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Nanotechnology - A Green Approach in Indian Food Industry

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Abstract

Nanotechnology has emerged as a potential remedy for human-related challenges associated with sustainable living, addressing essential necessities and desires. These fundamental human needs encompass sustenance, water, energy, attire, housing, well-being, and hygienic surroundings. Over the past three decades, dedicated endeavours by scientists and engineers have yielded notable advancements across diverse domains such as agriculture, culinary technology, water purification, automotive, energy retention, beauty products, textiles, and construction materials. This paper underscores the utilization of nanotechnology within the food sector, where it has demonstrated its efficacy in ensuring food safety, innovating food packaging, and enhancing food processing. Additionally, the Indian government is actively pursuing constructive measures to facilitate the integration of nanotechnology into the nation's framework, displaying a welcoming stance towards startups and their involvement in this transformative field.

Keywords

Nanotechnology, Nanoparticle, Nanoscience, Nanometer, Nanoengineering, Nanomaterial

Introduction

The term "nano" originates from the Greek word for "dwarf," and the realm of nanoscience is concerned with investigating the behavior of atomic and molecular particles on a scale measured in nanometers, which are equivalent to one billionth of a meter (10^{-9}). In essence, a nanometer is an exceedingly minuscule unit of measurement, delving into the dimensions of atoms and molecules at this level. The notion of nanotechnology originated from a presentation by physicist Richard Feynman titled "There's Ample Space at the Bottom," which took place during a gathering of the American Physical Society at Caltech on December 29, 1959. During this address, Feynman envisioned that the complete Encyclopaedia Britannica could be contained within the dimensions of a pin's head. The term "nanotechnology" was formally coined in a 1974 publication by Professor Norio Taniguchi of Tokyo Science University. In his paper, he defined "nanotechnology" as follows: "'Nanotechnology' predominantly involves the manipulation, segregation, merging, and reshaping of substances at the level of individual atoms or molecules." Even though researchers had been working with nanoparticles (NPs) for a considerable period, their progress had been curtailed by the inability to directly observe these NPs. This explains why Feynman presented this groundbreaking concept to his peers long before the invention of scanning tunneling microscopes and atomic force microscopes [1].

Nanotechnology has generated extensive discourse among researchers, media outlets, investors, and various other domains. It entails the capacity to scrutinize, gauge, handle, construct, govern, and produce substances at the nanometer level. This field holds the potential for enhanced efficiency: yielding smaller, more affordable, lighter, and quicker devices endowed with heightened capabilities, all while utilizing reduced raw materials and energy resources. The nanoscale has captured significant attention due to the distinct characteristics' materials exhibit at this level compared to larger scales. Nanoscience represents an intersection of physics, chemistry, materials science, and biology. It revolves around the manipulation of materials on atomic, molecular, and macromolecular levels. Nanotechnology, on the other hand, stands as an emerging field of engineering that employs techniques from nanoscience to develop products. Manufacturing processes can attain nanoscale dimensions through two approaches. The first involves a "top-down" approach, where dimensions are progressively reduced through machining. The second employs a "bottom-up" strategy, capitalizing on the capacity of molecules and biological systems to autonomously construct minuscule structures.

Nanoparticle

NPs are minute materials with dimensions spanning from 1 to 100 nm. They can be categorized into distinct groups based on their attributes, shapes, or sizes. These categories encompass fullerenes, metallic NPs, ceramic NPs, and polymeric NPs. NPs exhibit exceptional physical and chemical traits due to their nanoscale size and substantial surface area. Notably, their optical features are linked to their size, resulting in diverse colors due to visible region absorption. Their reactivity, durability, and other characteristics also hinge on their distinct size, shape, and arrangement.

These distinctive qualities position them as viable candidates for diverse applications, both in commercial and domestic spheres. These applications span catalysis, imaging, medical uses, energy-related research, and environmental applications. Certain heavy metal NPs like lead, mercury, and tin are recognized for their considerable stability, which makes their decomposition challenging and potentially leads to various environmental hazards (Figure 1).

Nanoengineering

Nanotechnology and nanoengineering hold the potential to yield substantial scientific and technological advancements across a wide array of fields, including medicine and physiology. In a comprehensive sense, they encompass the scientific and engineering aspects related to the conception, creation, analysis, and application of materials and devices whose primary functional arrangement possesses dimensions at the nanoscale. This range extends from a few to several hundred nanometers. A nanometer corresponds to one billionth of a meter, or roughly three orders of magnitude smaller than a micron, which is approximately the scale of a molecule itself. (For instance, a DNA molecule measures around 2.5 nm in length, while a sodium atom spans about 0.2 nm.) The potential transformative influence of nanotechnology arises directly from the specific spatial and temporal dimensions under consideration. Crafting materials and devices at the nanoscale

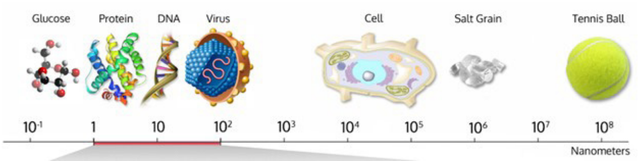

Figure 1: NPs size comparison chart [2].

entails the precise manipulation of individual constituent molecules and atoms to establish their organization within the larger macroscopic structure. Therefore, substrates engineered at the nano level can be intentionally tailored to manifest finely tuned chemical and physical characteristics on a larger scale. This capability originates from the meticulous control over the synthesis and arrangement of their molecular components, enabling the design of nanoengineered substrates with distinct and controlled bulk properties.

Nanomaterials

Nanomaterials are described as those containing organized constituents with at least one dimension measuring less than 100 nm. In the realm of quantum mechanics, the confinement of particles can be categorized as follows.

Two-dimensional quantum well

When materials are constrained in one dimension, creating a nanoscale dimension (allowing freedom in two dimensions), such as in thin films, they are termed two-dimensional quantum wells.

One-dimensional nanowires

When materials experience confinement in two dimensions, leading to two nanoscale dimensions (allowing freedom in one dimension), they are identified as one-dimensional nanowires.

Zero-dimensional quantum dots

When materials are restricted in three dimensions, resulting in three nanoscale dimensions (with no freedom in any direction or a zero-dimensional state), they are known as zero-dimensional quantum dots or nanoparticles. Examples of these include precipitates, colloids, and quantum dots (tiny particles composed of semiconductor materials) (Figure 2).

Past of nanotechnology

As far back as the 4th century AD, humans, specifically the Romans, harnessed NPs, and structures, presenting a fascinating instance of ancient nanotechnology. A remarkable illustration of this can be found in the Lycurgus cup, now part of the British Museum's collection, which stands as a pinnacle achievement in the historical glass industry. In 1990, researchers utilized transmission electron microscopy to explore the phenomenon of dichroism exhibited by the cup. This dichroism, characterized by dual colors, stems from the presence of nanoparticles measuring 50 - 100 nm in diameter.

Subsequent X-ray analysis disclosed that these nanoparticles constitute an alloy of silver and gold (Ag-Au), with a relative composition of approximately 7 parts silver to 3 parts gold, alongside around 10% dispersed copper (Cu) within a glass matrix. The Au NPs contribute to a reddish hue through light

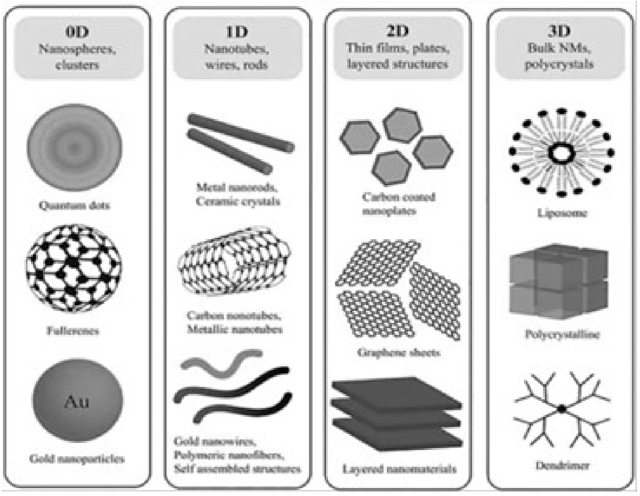

Figure 2: Classification of NPs [2].

absorption (~520 nm). The fusion of larger particles results in the reddish-purple shade, while the scattering of light by colloidal dispersions of Ag NPs, sized over 40 nm, is responsible for the green color. The Lycurgus cup holds the distinction of being one of the earliest instances of synthetic nanomaterials. A similar phenomenon is observable in later medieval church windows, emanating luminous red and yellow shades due to the incorporation of Au NPs and Ag NPs within the glass.

Literature Review

Saini et al. [3] describe the functions of various domains like disease diagnosis, drug transportation, and imaging. This article provides a concise overview of molecular imaging and NPs. Molecular imaging has become a potent instrument for observing molecular processes within an underlying ailment, often preceding its subsequent evident symptoms. The fusion of nanotechnology with molecular imaging yields a flexible foundation for innovatively crafting nanoprobes. These nanoprobes possess remarkable potential to amplify the accuracy, selectivity, and signaling efficiency of diverse biomarkers linked to human illnesses.

NPs probes have the potential to augment imaging methodologies by offering heightened signal sensitivity, improved spatial precision, and the capacity to furnish insights into biological intricacies at both molecular and cellular tiers. Basic magnetic NPs, for instance, can operate as contrast enhancement agents for magnetic resonance imaging. These magnetic nanoparticles can serve as foundational structures onto which supplementary functional elements can be incorporated. These additional components might encompass fluorescence labels, radionuclides, and other biomolecules, facilitating multimodal imaging, gene transfer, and the tracking of cellular movements.

Rehan [4] showcase the burgeoning uses of nanotechnology in the fields of food and nutrition sciences. It not only proposes avenues for deeper incorporation of these nascent technologies into nutritional research but also addresses the challenges and potential associated with introducing NPs in clinical and nutritional contexts. The exploration encompasses diverse aspects, including leveraging nanotechnology to enhance the bioavailability of bioactive nutrients in novel food items, harnessing nanotechnology's potential in food science, and tackling evolving safety and regulatory concerns. Additionally, the piece delves into fundamental research applications, such as the utilization of quantum dots to observe cellular mechanisms and interactions between proteins.

Haleem et al. [5] explores the utilization of nanotechnology within the realm of healthcare, outlining its applications and attributes for medical purposes. Effective progress of nanotechnology across diverse domains demands collective efforts involving scientists, governments, civil society entities, and the public. The present inquiry delves into numerous potential medical applications of nanotechnology. Consequently, this investigation delivers a concise and orderly overview of nanotechnology, offering a valuable reference for future research endeavors for researchers, engineers, and scientists.

Roco [6] highlight the pivotal role of NPs within the domain of nanotechnology. The production of NPs stands as a crucial facet of nanotechnology since distinct attributes are manifested at the NPs, nanocrystal, or nanolayer level. The synthesis of precursor particles and associated structures constitutes the most fundamental avenue for generating materials with nanostructured properties. It is underscored that the processes involved in creating NPs, crystals, and nanolayers aim to leverage four distinct effects: the emergence of novel physical, chemical, or biological traits due to the scaling down in size, the occurrence of fresh phenomena brought about by reducing size to a point where the length scales of interactions align with the particle's dimensions, and the corresponding microstructure grains.

Rangasamy [7] showcases the notable advancements achieved within the realm of nanotechnology, particularly concerning drug delivery systems. A range of polymers have been harnessed to create NPs in drug delivery research, aiming to amplify therapeutic advantages while mitigating potential adverse effects. The paper highlights that pharmaceutical nanotechnology comprises two core categories: nanomaterials and nanodevices, both of which possess significant relevance in pharmaceutical nanotechnology and other domains. Additionally, the paper outlines diverse varieties of pharmaceutical nanosystems, encompassing carbon nanotubes, quantum dots, polymeric NPs, metallic NPs, and liposomes. Furthermore, the study delves into numerous applications of pharmaceutical nanotechnology.

Woldeamanuel et al. [8] introduce the concept of veterinary nanotechnology, which holds promise for enhancing diagnostic and treatment systems, revolutionizing molecular and cellular breeding, and tracing the animal journey from birth to consumption. Veterinary nanotechnology also envisions advancements in animal nutrition, encompassing nutrient uptake and utilization, waste management from livestock, pathogen identification, and more. This article aims to review the application of nanotechnology within veterinary medicine, shedding light on its impact on animal health and productivity enhancement. The study explores a range of widely adopted NPs including fullerenes, quantum dots, nanopores, and nano-shells. Additionally, it delves into key nanotechnological approaches within veterinary science such as nano-vaccines, nano-pharmaceuticals, advancements in animal breeding and reproduction, and diagnostic techniques for diseases.

Doyle [9] propose that carbon atoms possess the capability to organize into nanostructures resembling geodesic domes, known as fullerenes or buckyballs. Indicate that nanotechnology has the potential to create highly responsive biosensors, capable of identifying pathogens and harmful substances in food products and processing facilities. Additionally, NPs might find application in the cleansing and sterilization of surfaces and equipment.

NPs can be generated through downsizing larger structures, employing methods such as ultrafine grinding, laser techniques, and vaporization followed by cooling. In cases involving intricate particles, nanotechnologists typically opt for a bottom-up strategy, which involves arranging molecules to construct intricate structures showcasing novel and beneficial characteristics. This is achieved through diverse techniques like solvent-based extraction/evaporation, crystallization, self-assembly, layer-by-layer deposition, microbial synthesis, and reactions involving biomass.

Shrivastava and Dash [10] explore the potential prospects tied to these opportunities, while also proposing strategies for effectively overseeing the extensive advancements within these domains. The discussion spans a multitude of well-established disciplines, drawing from physiology, biotechnology, chemistry, electrical engineering, materials science, and more. It is evident that this extensive array of knowledge is arduous for any single researcher to completely grasp. The comprehensive nature of this endeavor stands as a primary obstacle for newcomers entering the field. Additional challenges encompass insufficient funding, the intricate complexity inherent in biology, the way biologists accumulate and disseminate information, and the cultural disparities between engineering and biological sciences.

Singh et al. [1] shed illumination on nanostructures and categorize them into two main methodologies: the top-down approach and the bottom-up approach. It provides a succinct overview of diverse techniques for crafting NPs, organized under chemical, biological, and mechanical classifications. Nanomaterials are further categorized based on their dimensions into zero-dimensional, one-dimensional, two-dimensional, and three-dimensional forms. Additionally, NPs and nanoscale materials are classified into four types based on their composition: carbon-based, inorganic-based, organic-based, and composite-based. Concluding, the article delves into the various domains where nanotechnology finds application.

Garg [11] focus on the realm of nanoengineering, which involves incorporating inventive capabilities into conventional network technologies like energy production or distribution within novel systems. Nano-sized sensors possess the potential to offer cost-effective, continuous monitoring of the structural integrity of infrastructures such as bridges, roads, trains, parking facilities, and floors over extended periods. It highlights the synthesis and introduction of highly toxic organic compounds into the atmosphere, either directly or indirectly, for long-term use. Notable examples include polycyclic aromatic hydrocarbons and polychlorinated biphenyls. The discussion proposes that combining NPs with established treatments has demonstrated through numerous experiments the enhanced efficacy in eliminating pollutants, including organic substances.

Bachhav and Deore [12] highlight the significance of nanomaterials, encompassing varieties such as aerogels, carbon nanotubes, fullerenes, nano-polymers, nano-vectors, nanocomposites, nanocrystals, nanofibers, nano-clays, nano-filters, nano-horns, nanowires, nano-springs, nanorods, and more. Products crafted through the utilization of nanomaterials find wide-ranging as well as specialized utility in fields like tissue engineering, cancer treatments, sports equipment, lithium batteries, solar cells, aerospace materials, cosmetics, and beyond. This article comprehensively examines the attributes and application domains of nanomaterials. It also discusses the incorporation of nanotechnology-derived products to bolster sustainability, encompassing the creation of environmentally friendly nanoproducts and employing nanoproducts to advance sustainability objectives.

Brame et al. [13] place emphasis on various aspects, spanning from extending the lifespan of products and improving the isolation of microbes to upgrading the standards of food preservation and safety, and even encompassing the tracking and detection of pollutants and contaminants. The influence of nanotechnology has been felt across a wide array of domains within the food processing sector. It also addresses topics like potential health hazards, safety considerations, concerns regarding toxicity, and other associated difficulties.

Rajak [14] explore the progress made in the realm of nanotechnology, particularly within the domain of the food industry. It discusses the development of nanosensors designed to detect contaminants, pathogens, and harmful substances within food items. Nanoencapsulation techniques have gained widespread application for the purpose of releasing and retaining desired flavors, thereby ensuring culinary harmony. This process aids larger molecules in withstanding acidic conditions and seamlessly integrating into food products. The article also highlights the protective attributes of nanocomposites and nanolaminates, which serve as effective barriers against intense thermal and mechanical stress, ultimately prolonging the shelf life of food products.

Potential Applications in Food Production and Processing

In recent decades, nanotechnology has found application within the food industry to enhance food quality, extend shelf life, enhance flavors and textures, and safeguard against pathogenic contamination. The integration of nanotechnology has become a fundamental aspect of both food processing and packaging, particularly due to advancements in the creation of nano-polymers. Furthermore, nanosensors have been designed for the purpose of detecting contaminants, pathogens, and harmful substances present in food products (Figure 3).

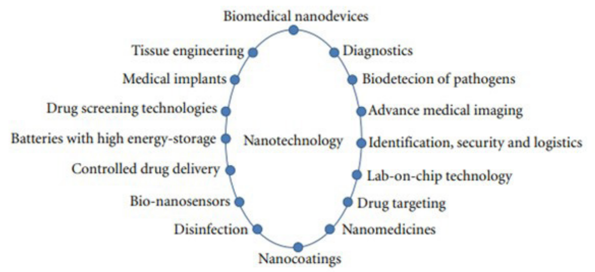

Figure 3: Revolution in biomedical sciences by nanotechnology [10].

Nanoencapsulation

It serves as a shield for food ingredients against heat, moisture, and deterioration throughout different stages of processing, production, and storage. Additionally, it enhances the harmonization of distinct compounds within the system. Various encapsulation and delivery systems based on polymers have been created to enhance bioavailability, preserve active components within food, and facilitate their penetration into tissues.

Nanocoating

Various food materials undergo nanocoating's, which have proven to be efficient barriers against both moisture and gas exchange. These coatings additionally contribute to the distinct colors and flavors of the food products. Moreover, they successfully transport enzymes and antioxidants, thereby extending the shelf life of processed foods once the packaging is opened.

Nanomaterials

These are classified according to their dimensions, composition, arrangements, and attributes. NPs possessing a substantial surface-to-volume ratio can exhibit remarkable physicochemical traits, encompassing factors like diffusion, solubility, bioavailability, toxicity, optics, thermodynamics, and magnetism.

Food additives

Food additives at the nanoscale, taking the form of flavor enhancers, preservatives, antimicrobial sensors, packaging materials, and encapsulated food constituents, have a recognized impact on the nutritional makeup while also enhancing the longevity, taste, and texture of products. Moreover, they can serve as indicators for food quality and safety through the detection of foodborne pathogens.

The utilization of nanotechnology is gaining prominence across various domains such as electronics, robotics, and medicine. However, its recognition in the food industry has been comparatively limited in comparison to these other fields. Notable applications within the food sector encompass food processing, food packaging, food preservation, and the monitoring of food quality. A diverse array of sensors has been devised to identify pathogens, leakages, gas presence, discoloration, alterations in pH, odor, and temperature changes (Figure 4).

Food packaging

Enhancements in the attributes of food packaging materials, including strength, barrier features, antimicrobial capabilities, and resilience to temperature fluctuations, are being achieved through the utilization of nanocomposite materials. These advancements in packaging could potentially lead to prolonged shelf life for food items. Polymer-silicate nanocomposites have also been documented to exhibit enhanced qualities such as improved resistance to gas penetration, heightened mechanical durability, and increased thermal stability (Figure 5).

Food processing

Certain food processing techniques employ enzymes to modify food constituents, aiming to enhance flavor, nutritional content, or other attributes. The immobilization of these enzymes onto NPs could potentially assist in their even distribution throughout food matrices and augment their efficiency. Nanosized silicon dioxide particles featuring reactive aldehyde groups were engineered and proven to covalently attach to a porcine triacylglycerol lipase enzyme. These particles effective-

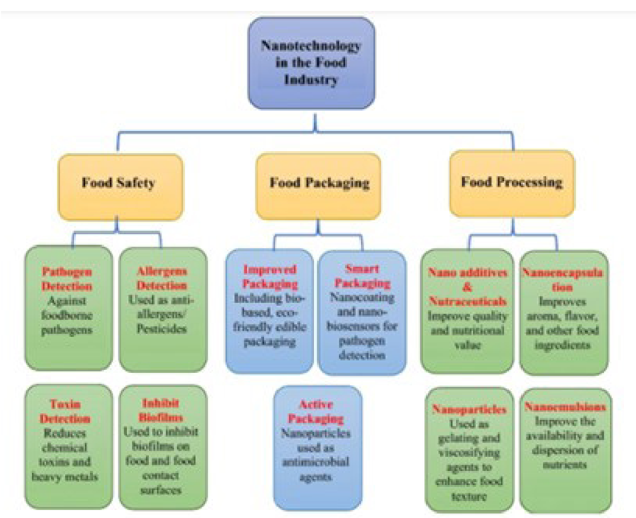

Figure 4: Nanotechnology in food industry [15].

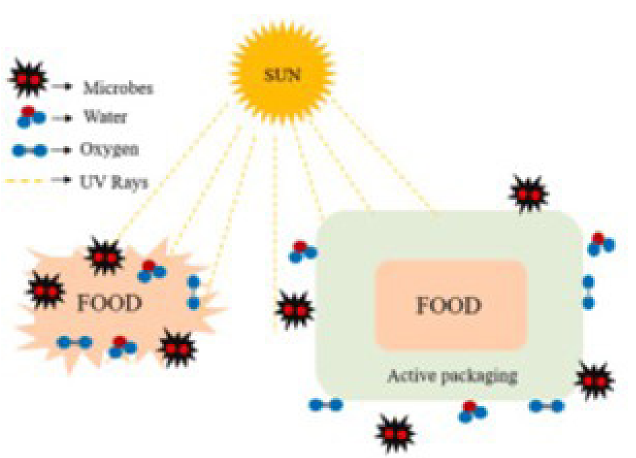

Figure 5: Safety using food packaging [16].

ly catalyzed the hydrolysis of olive oil and exhibited noteworthy stability, versatility, and reusability.

Cleaning and disinfection

Under the influence of Ultraviolet light, titanium dioxide produces active molecules like hydroxyl and superoxide radicals that initiate the breakdown of organic substances and, potentially, microorganisms. In specific refrigerators and food storage containers, surfaces incorporate Ag NPs, which are said to hinder the proliferation of harmful microorganisms and spoilage bacteria.

Sensors

Enhanced biosensor technology has the potential to identify gases found within packaged foods, serving as an indicator of the packaging material's integrity, compounds released during food spoilage or degradation, and the existence of pathogens or harmful substances in the food. These sensors could be integrated into packaging to provide alerts about food safety to consumers, producers, and distributors, or could also be deployed to identify pathogens within food processing facilities.

Nutritional supplements

The substantial economic benefit to a nation's economy arises from the overall market valuation of nanofood across various domains of food technology. Referred to as 'Nanoceuticals' in the business sphere, these nanofood additives possess the capability to enhance the intake of vital elements such as nutrients, vitamins, and minerals through the application of nano-powders. Consequently, the efficacy of incorporating nanotechnology into food supplements is heightened, as their reduced scale enables them to interact more efficiently within the human body.

Food quality monitoring

Nanomaterial-based sensors, primarily employed for identifying pathogens or impurities in food, exist at the nanoscale. These sensors exhibit remarkable sensitivity. The key benefit of these nano-sensor systems is their capacity to accommodate numerous nanoparticles on a single sensor, enabling precise identification of pathogen presence within stored grains in bins. Moreover, they can be strategically positioned and dispersed within the gaps of the grain bulk.

Pathogen identification in food

Numerous techniques are employed to assess food quality, and among them is the identification of pathogens such as *Escherichia coli* within a food sample. This is achieved by quantifying the light scattering caused by the cell's mitochondria using a sophisticated spectrometer. This interaction leads to the dispersion of nanoscale light, which can be subsequently captured through digital image analysis. In the last ten years, progress has been made in the realm of nanotechnology, involving the creation of biosensor particles with absorption indicators that are affixed to silicon or gold nanorod arrays, coupled with anti-*Salmonella* agents.

The Future of Nanotechnology

The potential economic scope of nanotechnology in 2015 spans from tens of billions to trillions of dollars. Japan has recently committed around £400 million in central government expenditure for the fiscal year 2002. In the USA, the federal budget for 2002 includes $604 million earmarked for nanotechnology research and development. In the UK, governmental spending on nanotechnology R&D in 2002 amounts to approximately $45 million annually. The National Science Foundation anticipates that the global market for goods and services utilizing nanotechnologies could reach a value of one trillion dollars by 2015. Concurrently, the growth of this rapidly advancing technology is projected to generate 2 - 5 million semiskilled and skilled jobs worldwide. The reach of nanotechnology's influence encompasses diverse domains, from the clothes we don to our energy consumption, and even to how we diagnose and treat diseases like cancer. To ensure the optimal commercialization of products based on nanotechnology, it is crucial to identify the significant catalysts within this expansive field at an early stage. A useful way to organize this area is by defining the following four competencies:

- **Nano-synthesis:** Producing building blocks at the nanoscale, encompassing nanoparticles, nanotubes, and nanostructures.
- **Nanofabrication and nano-processing:** Manipulating and processing building blocks on the nanoscale to achieve specific objectives.
- **Nano-incorporation:** Integrating nanoscale building blocks into end-product formats, spanning polymer composites, electronic components, and medical instruments.
- **Nano-characterization:** Assessing and describing fundamental attributes of nanoscale building blocks or finished products, both during manufacturing processes and in their final states.

Current Market of Nanotechnology in India

The inception of nanotechnology in India was initiated by the Nanoscience and Technology Mission, led by the Department of Science and Technology (DST), during the 10th plan phase (2002 - 2007), with an initial allocation of $12 million. Anticipated progress is foreseen in India's nanotechnology market, with a projected Compound Annual Growth Rate of 19.1% over the upcoming decade. This upward trajectory is fueled by an increasing demand for products based on nanotechnology, particularly in the healthcare and energy sectors.

The strategic aim of nanotechnology in India is to harness the nation's rich array of natural resources to address various burgeoning sectors, encompassing electronics, healthcare, pure food and water, and top-quality textiles.

Steps/initiatives by government

Establishment of a regulatory board for nanotechnology to oversee the regulation of industrial nanoproducts Services, and nanotechnology institutes such as the Indian Institute of Nano Sciences located in Bangalore, Mumbai, and Kolkata. Initiatives in the field of nanotechnology by the Department of Information Technology, specifically targeting nano-electronic products. The DST's Nanomission, encompassing nano-biotechnology endeavors through collaborations with DBT, ICMR, and the Center of Excellence in Nanoelectronics supported by MeitY, contributes to activities in nanoscience, nanotechnology, nanobiotechnology, and nanoelectronics. The DST's creation of eighteen Sophisticated Analytical Instrument Facilities across India is crucial for advanced characterization and synthesis of nanomaterials for various applications.

The establishment of the Center of Excellence in Nanoscience and Nanotechnology under the DST Nanomission, aiding research and postgraduate students in diverse focus areas. Thematic Units of Excellence are devoted to distinct domains of nanoscience and nanotechnology, pivotal in research aimed at product development to support the field of nanotechnology. AVANSA Technology and Services specializes in synthesizing and analyzing nanomaterials for industries, institutes, and universities that use nanotechnology. The company also manufactures graphene, carbon nanotubes, and various NPs.

Nanotechnology startups in India

There are some companies and exciting start-ups operating in the nanotechnology market of India NoPo Nanotechnologies is a manufacturer of advanced nanomaterials, specifically single-walled carbon nanotubes [2]. Amnivor Medicare is a healthcare company that uses nanotechnology to extract collagen from fish scales. Its collagen and collagen-based products can treat various ailments such as burns, diabetes, and chronic wounds. Nanosentrix produces conductive inks for use in printed electronic devices. The ink is made with conductive materials like carbon nano, graphene, and graphite, nano span manufactures and supplies various types of graphene, carbon nanomaterials, and nano-silicon-based flexible electrodes and anode for supercapacitors and Li-ion batteries. It also provides nanomaterial characterization and testing services using advanced equipment such as high-resolution transmission electron microscopy, Fourier transform infrared spectroscopy, and atomic force microscopy. Kanopy Techno Solutions offers nanotechnology and electrochemistry solutions, including multiscale simulation, electrochemical instrumentation, nano-fluidics, and nanofabrication technologies.

Saint-Gobain Glass India Manufactures a variety of glass known as SGG NANO, featuring enhanced thermal insulation characteristics and advanced energy-efficient solar management. The glass is fabricated by depositing multiple specialized layers of nanoscale metallic oxides and nitrides using magnetically enhanced nanotechnology-driven cathodic sputtering within a vacuum environment. This technique contributes to enhancing the glass's energy efficiency and insulation capabilities. Auto Fiber Craft Manufactures distinct nanomaterials, notably nano-sized silver powder designed for electronic purposes like conductive inks and pastes, alongside applications in RFID technology.

Future of nanotechnology in India

The advancement of nanotechnology in India has been primarily motivated by the conviction that this technology holds the potential to tackle societal dilemmas, such as healthcare accessibility and potable water provision, concurrently fostering economic growth through the establishment of nanotech-driven industries. As public consciousness expands, India can employ nanotechnology in educational initiatives and the construction of novel infrastructures, which can foster a proficient workforce essential for a knowledge-centric economy, thereby positioning the nation advantageously within the worldwide nanotechnology revolution. Nevertheless, augmented funding, including sustained investments in well-structured research programs yielding substantial outcomes, is imperative. Additionally, collaboration among research establishments across the nation has the potential to yield more efficient outcomes.

Conclusion

Nanotechnology presents a vision of a world where novel products are meticulously designed at the atomic and molecular scale, offering practical and cost-efficient avenues for harnessing renewable energy sources, and upholding environmental cleanliness. The applications of nanotechnology span a wide spectrum, encompassing fields like electronics, biology, chemical engineering, and robotics. While there lie numerous research hurdles ahead, nanotechnology is already yielding a diverse array of beneficial materials and showcasing potential advancements in the realm of the food industry. It has propelled scientific exploration to the realm of nanoparticles, ushering in a realm of fresh possibilities. A particularly remarkable innovation is nanotechnology's impact on the food supply chain in India, which includes precision farming techniques, intelligent feed solutions, improved food texture and quality, heightened bioavailability of nutrients, and advanced packaging and labeling methods.

Nanofood packaging resources have the potential to extend the shelf life of food, enhance food safety by indicating contamination or spoilage, repair packaging damage, and uniformly release additives to extend food longevity within the package. To retain a leadership role in the food and food-processing sector, embracing nanotechnology is imperative for future progress. The future landscape is primed for new products and processes aimed at personalization and customization.

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None.

Conflict of Interest

The authors declare that they have no conflict of interest.

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