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Advances in Nanotechnology Applications for Food and Healthcare Engineering: Review

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ABSTRACT

Nanotechnology is revolutionizing various sectors, particularly food and healthcare engineering, by enhancing safety, quality, and efficiency. In the food industry, nanomaterials improve packaging by providing barrier properties, extending shelf life, and detecting spoilage through nanosensors. These innovations ensure food safety and reduce waste. In healthcare, nanotechnology enables targeted drug delivery, enhancing therapeutic efficacy while minimize.ng side effects. Nanoparticles facilitate imaging techniques, leading to early disease detection and personalized medicine. Additionally, nanostructured materials are advancing the development of biosensors for real-time health monitoring. As research progresses, integrating nanotechnology in these fields promises to address critical challenges, foster sustainable practices and improve overall quality of life. This abstract underscore the transformative potential of nanotechnology in food safety and healthcare, paving the way for future innovations that could significantly impact public health and nutrition. Nanotechnology is poised to transform significantly, offering immense industrial, healthcare, and agricultural opportunities. The application of nanomaterials and nanoparticles in the food industry is increasing as they help prevent food spoilage. Using nanomaterials as biomarkers can assure food safety and quality by detecting viruses present in food. A primary concern for food safety is the potential migration and leaching of nanoparticles from packaging into food items. Nanotechnology is making substantial progress, if not entirely transforming, in several industries and fields of modern scientific advancements. Recent advancements in chemistry and biotechnology have paved the way for modern nanomaterials, which exhibit remarkable properties due to their nanoscale structures. This essay explores the various applications of nanotechnology that have emerged in recent years. It provides an overview of nanomaterials and their relevance across multiple industries, including solar energy, environmental conservation, future transportation, robotics in food and agriculture, food technology, computing, sensors, medicine, water filtration, and healthcare. Additionally, it examines the promising future applications of nanotechnology. The vision for nanomaterials involves developing new yields at the atomic and molecular levels, offering innovative and efficient solutions for achieving sustainable energy sources and environmental preservation.

Keywords: Nanotechnology applications; Food and health care; Nanotechnology in agriculture; Packaging and preservation.

1. INTRODUCTION

Nanotechnology works with structures between one to one hundred nanometers across and includes modifying or manufacturing materials within that range. It makes the substance lighter, more stable, faster, subdued, and more challenging. Nanotechnology gives us the ability to design precise, atomic-scale machine parts. Developing novel materials at the nanoscale scale is a significant focus of this discipline. These are often materials made of tiny particles, with each element being less than 100 nanometers (nm) in size. The key regulators of global inventive competition are science and design. Current research provides another foundation for development, information, and innovation reconciliation by combining aspects of nature at the nanoscale. Nanotechnology is occasionally promoted as a universally valuable breakthrough because it will significantly impact nearly every aspect of society and industry. There is a long-term progression of unity and disparity in the broad fields of design and science. Around 2000, assembly at the nanoscale peaked, and the following years saw a comparison of the differences in nanoframework structures (Abreu *et al.* 2012). Nanotechnology has emerged as a transformative field, offering groundbreaking solutions in food and healthcare engineering. By manipulating materials at the nanoscale, researchers have developed innovative applications that enhance safety, efficiency, and functionality across these industries. In recent years, nanotechnology has garnered significant attention for its potential to address critical challenges in food and healthcare engineering.

2. BRANCHES OF NANOTECHNOLOGY

This section provides a brief overview of the components of nanotechnology. Numerous Nanotechnology products are available, and still a sizable amount of exploration is taking place in research labs and universities. Branching off nanotechnology may impact the global agricultural, non-fuel, and mineral product markets. Using several nanotechnologies allows nanotechnology to provide potential solutions for a few problems.

2.1 Nano Engineering

The term "Nano-designing" comes from the nanometer, an estimating unit with a resolution of one billionth of a meter. In contrast to the profession's applied science portion, this branch emphasizes designing (Augustin and Sanguansri 2009). Nanoengineering uses the scanning tunneling microscope (STM) and subatomic self-gathering techniques. Meanwhile, molecular self-assembly allows a flexible grouping of DNA to be organized and employed to create unique proteins.

2.2 Uses of Nanotechnology

Nowadays, nanoscale materials are used to manufacture a sizable fraction of the products. Gas can be destroyed by dry nanopowder. Nanoscale materials are used to build batteries for instruments that can transmit more power more quickly while dissipating less heat. Nanoscale silver is used in the antibacterial wound dressing (Azeredo *et al*. 2009). Among nanotechnology's diverse uses are sports equipment, car parts, energy storage in batteries, increasing the viability of personal care products, medicine delivery, and other applications (Sim and Wong 2021).

2.3 Carbon Nano Tubes (CNT)

Allotropes of carbon with a tube-shaped nanostructure are known as carbon nanotubes. The length-to-distance ratio of nanotubes has been built up to 2,800,000:1, much larger than other materials. These carbon atoms are formed like tubes, extreme, and have unique electrical properties (V.S. Angulakshmi *et al.* 2022). Thanks to their unique features, they are incredibly beneficial in various applications, including hardware, nanotechnology, optics, batteries, solar cells, transistors, biotechnology, materials science, and design domains (Bigliardi and Galati 2013). Despite their potential, challenges such as high production costs, difficulty in controlling structural uniformity, and concerns over toxicity need to be addressed to enable widespread adoption. Fig. 1 shows a display of nanotubes.

2.4 Thin Nano Films

In low-budget films, many nanoscale materials can be used to build them water-repulsive, UV or IR-safe, aggressive to microbiological, antagonistic to self-cleaning, and electrically conductive (Bigliardi and Galati 2013). Nano film applications include PC displays, cameras, and eyewear. Fig. 2 illustrates nanofilm.

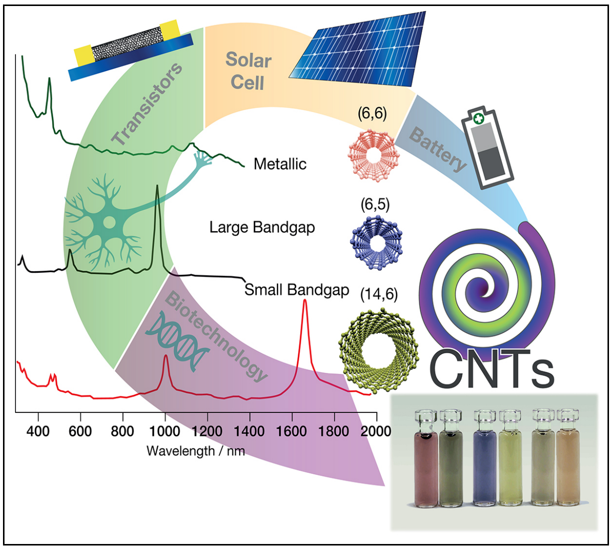

Fig. 1: Carbon Nano Tubes (CNT)

2.5 Nano-scale Transistors

A semiconductor is an electronic component that amplifies or switches electrical power and electronic signals. A small amount of power is used in semiconductors as an entry to control the evolution of a more significant amount of influence. The size of semiconductors has gradually become smaller, making PCs look even more impressive. Up to this point, the industry's best swapping skill produced CPUs with semiconductors. Current claims indicate that nanotechnology will enable semiconductors to be substantially smaller.

2.6 Drug-Delivery methods using Dendrimers

Dendrimers are remarkably dispersed, star-shaped macro molecules with dimensions at the nanometer scale (Cerrada *et al*. 2008). Dendrimers are exceptionally planned and made for various applications, such as cancer healing, medication delivery, quality reverie, catalysis, energy collection, and photosynthesis. Dendrimers perform various tasks consecutively, including spotting sick cells, diagnosing illnesses, delivering drugs, illustrating a location, and announcing treatment dates (Cha and Chinnan 2004).

2.7 Water Filtration Technique

Nanoscale sensors detect contaminants in the water framework, and carbon nanotube-based films are used for water desalination. The steps involved in using carbon nanotubes to filter water. The other nanoscale substance that may guide and remove water structures is nanoscale TiO_2, also used in sunscreen to kill bacteria.

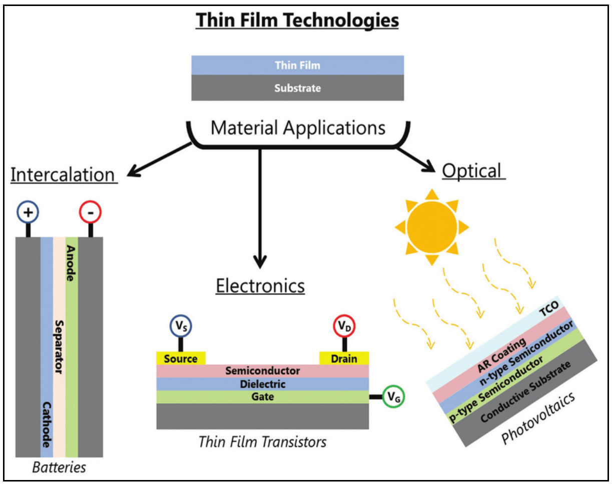

Fig. 2: Applications of Nanothin film

3. APPLICATIONS OF NANOTECHNOLOGY

3.1 Sustainable Energy Application

Model sun power-driven chargers integrating nanotechnology are more efficient than conventional designs at converting daylight into power, with the potential for small future increases in sun-orientated force (Chaudhry *et al*. 2008). Nanostructured materials are being sought to improve hydrogen layer and capacity materials considerably, and the driving forces behind this should be clear while considering how to develop energy units for cheaper optional transportation developments. To manage flexible electronic devices, researchers are developing flexible piezoelectric nanowires woven into clothing that can quickly produce helpful energy from light, grinding, and body heat, as well as thin film solar-based stimulating boards that can be put onto PC casings. Sustainable energy applications focus on harnessing renewable resources to meet the world's energy needs while minimizing environmental impact. Key technologies include solar, wind, hydroelectric, and geothermal energy, which provide cleaner alternatives to fossil fuels. Solar energy systems, such as photovoltaic panels and solar thermal collectors, convert sunlight into electricity and heat (Kalaiselvan *et al*. 2018).

Wind turbines capture kinetic energy from the wind, generating electricity without emissions. Hydroelectric power uses flowing water to produce energy, while geothermal systems tap into the Earth's heat for heating and electricity generation. These sustainable applications reduce greenhouse gas emissions, enhance energy security, and create green jobs. Innovations like energy storage solutions and smart grids further optimize renewable sources, enabling a more resilient energy infrastructure. By integrating sustainable energy applications, we can transition toward a low-carbon future, promote environmental stewardship, and support economic growth in a way that meets the needs of both current and future generations. Products with higher energy efficiency are becoming more numerous and have more uses. A large variety of clinical and biotechnology equipment and systems have the potential to be changed by nanotechnology to make them more specialized, practical, affordable, secure, and easy to use (Dasgupta *et al*. 2015). Here are a few occasions where there have been substantial developments.

3.2 Sensors and Medicine Application

Therapeutics have many functions in which a nanoparticle acts as a platform to work with an aggressive treatment, limiting the risk to healthy tissues (Alghamdi *et al*. 2022). Microfluidic chip-based Nano labs suitable for monitoring and regulating personage cells and Nano size tests to observe the advances of cells moving around in their environment are a few examples of exploration-empowering influences (Ditta 2012). Applications in medicine and health care using nanobio frameworks. Nanotechnology treatments and systems such that they are additionally individualized, adaptable, affordable, and easier to maintain. Here are a few examples of noteworthy advancements made there. Semiconducting nanocrystals called quantum spots can enhance natural imaging for medical diagnosis.

3.3 Future Transportation Applications

The ability to create or communicate energy is one example of how new frameworks could incorporate innovative capabilities into conventional foundation materials. Long-term monitoring of the state and performance of extension, burrows, railways, stop works, and asphalts may be possible with the help of nanoscale sensors and devices. The use of nanotechnology to encourage the development of impudence cells in spoiled synapses or the spinal cord is now being investigated (Durán and Marcato 2013). One method involves stodging the spaces between existing cells with a nanostructure gel, which encourages the enlargement of new cells. Early investigations have been done on this in hamsters' visual nerves.

3.4 Nanotechnology for Environmental Protection

Current innovation in this area is neither fundamentally nor fiscally sufficient to address all of today's cleaning requirements. One of the dominant scientific trends nowadays and one of the key inventions of the twenty-first century is nanotechnology (El-Temsah and Joner 2012). The management of pollution cleanup may greatly benefit from the use of nanotechnology. TCE decreases up to approximately 100% in a couple of days following the nanoparticle combination, demonstrating the long-lasting receptivity of nanoparticles to toxins in soil and water. Remediation, insurance, support, and upgrading are the four categories into which the use of nanotechnology in natural science is divided. Nanoparticles can be used in ecological atomic science, mesoporous components for green science, air and water treatment, and synergist applications. The particles get smaller while gaining new physical, electrical, and material properties. Nanotechnology is also prepared to advance environmental development by introducing effective control and preventing pollution. Numerous nanotechnology appliances have been efficiently used on the investigative ability scale for ecological treatment. The effectiveness of conventional cleanup technologies in reducing the convergence of air, water, and soil pollutants has been proven to be limited.

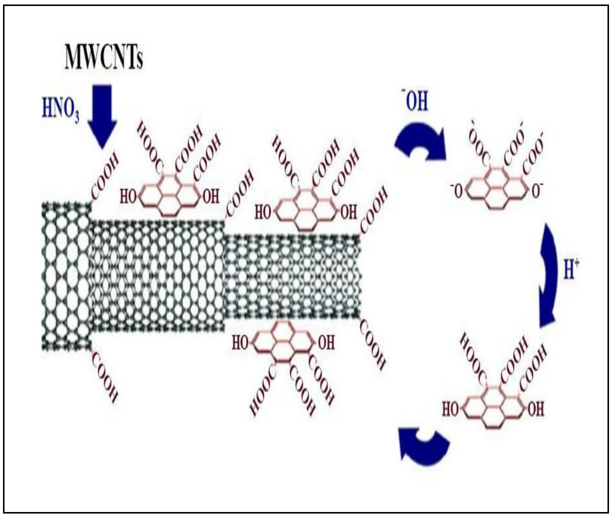

Fig. 3: Simplified scheme of the generation of covalently bound surface acidic groups

3.5 Remedial Technology by Nanomaterials

Nanoparticles occur in a region that rides the quantum scales and are often less than 100 nanometers, including 20–5000 particles (Gortzi *et al*. 2007). They can be made from a variety of materials and in a variety of shapes, including cylinders, rounds, poles, and wires. An emerging, trend-setting breakthrough for addressing environmental problems is nanotechnology. The attraction of nanoparticles is due to two key characteristics: When compared to media created by conventional methods, nanoparticles have a larger surface area per unit mass due to their initial small size (1–100 nm). Carbons are widely utilized as traditional adsorbents in European countries to remove dioxins from the vaporous emissions of trash cremation (Gu *et al*. 2003). Although sorption is undoubtedly quick, other materials should eventually replace the greatest concentration of the combinations (He *et al*. 2019). An alternative touch is debasement or material alteration (Hu *et al*. 2015). MWNT proved an effective adsorbent for removing PCBs and other chlorinated sweet-smelling chemicals from lubricating oil. Toxins from contaminated soil and water have been removed using various treatment techniques and cycles (Iannitelli *et al*. 2011). Adsorption is likely the most well-known of all the approaches suggested and is currently regarded as a potent, effective, and affordable way for soil and water filtration.

3.6 Applications of Nanotechnology in Remediation

The use of in situ handling improvements is growing due to the high cost and frequently extended working times for these treatments. This accounts for increased exposure to poisons, prompting a rapid decline in fixations on foreign substances. Iron nanoparticles can alter, regardless of whether their production processes are the same. Particle characteristics like reactivity, adaptability, and duration of use can vary depending on the assembly method or the person providing the molecule (Joye *et al*. 2014).

3.7 In-Situ Application of Nanoparticles

Utilizing existing observation wells, piezometers, or infusion wells is the fastest method of infusion. The surplus nanoparticles are mixed with the separated groundwater before being infused into the infusion well once more. Research is moving forward on infusion techniques that will enable nanoparticles to more easily sustain their reactivity and enhance their access to obstinate impurities by carrying out more extensive subsurface transportation (Karavolos and Holban 2016).

3.8 Application of Nanotechnology in Food Industry

Nearly 6 billion people live on the planet at this time, with half of them living in Asia. While there is an abundance of food in the created world, a significant portion of people who live in agricultural nations experience daily food shortages as a result of ecological consequences or political unpredictability. The goal for agricultural nations is to promote vermin-free harvests throughout the dry season, which also increases production. Nanotechnology has the potential to alter medical services, materials, and materials themselves (Yu and Huang, 2010). Innovation in the fields of data and correspondence, as well as energy, has received high praise. In fact, a few products made possible by nanotechnology are already in demand, including self-cleaning windows, simple sunscreen moisturizers, smudge-proof textures, and antibacterial dressings (Kerry *et al*. 2006). The EU aims to increase biotechnology's capacity to benefit the economy, society, and environment as part of its "information-based economy" agenda. Intelligent conveyance systems and smart sensors will help (Khan *et al*. 2015). Nanotechnology will also help to protect the environment by, for example, utilizing renewable energy sources, pathways for reducing pollution, and means of neutralizing existing toxins. In order to streamline green procedures, plants are grown in a controlled environment (Kim *et al*. 2003). The electrical framework controls and filters constrained situations, such as yield fields.

3.9 Application of Nanotechnology in Agriculture

As a result, they were forbidden. Integrated Pest Management frameworks, which combine conventional agricultural revolution tactics with natural irritant management measures, are becoming well known and used in many countries, including Tunisia and India, to keep up with crop yields. Later, "shrewd" agricultural systems could be created using nanoscale devices with unique features. Innovations like embodiment and controlled delivery methods have changed how pesticides and herbicides are used. Numerous businesses develop products using nanoparticles in the 100–250 nm size range that degrade in water more effectively than current ones, hence facilitating their mobility. They can be oil- or water-based (Lagaron *et al*. 2005). These have numerous uses for the protection, treatment, or conservation of the gathered object and can be easily combined in a variety of media, such as gels, lotions, fluids, and so forth. Additionally, new research aims to reduce contamination and make farming safer for the environment by enabling plants to use water, herbicides, and manures more efficiently. Over 60% of the population relies on horticulture as their primary source of income, making it the cornerstone of most agricultural nations.

This is similar to developing more advanced frameworks for analyzing natural circumstances and delivering vitamins or pesticides as appropriate. Additionally, it can provide training for higher-esteem crops or natural remediation. These strands can be used to create channels that can filter water to remove diseases, bacteria, and protozoan growths. Similar work is being done elsewhere, particularly in developing nations like South Africa and India. This could set the stage for nano hydroponics, which would benefit many ranchers worldwide. In any event, the development of nanotechnology has sparked discussion regarding the risks posed by ultrafine particles. In addition to artificial nanoparticles, ultra-fine particles can also be created accidentally. These also go by the name "non-produced nanoparticles" and include particles formed during the ignition of fuels, such as ultrafine particles emitted by diesel-fueled automobiles, heating cycles for polymers, or singing food varieties. They work with a broad range of nanostructured materials and nano methods, such as liposomes, polymeric nanoparticles, nanoencapsulation, nanotubes, nanocomposites, packaging, and nanosensors. This technique was created to improve food delivery, nutritional supplementation, fortification, bioactive chemical availability, food solubility and shelf life, and food constituent protection (Morris *et al*. 2017). It also acts as an antibacterial agent by producing reactive oxygen species (ROS), which harm cells, denaturize proteins, and destroy bacterial DNA (Mihindukulasuriya and Lim 2014).

3.10 Food Nanostructured Materials in Packaging and Preservation

Every step of the food production process involves packaging, yet a fundamental drawback of conventional food packaging materials is their porous and permeable character. Packing materials are not entirely immune to ambient gases and water vapours. By halting nutrient loss and degradation and extending shelf life, nanotechnology in packaging protects food safety (Reza *et al*. 2008). It usually involves packaging options that adjust to changing environmental conditions. They function by scavenging gases or producing healthy compounds like antioxidants or antimicrobials (Nair *et al*. 2010). These interactions improve food stability in several packaging technologies, including enzyme immobilization, O_2 scavengers, and antimicrobials (Paramasivam *et al*. 2024). The development of sustainable and environmentally friendly packaging using plant extracts, nanocomposite materials, and biodegradable components has the potential to lessen the adverse environmental effects caused by artificial packaging.

3.11 Future Perspectives and Challenges of Nanotechnology in Food

While there has been a great deal of scientific development in applying nanotechnology to the food industry, there has been far less success in the area of nanotechnology related to nanostructures. While there are many opportunities in the food sector for manufacturing new products and processes using nanotechnology, there are also many obstacles to overcome (Paula *et al*. 2016). However, a uniform set of guidelines for evaluating the safety of nanomaterials in food has not yet been developed. The primary concern is creating edible delivery methods that are both safe for human consumption and economically viable to produce. One of the main issues with food safety is the migration and absorption of nanoparticles from packaging materials into food products. Although materials behave very differently at the nanoscale, we currently only have a hazy understanding of how to study them. Understanding the toxicities and nanoscale functionalities of nanoparticles can help improve practical usage and safety requirements.

Furthermore, employing prediction models that only contained diffusion-based migrations made it difficult to determine the migrations of nanoparticles. The molecule diffuses through the food as a result of a concentration differential. However, there was a glaring lack of knowledge regarding the likely release pathways of the nanoparticles that had been detected (Pinto *et al*. 2013). Given that the physio-chemical features of nanoparticles, such as their form, composition, surface characteristics, charge and aggregation state, and functional components, had a variety of effects on gastrointestinal absorption. Environmental concerns, potential hazards, associated toxicological risks, and the effects of nanoparticles must all be taken into account. The European Commission has developed a comprehensive legislative framework pertaining to technology and advancements involving nanoparticles, smart materials, and active materials (Ramakrishnan *et al*. 2022).

3.12 Nanotechnology in Food Packing and Security

The packing process is one of many steps required to guarantee food safety. It is impossible for any packing material to completely resist the penetration of natural chemicals, air gases, and water vapours (Ray *et al*. 2006). When it comes to packaging fresh fruits and vegetables, it is not ideal to totally stop gas movement and permeability because these foods go through a process known as cellular respiration. On the other hand, carbonated beverages must never be exposed to air or carbon dioxide (CO_2) while still in their container (Rhim and Ng 2007). Less than 100 nm-diameter nanoparticles are approximately 100 times thinner than human hair, which is about 10,000 nm in thickness, and 1,000 times thinner than a book page, which is roughly 100,000 nm in thickness. If the proper regulatory processing approval is secured, different nanoparticle shapes could be extremely useful in a range of fields related to the food and pharmaceutical industries, especially in research projects involving food science (Rhim *et al*. 2013). Nanomaterials in the food industry are increasingly being utilized to improve various aspects of food production, packaging, and safety (Ashfaq *et al*. 2022). The application of nano-bio composites in food packaging has improved recently, as has the ability of packaging to act as a barrier against gas buildup. A succinct summary of the various applications for nanoparticles in food packaging. They encourage the use of environmentally friendly nano-fillers in addition to decomposable polymers. Nonetheless, there is a good reason to be concerned about ingesting these nano-compounds during mealtime. It is, therefore, imperative to study not only the immunogenic and toxic consequences of these nanoparticles but also their movement throughout the human body (Salvia *et al*. 2013). Additionally, questions have been raised regarding these nano-filled decomposable polymers' biological decomposability. These are important concerns for scientists searching for environmentally and human-safe nanomaterials.

3.13 Nanoparticles as Antimicrobial Agents in Active Packaging

Unlike standard food packaging, active food packaging eliminates air and water vapor and acts as a passive barrier. It also facilitates the release of antibacterial and antioxidant compounds through direct contact with the food. These interactions improve food durability most of the time. The performance and effectiveness of packed food can be enhanced by adding a variety of bioactive compounds to the packing material by capsulation, capping, or other nanotechniques (Siddiqui and Mukhtar 2010).

2.14 Nano Sensors

Nanosensors are miniature devices that utilize nanotechnology to detect and measure various physical, chemical, or biological signals. These sensors typically range from 1 to 100 nanometers in size, allowing them to operate at the molecular level. Their small size enables high sensitivity and specificity, making them ideal for applications in environmental monitoring, healthcare, and food safety (Caon *et al*. 2017; Singh and Yadava 2020). In healthcare, nanosensors can be used for early disease detection, enabling real-time monitoring of biomarkers in bodily fluids (Vargas *et al*. 2008). This can lead to quicker diagnosis and personalized treatment plans. In environmental applications, they can detect pollutants or toxins at very low concentrations, providing crucial data for public health and safety. Moreover, nanosensors are also being explored in the field of smart materials, where they can enable responsive systems that adapt to environmental changes. The ongoing research in this field promises advancements that could revolutionize how we interact with technology and monitor our surroundings, leading to safer, smarter solutions for everyday challenges. Nanosensors are being utilized to monitor soil conditions in order to improve agricultural production (Sorrentino *et al*. 2007). They are also helpful in locating pesticide residue on food items. It has proven possible to use nanosensors to detect carcinogens in food as well as pesticides.

3.15 Natural and Synthetic Nanostructures in Food Industry

Among the nanosized components included in the food chain are lipids and carbohydrates, which are examples of self-assembled higher-order structures. Unlike artificially produced nanomaterials or nanostructures, these components can be used (Valenti *et al*. 2001). However, nanostructures are used in many different applications, such as food preparation. Creation is not frequently associated with modern nanotechnology (Yu and Huang 2010). Food ingredients such as proteins, lipids, polysaccharides, and others are spherical particles with sizes varying from a few hundred to a few hundred nanometers (Wang *et al*. 2014). The assembly of nanostructures with different dimensionalities is necessary for both emulsification and coagulation. Dishes are heated to dissolve the tens of nanometer-thick, small, three-dimensional crystalline formations. Two naturally occurring components of milk are casein and milk proteins (Vijayakumar *et al*. 2024). The process of homogenizing milk yields 100 nm-sized fat globules. Nanotechnology plays a major role in the nutraceutical and functional food industries. NSM encapsulation may be advantageous for colourants and nutritional components such as vitamins and minerals because it increases the elements' solubility and bioavailability while shielding them from processing-related degradation. The most useful NSMs nowadays are nanoemulsions and nanocapsules, while other carbon-based, ecologically friendly nanomaterials that are green-synthesized are also in use.

3.16 Nanoparticles for Defense from Chemical Corrosion

A number of chemical reactions between the components of food and its surroundings lead to deterioration in food quality (Weiss *et al*. 2006). Researchers have discovered that a variety of nanomaterials can effectively stop these undesirable reactions in a broad spectrum of food media. However, some of these metal and metal oxide nanomaterials are dangerous because they can cause oxidative stress and reactive oxygen species, which can upset the redox balance of the cell. As a result, antioxidant carriers made of reduced reactivity nanoparticles are employed. The carriers are incorporated with nutraceuticals, including phytosterols, b-carotenes, and lycopene, to lower cholesterol levels in the body. It is commonly known that a small number of nanostructures found in food have the potential to cause unique nano-effects.

3.17 Nanotechnology for the Detection of Foodborne Pathogens

When biological receptors and a wide range of NSMs are combined to create an integrated system, nano-biosensors—bioanalytical devices—are created. SERS is a nano-biosensing technique that is used to quickly and accurately identify microbial diseases. Because of this, it is now possible to detect E. coli in food samples directly. Nanotechnology is revolutionizing the detection of foodborne pathogens, providing rapid, sensitive, and accurate methods for ensuring food safety. By utilizing nanosensors, researchers can identify harmful bacteria, viruses, and toxins at very low concentrations, significantly improving detection times compared to traditional methods. Nanosensors can be engineered to target specific pathogens through functionalization, where nanoparticles are coated with antibodies or other biomolecules that bind to the pathogen (Kumar *et al*. 2020). This specificity enhances the sensor's performance, allowing for real-time monitoring of various food matrices, such as meat, dairy, and produce. Additionally, techniques like nanoparticle-based amplification and lateral flow assays facilitate on-site testing, making it easier for food producers and safety inspectors to detect contamination quickly. As consumer awareness of food safety rises, the integration of nanotechnology in food testing offers promising solutions to prevent outbreaks and ensure public health, paving the way for safer food supply chains (Amini *et al*. 2014).

4. CONCLUSIONS

Nanotechnology envisions a future in which new yields are developed at the nuclear and atomic level and provides smart, practical methods for securing sustainable energy sources and preserving the environment. Numerous researchers and designers are now discovering more effective ways to use nanotechnology to develop the planet. Nanotechnology is used in many different ways, such as in hardware, science, substance design, and high-tech mechanical devices. Specialists are using nanotechnology to diagnose infections at their earliest stages and treat conditions like diabetes and disease with more efficient and safe treatments. Scientists are also considering new developments to protect both civilians and military forces against predictable and substance weapons. Although there are still many exploration obstacles to overcome, nanotechnology has previously produced a wide variety of valuable materials and showcased advancement in a number of disciplines. Nanotechnology provides a quick overview of nanomaterials and their uses in a diversity of industries, including solar cells, Environmental Protection, Future Transportation, Food and Agriculture robotics, food technology, computing, sensors, medicine, water filtration, and medical. It also covers the potential applications of nanotechnology in the future.

The materials exhibit highly disparate behaviours at the nanoscale, and the investigation of this phenomenon is currently severely constrained. Furthermore, in vitro and in vivo studies of nanoparticle interactions with biological entities are required prior to their commercial application. The toxicity of antimicrobial nanoparticles to people and the environment also has to be investigated. Nanotechnology impacts sustainability in food and healthcare by enhancing resource efficiency, reducing waste, and improving product longevity. In food, it enables better packaging and nutrient delivery, while in healthcare, it supports targeted drug delivery and more durable, biocompatible medical devices, minimizing environmental impact and cost.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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