottom-up approach involves assembling individual molecules or atoms to construct larger nanostructures. These synthesis methods play a crucial role in tailoring the size, shape, and properties of nanoparticles, allowing for the development of advanced materials with a wide range of applications. In the top-down approach, nanoparticles (NPs) are synthesized using physical methods, wherein the desired sizes of NPs are achieved through physical abrasion or slicing of bulk materials. This method can be traced back to ancient times, with humans practicing it for over 300,000 years, particularly during the Paleolithic period when they first acquired the ability to fabricate tools. Over time, humans developed sophisticated techniques to determine the structure and size of particles at the sub-micron level, employing methods such as ball milling and laser-induced chemical etching. With the advancements in science and technology, various processes have been adopted to synthesize NPs using the top-down approach. These processes include machining, etching, forging, extruding, rolling, casting, and molding, among others. However, it is important to note that in these methods, the precise positioning of each atom throughout the operation is not feasible. Consequently, defects and impurities may be introduced during the synthesis process.

The top-down approach has historically been employed due to its simplicity and the ability to produce NPs with well-defined sizes. However, it does have limitations in terms of controlling the atomic-scale structure and achieving uniformity in particle properties.[7-10]As a result, there has been a shift towards the bottom-up approach in recent years, which allows for greater control over the assembly of individual atoms or molecules to construct nanostructures with precise properties.

In summary, the top-down approach to NP synthesis utilizes physical methods such as abrasion or slicing of bulk materials to achieve the desired particle sizes. This approach has been practiced by humans for thousands of years and has seen advancements with the development of sophisticated techniques. However, it is important to recognize the challenges associated with controlling atomic-scale structures and achieving uniformity in particle properties using this method. As science and technology progress, alternative approaches like the bottom-up method have gained prominence for their ability to assemble nanostructures with precise control over atomic positioning and tailored properties.

The Bottom-up approach:

Bottom-up approach also known as the self-assembly approach, involves the synthesis of nanoparticles (NPs) through chemical reactions or the manipulation of physical forces between atoms, ions, or molecules. In this method, the fundamental building blocks are carefully designed and assembled to form larger structures. Through chemical reactions, atoms, ions, or molecules combine in a controlled manner to create nanoparticles with specific properties. This process often involves the use of precursors or starting materials that undergo chemical transformations, leading to the formation of the desired nanostructures. The precise control over reaction conditions, such as temperature, pressure, and concentration, allows for the manipulation of particle size, shape, and composition. Additionally, physical forces play a crucial role in the bottom-up approach. These forces, such as electrostatic interactions, van der Waals forces, and hydrogen bonding, enable the self-assembly of particles into larger structures. By leveraging these forces, researchers can guide the arrangement and organization of the building blocks to create complex nanostructures with tailored properties.

The bottom-up approach offers several advantages over the top-down approach, particularly in terms of achieving atomic-level precision and uniformity in particle properties. By carefully designing the building blocks and controlling the assembly process, scientists can fabricate nanoparticles with specific functionalities, unique surface properties, and intricate architectures. This level of control enables the development of advanced materials for applications in various fields, including electronics, medicine, energy, and catalysis. However, it is important to note that the bottom-up approach can be challenging due to the complex nature of self-assembly processes. Achieving the desired structures requires a deep understanding of the interactions between the building blocks and the ability to control the assembly conditions. Additionally, the scalability of bottom-up synthesis methods can be a consideration, as producing large quantities of nanoparticles with precise control over their properties can be time-consuming and resource-intensive. [6-15]

In summary, the bottom-up approach, also known as the self-assembly approach, involves the synthesis of nanoparticles through chemical reactions or the manipulation of physical forces. This method relies on the careful design and assembly of fundamental building blocks to create larger nanostructures with tailored properties. By controlling reaction conditions and leveraging physical forces, researchers can achieve atomic-level precision and uniformity in particle properties, opening up possibilities for advanced materials with diverse applications.

Biological Synthesis:

The chemical synthesis of nanoparticles (NPs) often involves the use of toxic chemicals, which can pose potential hazards such as toxicity, carcinogenicity, and environmental toxicity [8]. Hazardous substances like organic solvents, stabilizers, and reducing agents employed in NP synthesis can contribute to significant toxicity concerns. The presence of these toxic chemicals and solvents as contaminants in NPs may limit their utilization in various biomedical applications. Therefore, it becomes crucial to seek trustworthy, biologically appropriate, and eco-friendly methods or procedures for NP synthesis. In this context, the use of biological methods for NP synthesis has emerged as an attractive alternative [9].

Green synthesis of NPs utilizes both unicellular and multicellular biological entities [10]. Bacteria, actinomycetes, fungi, viruses, plants, and other biological agents have been harnessed in the synthesis of NPs. This biological approach has garnered significant interest due to its broad range of applications. The NPs synthesized through green methodologies exhibit diverse physicochemical properties, offering a variety of sizes and shapes. By adopting biological or green synthesis methods, researchers can overcome the challenges associated with toxic chemicals and promote environmentally friendly practices. These methods typically involve the utilization of natural sources and biological systems, allowing for the synthesis of NPs without the need for hazardous substances. The biological entities employed in these processes possess unique capabilities to reduce metal ions and facilitate the formation of nanoparticles. Moreover, these biological agents often act as stabilizers, helping to maintain the stability and functionality of the resulting NPs.

The green synthesis of NPs offers several advantages beyond their eco-friendliness. These methods allow for precise control over NP size, shape, and composition. Additionally, the use of biological agents opens up possibilities for functionalizing NPs with biomolecules, making them suitable for targeted drug delivery, imaging, and other biomedical applications. In summary, the chemical synthesis of nanoparticles using toxic chemicals raises concerns regarding their potential hazards and limited biomedical applications. In contrast, the use of biological methods, known as green synthesis, offers a safe, environmentally friendly alternative. Employing various biological entities such as bacteria, actinomycetes, fungi, viruses, and plants, green synthesis enables the fabrication of nanoparticles with diverse physicochemical properties. This approach not only mitigates the use of toxic chemicals but also provides opportunities for tailoring nanoparticle characteristics for specific biomedical applications.

PLANT BASED SYNTHESIS OF NANO MATERIAL

Plants are considered cost-efficient and eco-friendly chemical factories, known for their ability to detoxify heavy metals and combat environmental pollutants. Even at trace levels, these pollutants can be highly toxic. In light of this, the synthesis of nanoparticles (NPs) using plant extracts has gained significant attention as a clean and environmentally accepted concept known as "green chemistry" [11].Compared to synthesis through microorganisms, the use of plant extracts for NP synthesis offers notable advantages. Maintaining microbial strains and cultures without contamination can be a complex process. In contrast, plant extracts provide a simpler and more accessible alternative. Furthermore, the reaction kinetics of NP synthesis using plant extracts tend to be higher compared to other green synthesis approaches, and they are comparable to NPs synthesized through chemical methods. This makes plant-based synthesis a promising avenue for producing NPs efficiently [12].

Different parts of plants, such as seeds, fruits, leaves, stems, bark, and roots, have been widely utilized for NP synthesis due to their abundant production of phytochemicals. To initiate the synthesis process, the selected plant part is thoroughly cleaned and then boiled with distilled water. The resulting plant extract is collected through filtration. Subsequently, a metal solution is added to the extract and incubated at either room temperature or with stirring on a magnetic stirrer. The generated NPs are then collected through centrifugation and subsequently purified. Figure 2 illustrates a representative mechanism for the green synthesis of NPs using plant extracts [13].This plant-based approach to NP synthesis offers numerous benefits. Firstly, it minimizes the use of toxic chemicals associated with conventional chemical methods. Secondly, it harnesses the natural capabilities of plants to produce NPs with high reaction kinetics. Moreover, the wide variety of plant species and their unique phytochemical profiles provide ample opportunities for tailoring the properties of the synthesized NPs to suit specific applications.

In summary, the use of plant extracts for NP synthesis represents a cost-effective and environmentally friendly approach. Plants serve as natural chemical factories capable of detoxifying heavy metals and combating environmental pollutants. The utilization of different plant parts allows for the extraction of phytochemical-rich extracts, which can be employed to synthesize NPs with enhanced reaction kinetics. This green synthesis method bypasses the challenges associated with microbial strains and cultures, making it an attractive alternative for producing NPs with diverse applications.

The green synthesis approach has facilitated the synthesis of a wide range of metal nanoparticles (NPs). Various metals, including silver, gold, iron, zinc, copper, and many others, have been successfully synthesized using this environmentally friendly method. Silver nanoparticles (Ag NPs) are one of the most extensively studied metal NPs synthesized through the green approach. These NPs exhibit remarkable antibacterial properties, making them valuable for applications in healthcare, textiles, and water treatment. Gold nanoparticles (Au NPs) synthesized via the green method have exceptional optical properties, such as surface Plasmon resonance, which find applications in sensing, imaging, and catalysis. Iron nanoparticles (Fe NPs) synthesized using the green approach have attracted attention in environmental remediation due to their high reactivity and ability to degrade contaminants. Zinc nanoparticles (Zn NPs) synthesized through green synthesis methods exhibit diverse properties and have found applications in electronics, optoelectronics, and catalysis. Copper nanoparticles (Cu NPs) synthesized via the green approach possess antimicrobial properties and are used in various fields, including biomedical applications and electronics. These examples represent just a few of the many metal nanoparticles that have been successfully synthesized using the green synthesis approach. The green approach allows for the precise control of particle size, shape, and composition, leading to the tailoring of unique properties for specific applications. Additionally, this method avoids the use of hazardous chemicals and reduces the environmental impact associated with conventional synthesis methods.

The synthesis of metal nanoparticles using the green approach has opened up new possibilities in various fields, including medicine, energy, materials science, and environmental remediation. The biocompatibility, low toxicity, and sustainable nature of these green-synthesized metal nanoparticles make them highly desirable for a wide range of applications. Continued research and development in this area hold great potential for further advancements in green nanotechnology.

APPLICATIONS OF NANOPARTICLES:

Nanoparticles (NPs) offer a diverse platform with a wide range of applications across various fields represented in the Figure 2 Their unique properties at the Nano scale make them valuable in numerous applications, and some of these applications are summarized in this section.The field of nanotechnology holds immense potential in the agricultural sector, offering eco-friendly solutions to environmental challenges and promoting increased food productivity.

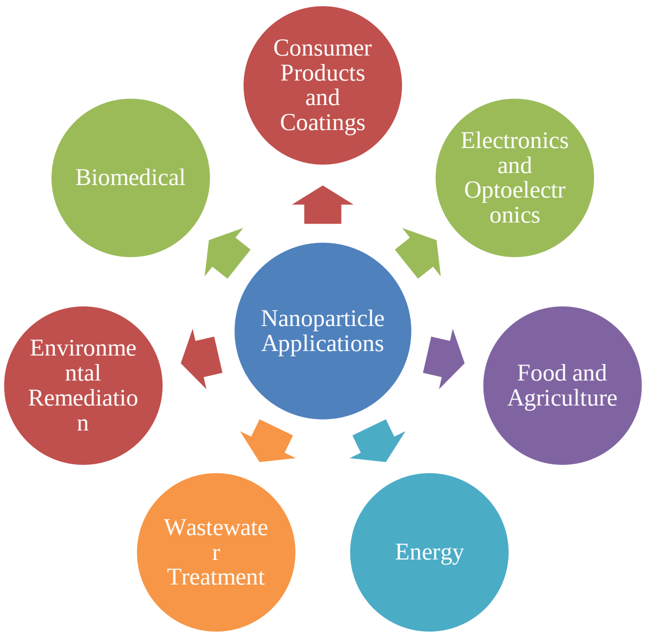

Figure 2: Applications of Nano Particles in various fields

1. Biomedical Applications: NPs have revolutionized the field of medicine. They are used in targeted drug delivery systems, where NPs loaded with therapeutic agents can be directed to specific sites in the body, enhancing treatment efficacy while minimizing side effects. NPs are also employed in medical imaging, enabling high-resolution imaging and early disease detection. Additionally, they play a crucial role in regenerative medicine, tissue engineering, and diagnostics.

2. Electronics and Optoelectronics: NPs are utilized in the electronics industry for various purposes. They are incorporated into electronic devices to enhance their performance, such as improving conductivity or providing advanced memory storage capabilities. NPs also enable the development of flexible and transparent electronic components. In optoelectronics, NPs are used in light-emitting diodes (LEDs), solar cells, and sensors, taking advantage of their unique optical properties.

3. Energy Applications: NPs contribute to advancements in energy production, storage, and conservation. In the field of renewable energy, NPs are utilized in solar cells to enhance light absorption and improve efficiency. NPs are also employed in catalysis, accelerating chemical reactions and reducing energy consumption. Furthermore, NPs are being explored for energy storage applications, such as in batteries and super capacitors, due to their high surface area and unique electrochemical properties.

4. Environmental Remediation: NPs play a vital role in environmental remediation efforts. They are used to remove contaminants from soil and water through processes like adsorption, catalysis, and photo catalysis. NPs can efficiently degrade organic pollutants and remove heavy metals from wastewater, contributing to the purification of natural resources and the preservation of the environment.

5. Consumer Products and Coatings: NPs find applications in various consumer products and coatings. They are used to enhance the properties of materials, such as increasing durability, scratch resistance, or UV protection. NPs are employed in the production of antimicrobial coatings, enabling the development of self-cleaning surfaces and reducing the spread of pathogens.

6. Food and Agriculture: NPs are utilized in the food and agricultural industries for diverse applications. They are employed as food additives for enhanced nutrient delivery or as antimicrobial agents to extend shelf life. In agriculture, NPs contribute to crop protection by acting as controlled-release systems for fertilizers or as agents for pest control.

Nanotechnology offers significant benefits in the agricultural sector by providing eco-friendly solutions to environmental problems and increasing food productivity. NPs have been found to stimulate seed germination and enhance plant growth. Due to their small size and large surface area, NPs can easily penetrate the pores of seeds and activate phytohormones responsible for germination. Additionally, NPs can stimulate growth hormones and enhance enzymatic activities, leading to improved plant growth. The non-toxic nature of green-synthesized NPs makes them suitable as Nano-fertilizers and Nano-pesticides.

In the field of fertilizer development, nanotechnology has enabled the conversion of fertilizers into Nano form. This allows for controlled release of nutrients, minimizing the risk of environmental damage. Various types of NPs, such as chitosan, zeolite, hydroxyapatite, clay minerals, and polyacrylic acid, have been utilized in the development of Nano-fertilizers. These Nano-fertilizers offer a cost-effective and environmentally friendly solution to enhance nutrient delivery and improve crop productivity. Furthermore, NPs can be employed as Nano pesticides, providing efficient pest control without the need for harmful chemical agents. Research findings have demonstrated the effectiveness of Nano pesticides against various pests, making them a valuable tool for future agricultural pest management practices.

7. Nano particles role in the Wastewater Treatment:

Nanotechnology plays a crucial role in the purification of water and wastewater, offering simple and low-cost methods with high efficiency. Metal NPs, known for their high surface catalytic activity and surface-to-volume ratio, are extensively used as Nano-catalysts in water and wastewater treatment processes. These Nano-catalysts exhibit excellent performance in degrading various contaminants, including nitro aromatics, polychlorinated biphenyls, herbicides, pesticides, and dyes, leading to improved water quality.

Green-synthesized NPs have shown exceptional efficiency in the degradation of organic pollutants, particularly dyes. They offer an eco-friendly alternative to traditional methods of wastewater treatment. Additionally, Nano adsorbents, which are NPs with high adsorption capacity, have proven to be remarkably effective in removing pollutants from wastewater. However, it is important to consider the potential toxicity of residual NPs in treated water, as a large number of NPs may be involved in the pollutant removal process. The application of nanotechnology in agriculture and wastewater treatment holds great promise for addressing environmental challenges, enhancing crop productivity, and ensuring the availability of clean water resources. On-going research and development in this field will continue to advance sustainable practices, promoting a greener and more efficient agricultural sector while safeguarding the environment and human health.[16-21] These applications represent just a fraction of the vast range of possibilities offered by NPs. As research and development in nanotechnology continue to advance, NPs hold tremendous potential for innovation and transformation in numerous fields, shaping the future of technology, healthcare, energy, and environmental sustainability.[18-23]

Energy-efficient manufacturing processes: Developing energy-efficient methods for large-scale production of nano materials is crucial to minimize the environmental impact. Techniques like microwave-assisted synthesis, sonochemical synthesis, and electrochemical deposition are being explored to enhance energy efficiency and reduce waste generation.

Recycling and waste management: The sustainable management of nano materials involves addressing the challenges associated with their disposal and recycling. Researchers are working on developing effective strategies for recycling and reusing nano materials to minimize environmental hazards and reduce resource consumption.

Life cycle assessment (LCA) studies:

LCA is used to evaluate the environmental impacts of nano materials throughout their entire life cycle. This approach helps researchers identify areas of improvement, optimize processes, and make informed decisions regarding the development and application of nano materials.

Environmental impact and toxicity assessments:

Assessing the potential environmental impact and toxicity of nano materials is crucial for their safe and sustainable use. Studies are conducted to understand the fate of nano materials in the environment, their interactions with living organisms, and their long-term effects on ecosystems.

Green Nano composites and coatings:

Nano materials are being incorporated into eco-friendly matrices to develop green nanocomposites and coatings with enhanced mechanical, thermal, and barrier properties. These materials find applications in various industries, including packaging, automotive, and construction, with reduced environmental footprints.It is important to note that the field of Green and Sustainable Chemistry is dynamic, and ongoing research is constantly advancing our understanding of environmentally friendly approaches to nano materials. Further studies are expected to refine existing techniques, explore new synthesis routes, and expand the application areas of sustainable nano materials.

Cellulose nanocrystals (CNC):

CNC are nano-sized particles derived from renewable sources such as cellulose. They possess exceptional mechanical properties, biodegradability, and low toxicity, making them sustainable alternatives for various applications. CNC has been explored for use in reinforcing biocomposites, drug delivery systems, and as stabilizers in food and cosmetic formulations.[11]

Graphene oxide (GO):

GO is a two-dimensional nanomaterial derived from graphite. It exhibits exceptional mechanical, thermal, and electrical properties. Researchers have explored the potential of GO in various applications, including energy storage devices, sensors, membranes for water purification, and as an additive in composites. GO can be produced from graphite using environmentally friendly processes, making it a sustainable nano material.[12]

Nanostructured metal-organic frameworks (MOFs):

MOFs are a class of crystalline materials composed of metal ions or clusters coordinated to organic ligands. They possess high surface areas, tunable porosity, and diverse functionalities. Researchers have explored nanostructured MOFs for various sustainable applications, including gas storage and separation, catalysis, drug delivery, and environmental remediation.[13]

Sustainable quantum dots (QDs):

Quantum dots are semiconductor nanoparticles that exhibit unique optical and electronic properties. Sustainable QDs are those synthesized using environmentally friendly processes and materials. These QDs have been explored for applications in energy conversion, display technologies, bio imaging, and sensing.[14]

Cellulose Nano crystals (CNC):

Cellulose Nano crystals can be obtained through a process called acid hydrolysis, where cellulose fibres are treated with acid to remove non-crystalline regions, resulting in the formation of Nano scale crystals. Characterization techniques such as X-ray diffraction, transmission electron microscopy (TEM), and atomic force microscopy (AFM) are used to analyse the crystal structure, size, and morphology of CNC. CNC has shown promise in various applications, including reinforcing materials in composites, enhancing mechanical properties of biodegradable polymers, drug delivery systems, and as stabilizers in food and cosmetic formulations.

Grapheme oxide (GO):

Grapheme oxide is typically synthesized through the oxidation of graphite using strong oxidizing agents such as sulphuric acid, potassium permanganate, and sodium nitrate. Characterization techniques like Raman spectroscopy, scanning electron microscopy (SEM), and X-ray photoelectron spectroscopy (XPS) are used to examine the structural, chemical, and morphological properties of GO. GO has found applications in energy storage devices such as super capacitors and batteries, sensors for detecting gases and biomolecules, membranes for water purification, and as an additive in composites to enhance their mechanical properties.

Nanostructured metal-organic frameworks (MOFs):

MOFs are synthesized through self-assembly processes by combining metal ions or clusters with organic ligands under controlled conditions. Techniques such as powder X-ray diffraction (XRD), N2 adsorption-desorption, and scanning electron microscopy (SEM) are used to characterize MOFs' crystalline structure, surface area, pore size, and morphology. Nanostructured MOFs have shown potential in applications such as gas storage and separation, catalysis, drug delivery systems, and environmental remediation.

Sustainable quantum dots (QDs):

Sustainable QDs can be synthesized using environmentally friendly methods such as green chemistry approaches, bio-inspired synthesis, or non-toxic precursor materials. Characterization techniques including absorption and emission spectroscopy, high-resolution TEM, and dynamic light scattering (DLS) are employed to analyse the optical, structural, and size properties of QDs. Sustainable QDs have applications in energy conversion devices (such as solar cells), display technologies, bio imaging for biological and medical diagnostics, and sensing applications.

CONCLUSION:

In conclusion, green sustainable nano chemistry represents a vital approach to harnessing the potential of nanotechnology while safeguarding the environment and human health. By applying the principles of green chemistry to nanomaterial synthesis and applications, this field seeks to minimize the negative impacts traditionally associated with nanotechnology and promote responsible innovation. Through green synthesis methods, biodegradability, resource efficiency, toxicity assessment, life cycle analysis, energy efficiency, and sustainable technology applications, researchers and industries can ensure that nanomaterial's are produced and used in an environmentally friendly and socially responsible manner. Embracing green sustainable Nano chemistry not only contributes to a more sustainable future but also addresses potential concerns surrounding the safety of nanotechnology. By prioritizing eco-friendly practices, the field can gain public trust and acceptance, paving the way for the responsible adoption of nanotechnology in various industries.

It is important for researchers, policymakers, and industries to continue collaborating and investing in green sustainable Nano chemistry to drive innovation, develop cleaner technologies, and address global challenges in a way that respects the delicate balance of our planet. Ultimately, by incorporating sustainability into Nano chemistry, we can unlock the full potential of nanotechnology while safeguarding the well-being of our planet and future generations.

DECLARATIONS

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Ethical approval: No animals were used during the research work

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