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Bionanotechnology: Nanoparticle Types, Microbial Synthesis, Properties, and Applications in Medicine, Agriculture, Industry

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ABSTRACT

Bionanotechnology is where biology meets nanotechnology, resulting in unique new materials and devices with greater capabilities. The different types of nanoparticles include metals, carbon, composite materials, and dendrimers, which can be created through mechanical and chemical means, or through low-cost and eco-friendly methods via specialized microorganisms. Microbially synthesized particles are biocompatible and far more eco-friendly than products created through chemical manufacturing methods.

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Bionanotechnology has unique nanoparticles with various engineered nanoparticles which enable their uses in broad categories. Bionanotechnology is used for targeted drug delivery systems, diagnostic tools, anti-microbial therapies, and other products in agriculture and medicine. Bionanotechnology is used for greater crop protection, better delivery of nutrients, and improved disease management products in agriculture. food packaging, energy generation, environmental cleanup and other products are supported, demonstrating broad interdisciplinary importance.

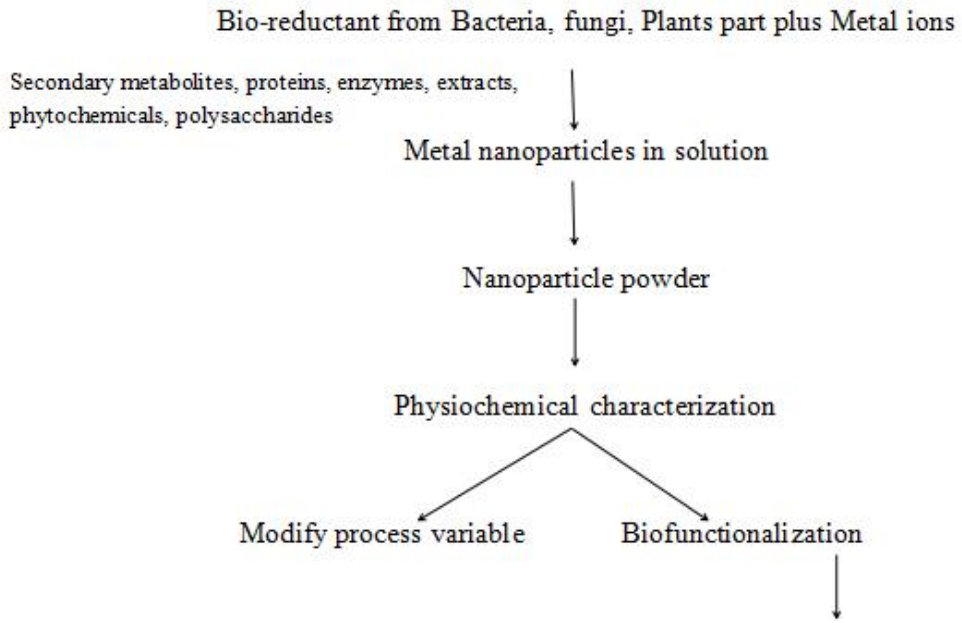
Keywords: Bionanotechnology; Nanoparticles; Microbial synthesis; Biomedical applications; Agricultural applications

Introduction

The bionanotechnology is the amalgamation of nanotechnology and biotechnology. Moreover, at IBM in USA, electron beam lithography technique was used for manufacturing devices and nanostructures as small as 40 to 70 nm in first 1970. Bionanotechnology is thus, a mixture of both molecular biology and engineering. Bionanotechnology has transfigured the world with nanaoparticles, nanocapacitors and nanopores.The importance of bionanotechnology arose when the synthesis of nanoparticles occurred naturally by using organic compounds like botanical extracts, biodegradable polymers, carbohydrates, lipids, proteins, microorganisms and vitamins.

General Flow Chart for Bionanosynthesis

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Nevertheless, ecofriendly nanoparticles are produced through biological materials sooner than artificially manufactured nanoparticles. More important is that the routes for the synthesis of biological based materials are safer without any toxic additives.

Table1: *Microorganism Usage For The Production Of Nanoparticles*

Gold nanoparticles		
Microorganisms	Location	Size range
Algae		
Chlorella vulgaris	Extracellular	9-20
Sargassum wightii	Extracellular	18-12
Bacteria		
E. coli DH5α	Intracellular	25-30
Lactobacillus strain	Intracellular	20-25
Fungi		
Fusarium oxysporum	Extracellular	20-40
Silver nanoparticles		
Bacteria		
Lactobacillus strains	Intracellular	

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Morganella sp.	Extracellular	20-30
Plectonema boryanum	Intracellular	1-10,1-100
Pseudomonas stutzeri	Intracellular	200
Fungi		
Aspergillus fumigates	Extracellular	
Phoma sp.3.2883	Extracellular	71.06-74.46
Yeast		
MKY3	Extracellular	2-5

Manufacturing Approaches of Nanoparticles

There are two famous essential approaches for the manufacturing of nanoparticles. The first one is the "bottom-up" approach, in which basic buildings blocks like atoms or molecules are consumed for the synthesis of nanoparticles, providing desired properties nanoparticles.

Table 2: *Basic Features of Nanoparticles are:*

Sr.no	Properties
1.	Improved physical chemical and biological property
2.	Mechanical strength
3.	Catalytic activity
4.	Thermal stability
5.	Electrical conductivity
6.	Optical properties
7.	Magnetic properties

Types of Nanoparticles

The most studied nanoparticles are carbon nanotubes, liposomes, quantum dots, gold NPs, paramagnetic NPs, and several others (Modugno, et al 2015). Largely nanoparticles are grouped into four groups:

Carbon-Based Materials

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The carbon based nanoparticles are ellipsoid, tube or hollow sphere shaped purely made up of carbon (Nasir, et al 2018). The buckyballs are the spherical fullerenes while nanotubes are cylindrical fullerenes. Carbon based nanoparticles are usually used in manufacturing stronger, durable and lighter materials and for high quality coatings and films.

Composites

Composites are combination of nanoparticles with any carrier or larger molecule.

Metal-Based Materials

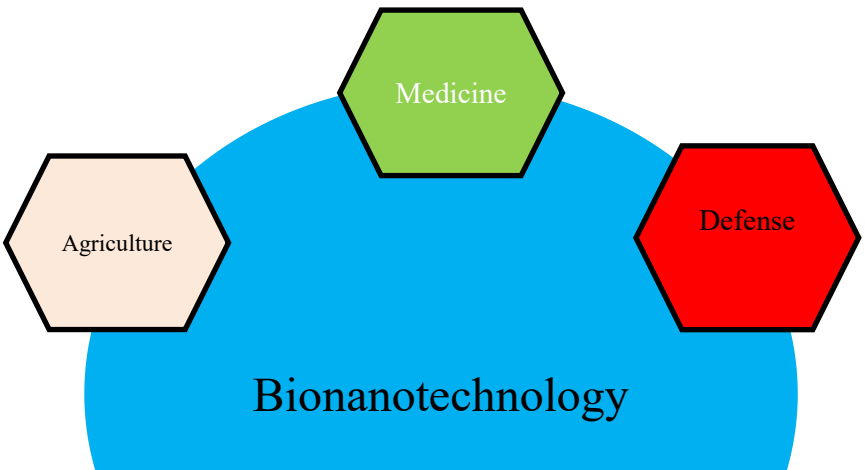
The physical properties of metal based nanoparticles can be handled. Almost 70% of the metal based nanoparticles atoms are surface exposed because of their small size changing the light emitting properties of metal based nanoparticles in chemical change on exposed surface, letting the emitting of multiple color form a single dot.

Dendrimers

The nano sized branched polymers are called dendrimers. The dendrimers have specific multiple surface chain ends which can be handled for performing specific chemical reaction (Sun, et al 2011). These three dimensional dedrimers have interior cavities onto which others molecules might be positioned. The distinctive properties of these different types of nanomaterials provide them innovative catalytic, electrical, imaging, magnetic, mechanical and thermal features which are vastly required for applications in commercial, environmental, medical and military sectors.

Applications of Bionanotechnology

The bionanotechnology have extensive range of applications in different sectors of society because of development of different techniques and tools (Chan, et al 2006).



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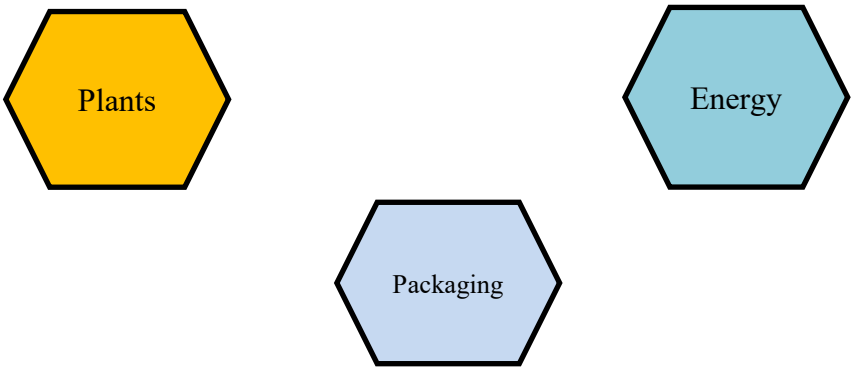


Figure1. Showing the bionanaotechnology applications in different sectors

Bionanotechnology and Medicine

Due to nano sized scale molecules applicable in almost all natural processes, Bionanotechnology is helpful in diagnosis and treatments of several ailments (Malik, et al 2023). So application of bionanotechnology for diagnosis, treatment, monitoring and controlling of diseases collectively has been referred as "Nano-medicine".Bionanotechnolgy is a marvelous tool for treating and diagnosis of various health and medical related issues like sensing, gene delivery system, targeted drug delivery and artificial implants. The surface plasmon resonance (SPR) depends on distinctive optical feature of nanoparticle. North America and Europe are the countries in which most articles were written in the field of nanomedicine as shown in table 3.

Bionanotechnology in Dairy and Food Industry

Food bionanotechnology open new ways of opportunities and development for dairy and food industry (Kaptan, et al 2025). Food nanotechnology usually focuses to improve food quality, taste, stability and targeted delivery of active compounds. The government and private sectors invested much money in the research of bionanotechnology. Various nano-tools and nano-techniques are used for the purpose of cultivation, processing, production and packaging of food termed as nano food. Nowadays people are facing different

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problems in the production of food globally. Bionanotechnology offer various techniques through which food polymer handled and better quality and safe food achieved (Primožič, et al 2021). The nanodrops are manufactured through nanobiotechnology capable of carrying minerals, phytochemicals and vitamins to digestive tract.

Food Packaging

The food packaging is the major concern for improving good quality food and bionanotechnology play its major role in it. By usage of nanocomposite material the chemical and physical properties like antimicrobial activity, barrier quality, resistance to temperature and strength are improved. Among many other applications of bionanotechnology is nanoclay nylon or silicon oxide coated bottles preventing gas diffusion and spoilage of packed food material, detected by biosensor (Bandyopadhyay, et al 2023). Similarly AgNPs act as antimicrobial, antiodorant and as health supplement. Silver nanoparticles being smaller surface area and larger volume deposited on bacteria and easily penetrated the cell membrane and then bound to cell organelles and destroy them.

Bionanotechnology and Agriculture

The major problems faced by agriculture sector are change of climate, decline soil organic matter, low crop yield and multi-nutrient deficiencies. Simillary shortage of water availability, pathogen resistance, fertilizers, pesticides accumulation, multi nutrient deficiency, food demand increasing day by day and requirement is to feed almost 6-9 billion population by 2025. The only better technique is the bionanotechnology, which help in the detection and controlled delivery of pesticides and nutrients assured, hence proliferate productivity and efficiency without any danger to environment (Yadav, et al 2023).

Controlling Plant Diseases

For managing plant diseases different types of nanoparticles are in used like alumino-silicates, carbon, silica and silver. Among these carbon nanoparticles are extensively used

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for making pesticides containing carbon nano fibers. The carbon nanotubes (CNT) which are allotropes of carbon have ability of penetrating soil which in turn increases the water holding capacity of soil thus helpful in rapid growth of tomato seedling (Vithanage, et al 2017). Preferred molecules and nutrient biocides can be anticipated to their places with the usage of CNT. Silica lacks any antimicrobial activity but in conjunction with AgNPs become helpful in controlling pathogenic microorganism. The alumino-silicate nanotubes are ecofriendly and much safer.

Bionanotechnology in Hydroponics

Hydroponics is a widely used technique for food crop production in which plants are grown without any soil (Sardare, et al 2013). Many super markets selling hydrophonically produced food worldwide. Crops are grown hydroponically. Hydroponically produced crops are cucumbers, chilies, eggplant, herbs, lettuce, melons, strawberries, sweet peppers, tomatoes and melons. Production of biofuel crops and fodder are the other applications of bionanotechnology.

Bionanotechnology and Energy Sector

Three major sources of energy are fossil fuel, hydroelectric and nuclear. Due to excessive manipulation of these sources, environmental crisis increases like biosphere and geosphere destruction, ecological misbalance, global warming and ozone layer depletion (Singh, et al 2016). Almost 80% of CO2 released from energy sector and is the chief reason of global warming. Other sources of energy are renewable sources which are mainly in form of geothermal, solar, thermal, tidal, ocean and winds with no emission of CO2. USA achieves 7% of its energy need from biomass and hydroelectric sources, 8 % from nuclear energy and 85 % from fossil fuel. Germany fulfills 56% energy requirement from fossil fuel, 27% from nuclear source and 125 from renewable sources. Bionanotechnology is a best tool for industries for producing cost effective bioenergy from biomass thus helpful in viable economic growth (Chandel, et al 2024). By applying bionanotechnology everyone can get clean and cheap energy for different purposes. Its incorporation with energy changes the

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mode of energy generation, storage, transmission, distribution and management.

Bionanotechnology and Defense Sector

Nanotechnolgy has wide applications in the different areas of defense sector and battle. The usual battlefield necessities are artillery, combat suits, logistics, transportation and tool for hazard detection and prevention can be achieved by assemblage of nanotechnology and biology (Armstrong, et al 2003). CNT being product of bionanotechnolgy are useful in the production of bullet proof and lightweight combat suits possessing thermal properties. The CNT body armor is 117 times stronger than steel. The nanosensors embedded in suits are helpful in monitoring body thermal adaptability thus handling temperature. Anti-fog lenses are created by using nanoparticle silica paint. Nanoparticles having optical property are used for filtering specific and harmful radiations, self-cleaning glasses for controlling heat and UV dispersion, thus protect eyes and improve vision and give safety to soldiers in extremely high temperatures (Maitlo, et al 2025). Biosensors in the bionanotechnology consumed for the exact detection of environment and accurate position of target.

Conclusion

Bionanotechnology deals with the fusion of biotechnological systems with the production of nanoparticles in a sustainable and eco-friendly way. These nanoparticles exhibit superior properties and have numerous applications in the fields of medicine, agriculture and industry. These include drug delivery, pest and disease management, food packaging, and innovations in energy and sustainable technology.

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