Nanotechnology Breakthrough in Food Industry

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Abstract

Latest study has demonstrated that nanotechnologies have an opportunity to be used in a variety of applications involving food, such as enhancing dietary supplements, fresh food packaging, expanding the diversity of flavor profiles, colors, and preferences, boosting the effectiveness of beverage effects, enhancing oil for cooking catalyzation, and intended agricultural insecticides. Bionanotechnology has grown increasingly important in the world of alimentary packaging as a method for incorporating biological materials into nanoartifacts. It provides sophisticated food packaging expectations that can assure longer product shelf life and safer packing with increased food quality and traceability. Uncertainty have been raised about the straight incorporation of nanoparticles that have been engineered into foods, such as those used as color, aroma, additive, nourishment, and nutritional product delivery techniques, or those utilized to alter the optical signals , or fluid characteristics of foods or food containers. The present review outlines the use of an inorganic (silver, iron oxide, titanium dioxide, silicon dioxide, and zinc oxide) and organic (lipid, protein, and carbohydrate) nanoparticles in foods, emphasizes some of the most important nanoparticles properties that impact their conduct, addresses the significance of food structure and gastrointestinal tract responses to nanoparticles features, and points out the possible harmful processes for various food-safe nanoparticles. Even though the implementation of nanotechnology in food manufacturing has been growing, there are some unfavorable or hazardous health consequences associated with the contaminants and hazards of swallowing small particles in food. The investigation focused on the application of nanomaterials in the food organization, namely in being processed, food preservation, and wrapping, and its promising prospects.

Keywords: Nanotechnology, Food preservation, Nanoparticles, Nanoencapsulation, Biosensor, Nanolaminates, Nanoclay, Biodegradable, Agriculture, Nanofilms, Bioreduction, Product, Nanofibres.

1. Introduction

Nanotechnology defines as the technology that involve in manipulation of matter at nano scale with the size of less than 100 nm and up to 1 nm size [1]. It has different nano forms; namely nanoparticles, nanotubes, fullerenes, nano-whiskers, nanosheet and nanofibres that are constituents of nanomaterials andnanoparticles.

Food security is becoming a major worry since the food organisation is becoming more globalised; customers are expecting higher food quality, market trends, and ever-changing laws. Controlling foodborne pathogens is critical to reducing the potential of illness outbreaks; food makers add synthetic preservatives and antibiotics to food to prevent this problem and keep germs at bay. However, excessive and incorrect use of these preservatives leads to bacterial resistance. The food industry is crucial and essential to any nation. It is essential for health, food safety, food security, and food nutrition. In the food industry, product quality is extremely important. Food supply, production, harvesting, processing, packing, transportation, distribution, consumption, and disposal are all part of the food enterprise.

The fundamental purpose of food organisation development and research is to create new products and efficiently promote them. Decrease costs, which bring down item costs; make strides tactile characteristics, which make nourishment more engaging; progress dietary cost to supply for dietary requests; move forward nourishment security; increment comfort; and give shoppers with a more prominent assortment of nourishment things are a few particular vital objectives. These points of interest are the result of either persistent item enhancement or a significant item step move. The last mentioned is regularly due to unused innovation - edit, component, procedure, or capacity - but it may moreover be due to a unused information of client desires [2]. There's a developing body of information around the linkages between client needs, quantitative estimation of nourishment qualities, and the affect of handling and capacity on nourishment quality[3]. Nanotechnology is a technological self-discipline that functions as a mechanism to produce numerical phenomena or manipulate counting at the microscopic level. Nanotechnology has ushered in a new economic revolution, and both developed and emerging economies want to invest more in this technology [4]. The development of innovative nanomaterials makes it possible to improve food quality and safety, crop growth and environmental monitoring. The resulting substances have unique properties such as a high surface-to-volume ratio and their various physico-chemical properties such as colour, solubility, strength, diffusion, toxicity, magnetic properties, thermodynamic properties, etc. As a result, nanotechnology has introduced in a unused mechanical insurgency by giving a tremendous cluster of conceivable outcomes for the enhancement and application of structure, materials, or structure in a wide run of businesses such as nourishment, medication, and so on. Besides, it is one of the speediest developing businesses within the nourishment industry. Bio-nanotechnology is the joining of natural compounds into nanostructures. The developing client require for great nourishment and understanding of a solid way of life are persuading analysts to move forward nourishment quality whereas relinquishing nourishment item esteem [5].

Food technology has penetrated different customer things, counting nourishment bundling, added substances, and nourishment conservation. The understanding of this progressive science has made strides nourishment preparing and capacity in terms of nourishment security. Numerous conventional chemical compounds utilized as nourishment added substances or bundling materials have moreover been found to be show in portion at the nanoscale scale [6]. With improved colour, texture, sturdiness of foodstuffs, taste, flavour, food antimicrobial substances, durable food packaging substance with enhanced durability and antimicrobial effects, nano-sensor for traceability of health hazard, bionano-sensor to check food during transit and preservation, and encapsulation or coating of food element or additives, this has been a boon to the food industry [7]. Nanotechnology has developed two broad avenues for nanostructures in the food industry: food components and sensors. Nano food elements offer a wide range of applications in the food industry, from food processing to food packaging. In food processing, nanostructures act as anti-caking agents, antibacterial agents, nanocarriers and nanocomposites, and certainly also as nanosensors in food packaging [8]. Pathogens (such as E.coli and Salmonella), allergies, nutrients (antioxidants), and pesticides, unlawful additives, mycotoxins have all been seen using biosensors. Biosensor has helped researchers to overcome the issues of costly and time-consuming laboratory procedures [9].

AgNPs, TiO_2, and Si02 nanomaterials are the most often used nanomaterials in consumer items [10]. To avoid degradation of food and extend its lifespan, nanoparticles made of SiO_2 were used to develop a thin, solid heatproof plastic with gas barrier properties [11]. The addition of nanoparticles to food serves numerous functions: For nutritional supplementation (e.g., omega-3 fatty acids encapsulated in thin films-liposomes for dairy fortification) [13]. The nanoencapsulation is used to maintain and improve the long-term stability of beneficial compounds, nutrients, or nutraceuticals (e.g., vitamin D that is encapsulated in casein micelle) [12]. Encasing the top layer with vibrant nanoparticles which to provide a barrier of protection characteristic (for example, silver NPs for antibacterial packaging) [14]; fillers to be used for better package physical characteristics (for example, nanoclay)[15] ; recognising substance to strengthen processes for in-situ evaluation of the integrity of food, ideally associated to or included in wrapping (for example, TiO_2 for O_2 sensing) [16].

2. Synthesis of Nanoparticles

Initiatives for the synthesis of NP are often divided into two groups. The initial phase is to begin breaking down larger components into smaller fragments. Chemicals, crushing, or the vaporisation of an inert substance and resulting condensation of the vaporised particles are some examples of this process. To create NPs, the further method involves condensing molecular components in the form of gas. The subsequent approach becomes far easier for creating NPs [17].

Nanoparticles are used in several sectors, including gadgets, optoelectronics, catalysis, biology, even food. Aggregation of AuNPs is prevented, interface properties are controlled, and visual, electrical, and chemical properties of the precious metal core are adjusted. The accumulation and diffusion of colloidal NPs, as well as the manufacturing, modification, and surface composition of monolayer AuNPs, are two of the key concerns surrounding their prospective uses [18].

3. Physical and Chemical Synthesis

Agro-industrial waste can be utilised to kickstart the creation of nanoparticles [19]. Produced NP cellulose sheet from dehydrated agave that had been acid hydrolyzed. Electron microscopy (EM), Fourier transform [FTIR], X-ray diffraction, nuclear magnetic resonance [solid state], and transmission electron microscopy, which has a high resolution, were used to characterise these [TEM]. The synthesised NPs were polyhedral in structure, range of 31 to 198 nm.

4. Method of Synthesis of Nanoparticles

NAME	METHODS	CHARACTERISTIC OF NANOPARTICLES
Colloidal Method	In an ongoing phase or dispersant, a reluctant and stabilizer are made by dissolving a metal oxide source.	They are approximately 20 nm in size and consist primarily of Au, Mg, and other metal.
Photo and radio-chemical degradation	The energy used is beneath sixty eV, while the radioactive decay energies are 105 eV. The necessary ions are allowed to dissolve in either water or chemical solvents to produce them.	Formation of high-purity metal, primarily silver.
Microwave radiation	Although perfect control is not always attained in morphology. Formation of small size nano- particle.	Platinum, ruthenium, silver, and palladium nanoparticles
Thermal synthesis	In a closed container, a metallic precursor is soaked in a liquid of ammonia and hydrazine and heated beyond its boiling point, producing atmospheric pressure.	Si, aluminum silicate
Wet chemical method	A mixture of sol material that functions as a starting point to an aggregated tiny particle or polymeric network. Metal alkoxides and metal chlorides are common sol-gel precursors that go through hydrolysis and polycondensation to produce a colloidal dispersion.	Metal oxide NP 1-3 nanometre utilized in the production of nanomaterials.

Source: Zanella, R., 2012. Metodologías para la síntesis de nanopartículas: controlando forma y tamaño. Mundo Nano 5 (1), 69-81.

Because of its unique properties that combined biological degradation and biosustainability, reversible polymer nanocomposites are offered as a biosustainable replacement to traditional substances used in the food manufacturing and packaging firm. The use of tiny fillers in re - melted biodegradable polymers substitutes for structure while having no effect on decomposition rate. The method of creating NPs from plant extracts is known as green synthesis, also known as bioreduction.

5. Bioreduction

Due to the negative environmental effect of the synthesis of nanomaterials, less toxic waste-producing alternatives have been investigated for the manufacturing of nanoparticles.The extraction of nanoparticles from plant derivatives, often known as "green synthesis" or "bioreduction," is now being used [20]. Plant growing conditions, the usage of powdered components, and the environmental conditions during which the process is performed are just a few of the many factors that must be taken into account when synthesising NPs from plants.

Plant derivative used in the synthesis of NPs,

Source	Nanomaterial	Sizes (nm)	Application	Reference
Cucumis sativus	Ag	6	Antibacterial activity	[21]
Olive fragrant	Ag	20	Antibacterial activity	[22]
Corn Husks	AgCl	20	Antibacterial activity	[23]
Neem	Ag	30	Antibacterial activity	[24]
Moringa	Au	35-85	Hepatoprotective Antibacterial	[25]

The temperature and quantity of extract are two factors that affect the biological reduction mechanism. Temperature accelerates NP formation, but extract concentration reduces NP size. Plant chemicals and metabolites, both primary and secondary, are significant sources of energy for the production of nanoparticle. Using NP plant chemicals as antioxidants and stabilisers, several authors have accomplished synthesis.

Naseem & Akhyar (2015) [26] created AgNPs from an Opuntia ficus aqueous extract using a silver nitrate (AgNO3) solution. These AgNPs were then examined using TEM and UV-Visible spectroscopy. It was discovered by TEM that the typical size of NPs. The achieved optical density was 23nm. The efficiency of iron particles (FeNPs) derived from various plants, including L. inermis, G. jasminoides, A. indica, and C. sinesis, was investigated. According to Naseem & Akhyar (2015), plant-based nanoparticles synthesis generally retains the biological features of the plants used while also being less costly and more ecologically friendly. As indicated in the picture, solutions containing extract of Moringa, Ferrous Suphate Solution, and Iron nanoparticles darkened over 24 hours of shaking at 40°C, indicating the formation of crystalline FeNPs.

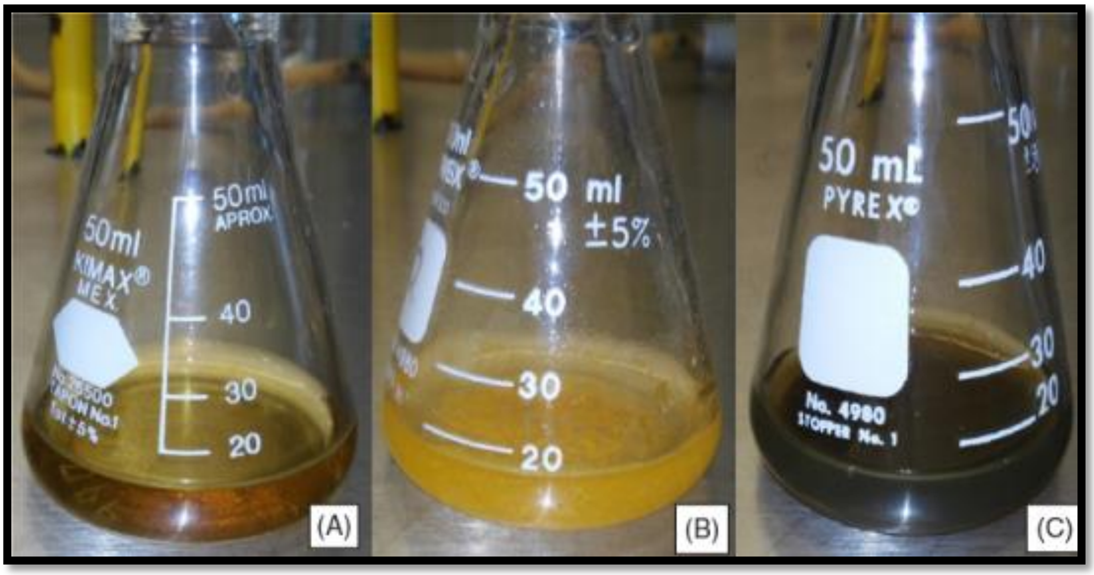


Fig: 1

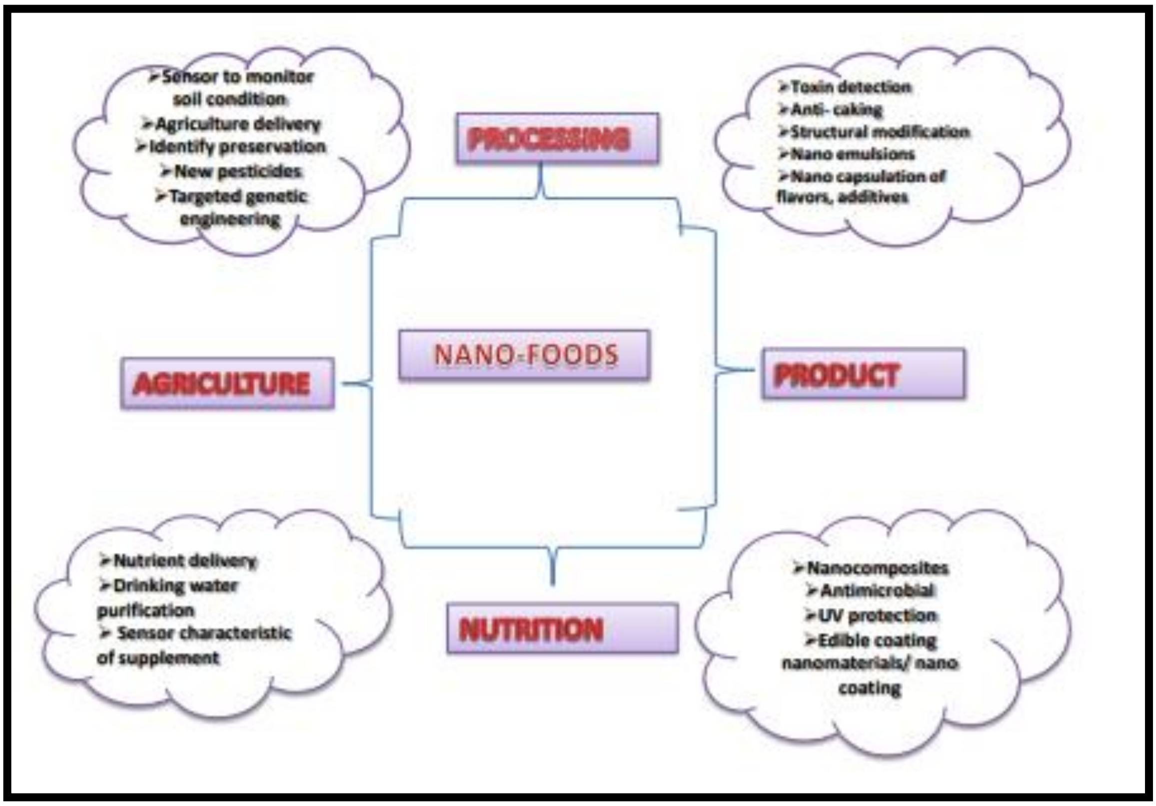
A. Extract of Moringa, B. Ferrous Suphate solution, C. Iron Nanoparticles
B.

6. Food Industry Application

Nano-food products that are grown, produced, processed, and packaged using nanotechnology techniques. Aluminium silica, which are added to grains and milk powder for flavoring, and titanium dioxide, that is utilized to give pork a shiny look, are two examples of nanotech-manipulated chemicals used in the food industry. Nanomaterials include Iron NPs and nanocapsules carrying nutrients, fish oil with omega-3 fatty acids, or nanoenhancers. Controlling the viscosity of food powder, making disposable nanosensors for monitoring the moisture and temperature in food, and crafting nanofilms to limit the uptake of oxygen are all examples of how NPs have been used to improve digestion of nutrients and usability.

7. Nanostructured Food Materials

A variety of their distinct qualities and possible benefits, nanosized components in food have grown in popularity in recent years. These nanosized components differ from synthetically generated nanomaterials, which are typically used for industrial purposes. The most important synthetic nanostructured components in food are those composed of various molecules and atoms. A range of different nano colloidal forms, such as: can be used to increase the shelf life and safety of food goods while simultaneously reducing their environmental effect. Liposomes (100-400nm) are small, spherical artificial vesicles made largely of lipid bilayer and constructed of biodegradable polymers for long-term pharmaceutical or antioxidant release. Lipophilic and lipohobic medications are encapsulated in surfactant-stabilized micelles (10-100nm in diameter). Nanocapsules (10-1000nm) contain a significant quantity of medications and genetic material such as human DNA, microRNA. Dendrites (3-20nm) are monodisperse molecules capable of encapsulating or covalently conjugating medicines, scanning agents, and aiming compounds. Nanoconjugates are polymeric that have been created bonded covalently with medicinal properties.



Nanotechnology's applications range from agriculture to food processing safety, packaging, and nutrition in food science. (Duncan, 2011;Pathakoti et al., 2017; Sahoo et al., 2021) Furthermore, through Nanoencapsulation, nanotechnology can expose food-related illnesses; establish appropriate diet programmes for a number of target groups including the population and food production. Food fortification can be used to create unique goods while nutrition nanotherapy, develops smart/intelligent systems for controlled nutritional delivery [29]. The usage of modified nanoparticles in food products surely enhances oral nanoparticles exposure in humans [30]. Human exposure to nanomaterials is increased by the ingesting of nanoparticles-improved food and the ingestion of micron-sized particles that have migrated from packaging [31]. Ingestion of nanoparticles linked to a variety of health effects, including destruction of DNA [32], inflammatory response stimulation, and protein degradation. Numerous investigations have shown that oral exposure to the nanomaterials, particularly solid nanoparticles, can cause adverse effects on the intestinal tract and other organs [30], emphasizing the importance of exercising caution when incorporating nanoparticles into food.

Revolutionizing Packaging with Food Nanostructured Materials

Packaging for foods is a crucial component of the food manufacturing process because it shields the food against external factors such as moisture, humidity, temperature, microbial contamination, gas-like combinations, leak testing, and hardening. Production process involves packaging in some capacity; however the traditional materials used for food packaging have a basic problem in that they are porous and permeable. There aren't any packaging have a basic problem in that they are porous and permeable. There aren't any packing materials that can withstand water vapors' and other environmental gases totally [33]. Nanotechnologies in packaging protect food against deterioration and nutritional loss, extending shelf life and ensuring food safety. In addition to providing and barrier from external conditions, active packaging appears to play role in food preservation. Because of these interactions, packaging technologies such as antibacterial medication, gas explorers, and enzyme encapsulation methods can improve food stability. Nanocomposites may additionally serve as carriers in controlled-release packaging to promote the intake of nutritional supplements such as minerals, probiotics, minerals in nourishment, which is another application for them in active packaging [34]. Antioxidants are used by potent antibacterial to improve the rigidity, membrane efficiency, including thermal durability of standard food packaging [35]. The use of plant extracts, nanocomposites, and disintegrating components in the development of sustainable and environmentally friendly packaging has the potential to lessen the negative ecological repercussions caused by artificial packaging [36].

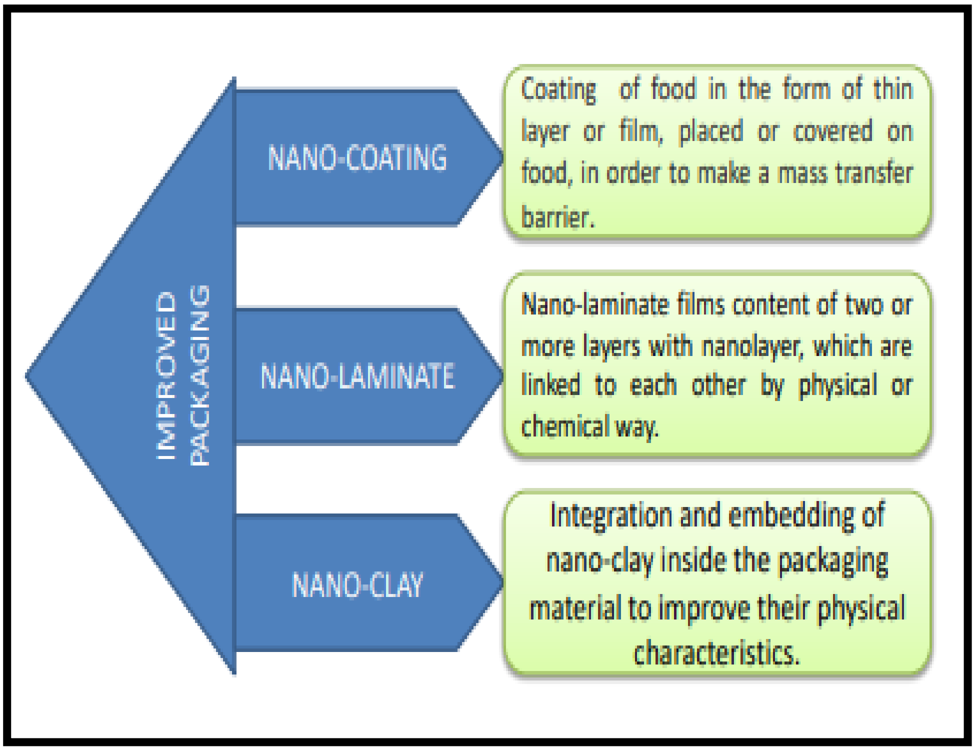


Figure: Improvement of mechanical and physical properties of food packaging
Source: Arora, A.; Choudhary, V.; Sharma, D.K. Effect of clay content and clay/surfactant on the mechanical, thermal and barrier properties of polystyrene/organoclay nanocomposites. J. Polym. Res. **2011**, 18, 843–857.

8. Nano-Sized Preservation for Optimum Freshness

Nano Material	Technique	Activity	Application	Reference
Ag-based	metal oxide nanoparticles should be categorized.	increased reactive ; antibacterial property that is working across both gram-positive and negative bacteria; improved mechanical and barrier qualities; poor discoloration, and thermal durability.	Active food preservation packaging extends the durability of the food and reduces harmful and spoilage germs.	[37,38,39]
Zinc oxide		To prevent oxygen passage within packaging containers, triggered air shielding substances are utilised. Irradiation with ultraviolet (UV) radiation showed no influence on the physical features of the nanomaterial produced. as well as a potent antibacterial agent	The antibacterial properties of packaging used for food preservation.	[40,41]
Cu- based		It inhibit the growth of bacteria, fungi; due to wide surface area, they may react with cellular membranes, increasing	active food preservation packaging that controls harmful and	[42,43,44]

Nano Material	Technique	Activity	Application	Reference
		antibacterial activity; UV radiation, durability against heat, moisture penetration, barrier characteristics, and antibacterial activities	spoilage germs and extends the shelf life of food	
SiO2		Demonstrates by absorbing moisture in food, which reduces leakage.	active food packaging preservation that controls harmful and spoilage germs	[45,46]
Polymer-based : PLA (polylactic acid)		Has significant characteristics including outstanding mechanical properties, renewability, crystallinity, biodegradability, and processability.	Active food preservation packaging extends durability of the food and reduces harmful and spoilage germs.	[47,48]
Polysaccharide – based: Starch-based		Strongly influenced by mechanical properties, which may reduce moisture absorption and water vapour transmission	Food preservation packaging extends food durability and reduces harmful and spoilage microorganisms.	[49,50]
Chitosan-based		integrated into packing sheets; effective surface considerably decreased microbiological investigated antioxidant properties of epicatechin gallate nanocapsules; integrated with epicatechin gallate	Active food preservation packaging reduces harmful and spoilage germs.	[51,52]
Nanocomposites		Deduction of lipopolysaccharides, irreversible DNA damage, and assist the battle against microorganisms	component of enhanced food packaging with distinguishing features (antimicrobial agent)	[53]
Polymer & nanoparticles (nano clay)		Carbon dioxide leaks from bottles of carbonated beverages are reduced using gas barriers.	enhanced food packaging composition with distinguishing features	[54]
4Nanolaminates		It is a coating used on baked goods, cheese, veggies, and fruits.	composition of the improved food packaging that has special qualities	[55]

Nano Material	Technique	Activity	Application	Reference
Garlic oil nanocomposites coated with PEG		get rid of the bugs that regularly infest packaged foods at stores	component of enhanced food packaging with distinguishing features	[55]
Immobilization of enzymes		It is possible to transmit data more quickly and over larger areas.	component of enhanced food packaging with distinguishing features	[55]
Nano-biosensor		Identification of viruses and bacteria	smart food packaging that controls and identifies microorganisms that can ruin food and extends its shelf life	[56]
Nano-smart dust		evaluation of all types of environmental contaminants	Food that is packaged intelligently to extend shelf life and to identify and control microorganisms that might degrade food.	[57]
Nano-strip test		It changes color when comes in contact with any indication of food breakdown.	smart (intelligent) food packaging	[58]
Smart Biosensor		Mycotoxins and a range of other dangerous compounds are recognized; they operate as fictional cell	Identify the pathogenic bacteria	[57]
Nanosensors made of gold, palladium and platinum		observable changes in light, moisture, heat, gas, and chemical composition are transformed into electrical impulses; noticing any change in the food color; In milk, poisons including aflatoxin B1 have been found; identifying any gases produced as a result of deterioration	Chemical changes are observed.	[59,60]
Integrator iSTrip		Food degradation can be detected using temperature monitoring.	Temperature control and regulation are performed by a	[61]

Nano Material	Technique	Activity	Application	Reference
			temperature monitoring system in a specific environment.	
Polyaniline with carbon		Food carcinogens are being identified, and food-borne illnesses are being diagnosed	Food-borne bacteria are identified	[62,63]
Silicon wire with carbon nanotubes		Identification of the cholera toxin and staphylococcal enterotoxin B	Identify the pathogenic and spoilage bacteria	[64]

9. Risk to Human Health is a Factor in the Toxcity and Safety Evaluation of Nanoparticles in Food

The public's health is seriously threatened by a number of nanotechnology-related items that are now on the market. Instead of this many food ingredients and constituents have a nanostructured as part of their natural makeup; synthetic nanoparticles may harm the environment and endanger human health by collecting in foods and polluting them with harmful chemicals. Food packaging nanoparticles were developed to improve the mechanical and barrier properties of traditional and biodegradable packaging materials, as well as to provide fresh active and smart activities in which packaging materials have active components that allow or ingest substances into, onto, or out of the packed food or exterior area, or offer the required details about their usage circumstances. [65]. Hence, nanotoxicity may result in DNA damage, uncontrollable cell stimulation, alterations in cell motility, toxicity, cytotoxicity, apoptosis, and the development of cancer [66]. It would have a different effect with respect to the type of wrapping material used, the variety of nanomaterials used, their level of movement, and the extent during which that particular food is consumed. [67] There is growing evidence that eating nanoparticles poses a health risk, and that excessive use of nano-based items has a deleterious impact on health.

Consequences of Nanotechnology Use in Biological Systems

Application	Harmful Material	Emulsion	Factor	Reference
Procedure	Carbohydrate is surfactant.	Digestible nanomaterial	Protein breakdown and cardiovascular diseases	[68,69]
	Gold particles	inedible compounds that are inorganic	Chromosomal abnormalities include DNA damage	[70]
Packaging	Surfactants include proteins, lipid.	Digestible organic nanostructured material	Cell disruption and bioaccumulation	[71]
	carbon-based nanotubes	Biodegradable nanostructured substances that are digested	Harmful for lungs & skin	[72]

Application	Harmful Material	Emulsion	Factor	Reference
	Nanomaterials using Ag	Materials with inedible inorganic nanostructure.	Reducing the quantity of ATP in the body while producing more ROS.	[73]
Preservation	Proteins, lipids, and carbohydrates are all types of surfactants.	Easily absorbed organic nanostructured materials	Obesity	[74]

10. Conclusion

The implementation of nanoparticles in the food sector aims to enhance the safety and quality of food by facilitating the incorporation of nanomaterials in food products or packaging products. The adoption of nanotechnology to generate novel containers for food functionalities allows for the possibility of altering the qualities of nutrition, such as better tasting, healthier, and more wholesome food, once the item is wrapped. According to ongoing food packaging investigation, nanotechnology offers a number of alternatives for improving food manufacturing that employ multifunctional nanomaterials, comprising biodegradable containers to innovative packaging. Because of the growing market for exotic foods with the concomitant necessity for safety wrapping of products, the conceptual framework of nutritional wrapping will become more sophisticated in the food sector in the decades to come. As a result of their capability to improve food safety, flavour, or nutritive qualities, both natural and artificial nanomaterials are gaining popularity in the field of food. Yet because particles are so small in size, they might act distinctively in the human body than big particles or larger particles that are frequently utilised as food components.It's an imperative to properly recognize the gastrointestinal outcome of nanomaterials that have been consumed and to characterise their possible harmful effects. At the moment, the majority of edible nanoparticles possess a rather inadequate understanding regarding their GIT outcome and toxic effects, making it impossible to give a single broad guidance regarding the health hazards for all nanoparticles types. Rather, the health implications of nanomaterials should be assessed on each individual case, taking into account the nanoparticles' composition as well as the qualities of the structure of the food in which they are disseminated. The potential of nanoparticles made of inorganic substances to be ingested by the body, aggregate in specific tissues, and cause damage will probably to serve as the most relevant strategies. The capacity of naturally occurring nanomaterials to increase the absorption of chemicals that could be toxic (including chemical agents or hormonal) or compounds that are only hazardous at excessive levels (which are referred as specific lipid-soluble vitamins) is going to be more important. Nonetheless, more research is required to determine the magnitude and significance of these effects. These modifications have greatly enhanced the lifespan of food by reducing the level of deterioration of food goods. The result has alleviated food shortages by guaranteeing that food serves those in need. It is important to recognize that with this sort of technology, the prevalent issue of food scarcity in certain portions of the globe can now be easily solved.

Abbreviation:

NPs: Nanoparticles
Ag: Silver
GI: Gastrointestinal
Nm: Nanometer
UV-Visible: Ultraviolet Visible
ATP: Adenosine Triphosphate
DNA: Deoxyribo Nucleic Acid
PEG: Polyethylene Glycol
PLA: Polylactic Acid
TEM: Transmission Electron Microscope
SiO2: Silicon Oxides
Cu: Copper
FeNP: Iron Nanoparticles
EM: Electron Microscopy
FTIR: Fourier Transform Infrared
NMR: Nuclear Magnetic Resonance
E.coli: *Escherichia coli*

Conflict of Interest:

The authors declare no conflict of interest

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