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BIONANOTECHNOLOGY IN ENVIRONMENTAL RESTORATION – A REVIEW

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ABSTRACT

Nanotechnology has emerged as one of the most vital fields of research these days and has made remarkable changes in many aspects, particularly in the environment. This review covers the interdisciplinary approach of Bionanotechnology, integrating biological systems with nanotechnology to solve some of the major environmental problems. The unique properties of nanomaterials have high surface area and catalytic functions are utilized for environmental remediation. Various green synthesis methods have been demonstrated as eco-friendly pathways in the fabrication of nanoparticles using biological agents such as plant extracts. Case studies showing the effectiveness of nanoparticles in the restoration of ecosystems, including soil and water purification are discussed. The review further deliberates the role of Bionanotechnology in the management of polymer waste through the development of biocomposites that have a reduced impact on the environment. Although Bionanotechnology faces a few challenges relating to toxicity and waste management, this technology restrained as a consistent pathway towards a sustainable and biocompatible future that aligns well with the global sustainability.

Keywords – Bionanotechnology, Nanoparticles, Environment, Ecosystem.

1. INTRODUCTION

Nanotechnology has rapidly evolved as a significant field of research that has stepped up fundamental research using the foundation of novel state-of-the-art tools (Santos *et al.*, 2024). Nanotechnology research comprises the production outline and influences the structures or particles with dimensions smaller than a hundred nanometers. Within a hundred nanometers, the particles having the desired and suitable properties can be made into a nanoparticle by manipulating the dimensions of the material (Jin *et al.*, 2001; Chan *et al.*, 2002). The biological and medical research societies have utilized the exclusive properties of nanomaterials for several applications. Considering these manifestations, new approaches have arisen in the field of nanotechnology (Cevallos *et al.*, 2022). There appears to be a strong connection between nanotechnology and biology.

Bionanotechnology is a multi-disciplinary science that derives and inspires artificial systems by fusing biological systems with nanotechnology (Cevallos *et al.*, 2022). Bionanotechnology equips a fresh overview of ecosystem regeneration and sustainable development to devise perfect and decisive solutions by applying multidisciplinary knowledge. This approach is vital for advancing science and increasing resource productivity (Gabal *et al.*, 2020; Saleem *et al.*, 2022).

Hence Bionanotechnology arises as an endeavoring field in restoring ecosystems and emerging social, environmental and medical issues. Using an interdisciplinary approach, we can progress toward a sustainable future where technological modernization aligns with nature's conservation and society's welfare.

2. NANOTECHNOLOGY FOR A GREEN ENVIRONMENT

Various human activities cause environmental contamination, which presents a consequential risk to the balance of ecosystems, the welfare of the public and the everlasting viability of the planet (Naiman *et al.*, 2010). The pollution of the atmosphere, hydrosphere and lithosphere with a mixture of harmful particles, including toxic metals and organic compounds, as well as pharmaceuticals and microplastics. It is vital to develop a novel remediation to overcome the traditional procedures (Ahmed *et al.*, 2022).

Nanotechnology has become a radical method in providing remarkable potential for tampering with the complex problems of environmental pollution (Theodore *et al.*, 2005). Nanotechnology is used in environmental remediation to apply diverse strategies that make use of the unique features of nanoparticles to precisely reduce pollutants (Khan *et al.*, 2021). Nanoparticles possess a broad surface area and show strong sorption and catalytic possibilities, preparing them as active agents for eradicating and decaying contaminants (Khin *et al.*, 2012). The wide use of nanotechnology in environmental cleanup is deprived by various complex hurdles that require accurate scientific tests and technical progress (Ahmed *et al.*, 2022).

Nanotechnology yields a significant part in output over the control of nutrients (Mukhopadhyay, 2014), as well as it can also engage in the monitoring of water quality and pesticides for sustainable development of agriculture (Ram *et al.*, 2014). Nanomaterials have such diverse assets and activities that it is impossible to deliver a general assessment of their health and environmental risks (Ram *et al.*, 2014). Nanoscale biosensors help in the detection and diagnosis of pathogens. Nanotechnology can supply biologically active substances in staples to hosts while enhancing the knowledge of food products at the nanoscale level (Martirosyan *et al.*, 2014). It also aids in nanoscale filtration systems for enhanced quality of food.

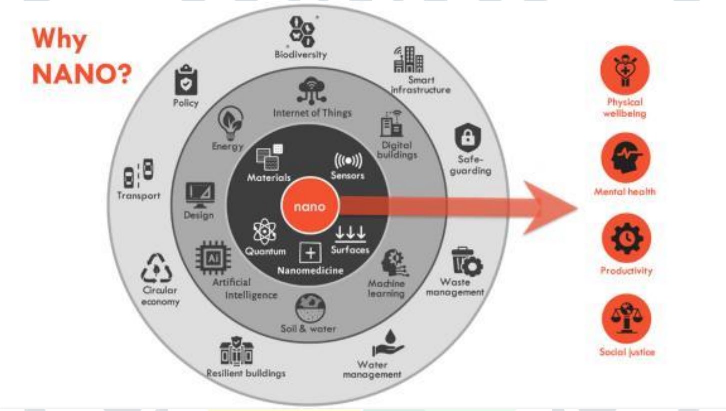

Figure 1. Potential applications of Nanotechnology

3. GREEN SYNTHESIS OF NANOPARTICLES

In order to create green nanoparticles, plants or plant components are used to bioreduce metal ions in the size range of 1 to 100 nm into their elemental form (Hussain *et al.*, 2015). Green synthesis has made it simple to create several nano participles, including iron (Huang *et al.*, 2014), zinc oxide (Elumalai *et al.*, 2015), palladium (Yang *et al.*, 2009), gold (Velmurugan *et al.*, 2014), and silver (Khalil *et al.*, 2014). Phytocompounds like polyphenols, terpenoids, and polyols found in plant extracts are the agents that cause the bio-reduction of metallic ions (Zeiri *et al.*, 2014). The green synthesis of nanomaterials is a sustainable, cost-effective and ecologically benign process. Environmentally benign nanoparticles can be produced using green synthesis, which substitutes dangerous chemical products and creates new methods to cut down on or even remove materials that are harmful for the environment and human health. Owing to the need for environmentally friendly technologies, nanoscience is now delving into biology to develop a novel platform for the aseptic synthesis of nanomaterials using bacteria, fungi and plant extracts. (Fig. 2)

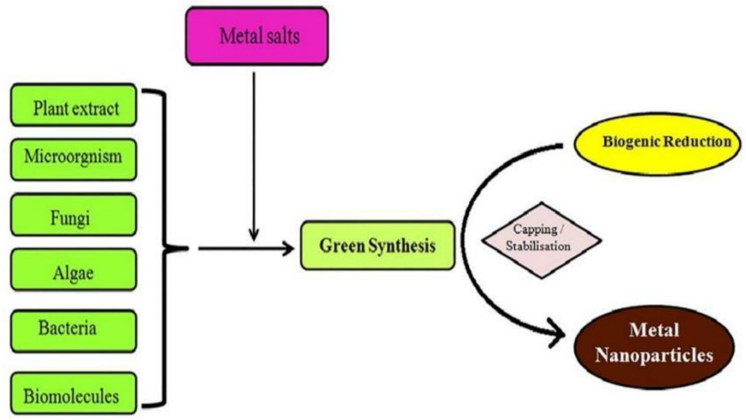

Fig. 2. Schematic diagram of Synthesis of Nanoparticles by Green Synthesis.

Gold nanoparticles are an attractive nano-carrier in drug delivery systems (DDSs) due to their numerous characteristics, including as their exceptional optical and physicochemical properties, biocompatibility, viable flexibility, controlled dispersity and nontoxicity.Several researchers have proposed that metal nanoparticles are particularly effective catalysts because a significant portion of their atoms remain at the surface, where they can be used to catalyse the chemical transformation of substrate. Metals and their oxides, sulphides and silicates are among the several nanomaterials that are employed as catalysts.

Nanosized ligno-cellulosic materials are derived from trees and harvests, which can be applied as nano-fertilizer, nano-pesticides that intertwine with nano-herbicides, nano-coating, etc.

Silver is currently utilized in the rapidly developing field of nanotechnology and can be found in a wide range of consumer goods, such as deodorizing sprays, infant pacifiers, acne treatments, computer keyboards, and apparel (such as sportswear and socks) that prevents the release of body odour. It is commonly known that compounds made of silver nanoparticles have higher catalytic activity when it comes to reducing and removing dyes.

Over the past few years, advancements in textile laminations, yarns and fabric finishing made possible by nanotechnology have led to the development of countless improved and novel textile goods. The nanocarrier technology, which enables cosmetic compounds to penetrate the skin's layers and accelerate skin metabolism, can improve the appearance of skin. Liposomes (vitamins A, E, and CoQ10) are used in cosmetics to boost the concentration of active ingredients (Mu *et al.*, 2010).

Nanoparticles have been shown to exhibit antibacterial properties at low doses. The research claims that zinc acetate has a higher microbiological and inhibitory concentration than zinc oxide nanopowders.

Food nanotechnology can have an impact on food's nutritional value and bioavailability. A nanomaterial's physicochemical qualities determine its biological properties primarily. Enhancing food security, improving flavour, extending shelf life, delivering nutrients and providing functional meals are the primary ways that nanotechnology and the food business are related (He X *et al.*, 2016).

4. BIONANOTECHNOLOGY IN ECOSYSTEM RESTORATION

The history of mankind is well defined by a deep realization of the ecosystem, notably since the 18th century industrial revolution. This has led to considerable and unfeasible effects including biodiversity loss, climate change, socio- economic challenges and diseases (Malhi, 2017). Nowadays, there is an increase in the rate of pollution and problems due to the rapid growth of population and industries. The uncontrollable pollution causes damage to our ecosystem and living things, so the need for the emergence of new technologies has increased to remove the pollutants from the ecosystem.

The main objective of this ecosystem restoration technology is to provide healthy an environment to the human society. Nanotechnology aims to provide new means for contaminant restoration and limited destructive ways to construct goods. However, intrinsic toxicity is on the other side: the physical and chemical properties of nano-size materials are completely different from bulk amounts of chemically the same compounds. Some of the differences are effective but the others have the potential to be less beneficial (Subbiah Balaji, 2010).

Bionanotechnology advancement known as a tool to undertake the complex challenges in the ecosystem of our society. These days, soil and water pollution leads to a major problem, and this also affects human health, the cultivation of agricultural products and the welfare of flora and fauna destroying the earth's natural resources (Pakshirajan *et al.*,2015).

The restoration method involves the application of reactive materials for the detoxification and transformation of the pollutants. These materials initiate the action of the chemical reduction and catalysis of the pollutants.

Environmental pollutants can be cleaned up by using different nanomaterials. These pollutants are detected and monitored by nanoscale devices. The advantage of this restoration technology is that nanoparticles can enter a particular polluting area where even other particles cannot. Several nanomaterials can make use of the ecosystem by utilizing the reactive nanoparticles. Some of the nanomaterials are organic, inorganic, carbon-based and polymer -based materials.

4.1 Case Studies

Healthy soil is necessary for ecosystem sustainability, supplying essential nutrients to flora and contributing to the welfare of the environment (Handayani, 2022). The use of metallic nanoparticles in the restoration of contaminated soil has been a growing area of research. Studies have explored the inherent of these nanoparticles such as iron oxides, used in the absorption and removal of various pollutants including heavy metals and organic compounds. Due to their smaller size and large surface area, these nanoparticles can deactivate the contaminants and reduce their effect on the affected environment (Ripp *et al.*, 2020)

Silver nanoparticles obtained from different industrial and agricultural by-products give biological properties including antimicrobial action and promote the restoration of contaminated soils. The notable development in the field of Bionanotechnology is addressing the problem of contaminated water. Pure and clean water is mandatory for maintaining human health and the ecosystem. The most common method used to purify water is using activated carbon, though it is common, and cost-effective. So, it is not feasible for all kinds of people. Therefore, carbon-based nanomaterials such as graphene, have effectively removed the contaminants from the water bodies. Graphene effectively removes pollutants like heavy metals, inorganic anions and gaseous compounds and results in water purification. This method provides the consumption of chemical-free water, and it is the best alternative to conventional water treatment methods (Sarma *et al.*, 2019). In another study, zero-valent iron particles are used to treat the polluted groundwater, particularly in areas near landfills.

5. ROLE OF BIONANOTECHNOLOGY IN COMPOSITES AND POLYMER WASTES

The growth of polymer composites in the newfangled world is rampant in recent decade, hits about 460 million tonnes which took over by the resiliency of the Biocomposites of industrial and day to day life. In the modern society, the Biocomposites and its polymer wastes management is very much vital, though people are much determined about disposal of composites waste with advanced technology (Chugh *et al.*, 2012).

The underprivileged management and failure to recycle plastics and other polymers result in the accumulation of these waste materials in landfills and oceanic ecosystem, harming wildlife and human health. Although its adsorption capacity may be lower than that of other manufactured adsorbents, its low cost makes it an economically viable option for cleaning soil and water contaminated with contaminants. The adsorption of pollutants can be improved by doping the biochar with doping materials; doing this with bivalent or trivalent metals. The study utilizes red mud, an alkaline industrial waste that contains iron, aluminium, and calcium, which has been considered a relatively economical source of dopants for compost biochar production (Qin *et al.*, 2022). The article claims that lignin, a naturally occurring polymer present in biomass, is the second most common terrestrial biopolymer after cellulose and has a great deal of promise for use in hydrogels (Zheng *et al.*, 2024).

5.1 Challenges

The environmental problems are brought up by careless recycling and reprocessing, indiscriminate littering and the inability of plastic trash to decompose. Fugitive emissions are generated during the polymerization process. Different kinds of gases are released during the product manufacturing process. Because plastic garbage has barrier qualities, it becomes sterile when it is disposed of carelessly on land. Toxic emissions including carbon monoxide, chlorine, hydrochloric acid, dioxin, furans, amines, nitriles, styrene, benzene, 1, 3-butadiene, CCl_4 and acetaldehyde are produced when plastics burn. Disposal issues arise with non-recyclable plastic waste, such as thermoset plastic and multilayer, metalized pouches. Packaging films and substandard plastic carry bags (Bhosale *et al.*, 2022).

5.2 Advantages

The advantages of these composites are numerous, including lower environmental impact, improved biodegradability, reduced weight and enhanced tensile strength, among others (Manu *et al*., 2022). It is possible to mention the biochar bio composite, which is a solid material formed by the thermochemical conversion of biomass in an oxygen-free environment (Razzaghi *et al.*, 2020), Having a high concentration of ions, it is efficient at adsorbing ions, so it is ideal for treating acidic water from mines and soils contaminated with chemical traces. This helps reduce water pollution or desalinate it (Razzaghi *et al.*, 2020).

Biocomposites have found widespread use in the production of construction materials, including siding, windows, doors, roofing, decking, and so forth. Fibers from flax and hemp can be utilized in a variety of products, including soil amendments, drilling muds, animal bedding, pulp, paper, textile segments, composite fillers, nonwovens, insulation, and absorbents (Rowell, 2020).

Flax and hemp fibres can be used in several applications such as composite fillers, geotextiles, nonwovens, insulation, textile segments, pulp, paper, fibreboards, soil amendments, drilling muds, animal bedding, and absorbents. Wheat straw is also one of the competitors for hemp and flax in some of these applications (Fowler *et al*, 2006).

6. CONCLUSION

Bionanotechnology plays a vital role in research to find a sustainable solution to distinct problems, such as environmental deterioration, accessing to drinking water, resistance to pathogens, enormous use of agrochemicals and other objections that humans facing today. Interdisciplinary collaboration is essential for advancing nano particle synthesis, enhancing manufacturing processes, and analyzing creative uses of nanotechnology in remediation activities. Studies related to nano particles have already endorsed positive results for soil remediation and water purification, using nano stimulants to increase agriculture production, nanoparticles as a drug-delivery nano machine for pharmaceuticals and the battle against pathogens of high clinical pertinence. Over this investigation of the exclusive properties of nanomaterials, Bionanotechnology is accessible to new horizons in the exploration for a more secure, sustainable, and biocompatible future for our planet, searching to recognize the objectives of sustainable development. Bionanotechnology ensures the sustainability goals, which are aimed at reducing pollution, protecting our planet Earth to ensure that all the living being enjoy peaceful and well-being equally by 2030.

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