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Nanotechnology for Food Applications: Benefits and Hazards

Marwa Hanafy Mahmoud
Dept. of Food Tech., National Research Centre , Dokki ,Giza, Egypt

Abstract
The manufacture of high-quality food requires sophisticated processing, packaging, and long-term storage techniques. Nanotechnology has a significant impact on the food business by enhancing food quality, flavor and texture. Consumers may offer information on the food condition inside and its nutritional status using nanomaterial and nano-sensors, which also improve safety by detecting pathogens. Given that the majorities of food bioactive compounds that fight various diseases which are hydrophobic and have the lowest bioavailability and stability, nanotechnology-based delivery methods have been able to increase food bioactive compounds' bioavailability and transport them to specific locations. Foods based on nanotechnology provide substantial hurdles for both government and business, assuring consumer acceptance of nano foods on the market. It is challenging to draw any conclusions about the efficacy of nanoparticles because of the lack of scientific investigation into these systems. Consequently, a detailed analysis of potential risks to human health is necessary before the release of nano-food items for commercial sale.

***Keywords*:**Nanotechnology, nano application forms, nano processed food, nanoparticleshealth hazards

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1. Introduction

Nanotechnology is a novel emerging, multidisciplinary field of science that unites multiple fields including biology, chemical, mechanical, and electronics engineering, in order to comprehend, manipulate, and generate systems and devices with extraordinary functionalities and characteristics at the atomic, molecular, and supra-molecular levels [1]. According to [2], this technology involves the study of materials, properties and structures at the nanometer-scale structures (1 to 100 nanometers) (Fig. 1). In terms of enhancing physicochemical properties and boosting nutritional stability and bioavailability, nanotechnology has brought alternative ways to food processing [3]. Nanotechnology offer new applications in the fields of electronics, environment, water, agriculture, food, medicine, and energy [4].

Long-term exposure to nanoparticles is probably associated with potential health hazards due to their high absorption and higher reactivity. In 2006, the FDA [5] published a report that called for additional funding and regulatory oversight of the usage of nano products and identified the gap in the field of nano food regulation. The WHO recently conducted an expert meeting on the application of nanotechnology in the agricultural and food sectors and food safety discussion of possible consequences [5]. Among the significant recommendations were the need for up-to-date and reliable risk assessments and a higher requirement for information sharing concerning data and research findings related to nano food [6].

Furthermore, nanotechnology is sometimes used to improve stability characteristics, optical and rheological of food items [7]. Despite the increased prevalence of nanoscale materials in food, the safety or toxicity of their use requires careful consideration.

According to [8], the use of nanotechnology in food systems has produced varieties of unique products with enhanced food quality including sensory properties, taste, texture, stability, colour etc. In almost every aspect of the food industry, including agriculture, food processing, safety, packaging, and nutrient delivery, nanotechnology has already been cited as a potential use by scientists and business organizations [9,10].

Additionally, using nanotechnology can reveal food-related disorders, create appropriate diet plans for a variety of target demographics, elderly groups, and situations, and ensure the sustainability of food production through nano-encapsulation. Additionally, food fortification, nutrition nano-therapy can construct smart and intelligent systems for controlled the delivery of nutrients [10].

Encapsulated food components including, antimicrobial sensors, preservatives, packaging compounds, flavouring materials, and food nano-particles are used to affect the nutritional content, and improve product shelf life, texture and flavours. It is also used to find food microorganisms that give hints for the food standard quality attributes [11].

Nanotechnology is widely employed as an antibacterial ingredient in food preservation, food additives, and food packaging (specifically Cu/CuO, Ag, MgO, TiO_2, ZnO, mesoporous particles, carbon dots, graphene, etc.) [9,12]. Due to their enhanced antibacterial characteristics, nanomaterials can be used by nanosensors to monitor food degradation [13]. Structured polymeric films used in antimicrobial packaging or encapsulating materials prevent the growth of bacteria on the surface of the food they

*Corresponding author e-mail: marwahanafy78@yahoo.com(Marwa Hanafy Mahmoud)
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are protecting [14]. To increase the shelf life of food and prevent deterioration, antimicrobial nanoparticles are utilized in active packaging [15,16]. Additionally, it enhanced the biological comfort and enticement of both drug delivery systems [17] and nutraceuticals [18].

As a revolutionary food packaging material with enhanced mechanical, fencing, and antibacterial properties, nanotechnology is advantageous to the food sector [19]. Other benefits of the technique include encapsulating food modifiers or additional components, tracking the status of diet during transportation and storage, and using nanotechnology-based sensors for trace detection [20].

Generally speaking, nanotechnology has the most potential for the creation of novel, better products. However, many scientific groups disagree with the public's worry about the health concerns connected to nanotechnology goods, and further research is required [21, 22].

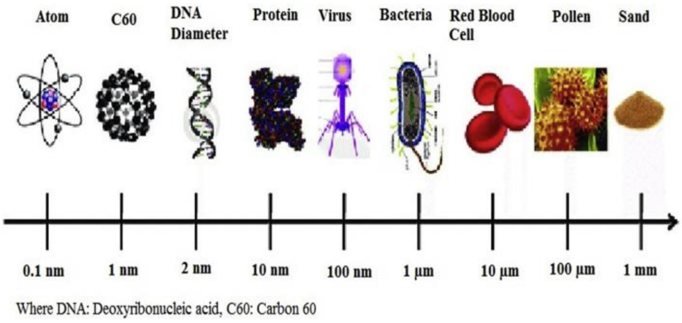

Fig. 1: The "nano" (<100 nm) and "micro" (>100 nm) size ranges

2. Nanotechnology overview

2.1. Nanotechnology synthesis approaches

2.1.1. Top-down approach

After going through multiple rounds, these technologies start with large structures before being reduced to nanoparticles. Since they are not widely employed in the business world, these techniques are acknowledged to be rather costly. For laboratory use, they are often appropriate. These techniques consist of vapour deposition, lithography (electro and X-ray), and others [23]. For example, milling pomegranate peel using ball mill to get nano powder [24].

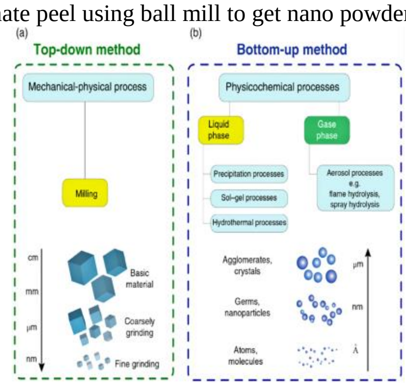

Fig. 2: Nanoparticles approaches: (A)top-down and (B)bottom-up [25].

2.1.2.Bottom-up approach

It refers to the creation of nanostructures by additional processes after producing nanoparticles from tiny materials. Using this technique, nanoparticles are produced on a large scale. The electroposition procedure includes the use of sol-gel, colloidal precipitation, hydrothermal treatment, and electrodeposition. The technique for creating nanoparticles is determined by the needs [23]

3. Food Nanotechnology

Numerous areas of food science and industry have altered as a result of the quick development of nanotechnology, leading to a rise in investment and market expansion. The food industry may be changed by nanosensors, nanoemulsions, nanopesticides, and nanocapsules (Fig. 2). A large number of patents have been filed as a result of opportunities to use and develop nanotechnologies in the food industry. In the quest to develop patented technology, worries regarding consumer health and safety when incorporating nanoparticles in meals continue to be a challenge [6].

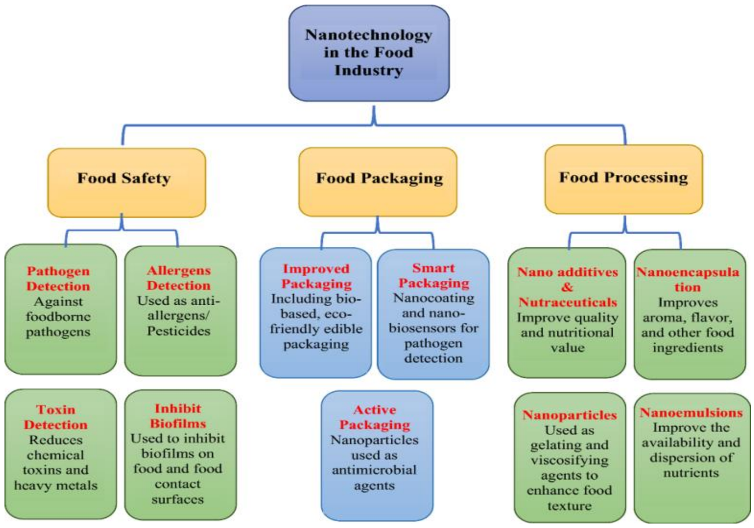

Fig. 3:Nanotechnology in Food industry [33].

4. Why we need of nanotechnology in food

Providing food security for a globe whose population is constantly expanding is the biggest global problem we face. According to predictions, by 2050, there will be 9 billion people on the planet, increasing the global food demand from 59 to 98% [26]. Farmers all across the world will concentrate on using discoveries and technological advancements to increase crop yield through intense and extended agriculture. Precision farming and the usage of nanomodified stimulants are used to further increase the present efforts. Basic elements of food security include agricultural productivity, soil enhancement, secure water usage, food distribution in shops, and food quality. These aspects may be enhanced by advancements in nanotechnology research [27].

More than 1.3 billion tons of usable food is annually lose, according to the FAO [28]. Both of food deterioration and microbiological contamination are the main reason of food loss [29]. In the food industry nanotechnology is employed at all steps of the manufacture, processing, storage, and distribution (Fig. 3). Traditional food packaging that employs plastic barriers may be improved using nanotechnology, and at the same time, functional elements like antibacterial properties extend the shelf life of the food.

Additionally, it contributes to flavor creation, color generation, and the detection of dietary contaminants [30]. Systems with enhanced efficiency and security for localization, sensing, reporting, and remote control of food products are based on nanotechnology. Furthermore, nano-based delivery technologies enhance the nutritional benefits of the food's constituent parts. In addition to its uses in the food business, nanoparticles are used to improve plant productivity. For instance, it has been demonstrated that TiO_2, gold nanoparticles, and cellulose nanocrystals all improve plant development. TiO_2 has also been found to increase the production of seeds in Arabidopsis, due to their great water absorption capacity [31]. In addition to controlling plant diseases, the efficient antibacterial properties of biologically synthesized metallic nanoparticles significantly lessen microbial contamination. Carbon nanotubes are an example of a nanomaterial that has potential as an antibacterial. When in close contact with the bacteria, carbon nanotubes are aggregates and induce cellular injury or mortal in E. coli [32]. It has been extensively reported that the use of nano-biosensors in the preparation of high-quality, contaminant-free food includes the identification of cancer-causing microorganisms.

5. Nanoscale materials are not new

Food is made up of ordered, functional nanostructures that are made up mostly of nanoscale carbohydrates, amino acids, peptides, and proteins. Throughout human development, these food additives have been ingested by people without any indication of a negative impact on their health because of the materials' nanoscale size. Through the air, food, and water, humans are also exposed to ultrafine and nanoscale particles including smoke, dust, ash, and tiny clays. Homogenization and milling are used to produce nanoparticles from basic meals, but there is a larger likelihood that the constituents in complex foods may spontaneously self-assemble into micelles and nanofibers. For instance, during digestion, bile pigment is transported in the form of nano-micelles together with lipid particles such as fatty acids, cholesterol, and monoglycerol [30]. It's intriguing to learn that the study of nanomaterials is not a recent development but rather a common practice intimately related to the biological system's metabolic activities.Self-assembled lactalbumin nanotubes, a milk protein that has been hydrolyzed, are present in several naturally occurring nano foods and may serve as a unique carrier for the nano-encapsulationof medications, minerals, and vitamins. Casein, a crucial milk protein, confirms that it can produce micelles when milk curdles. Casein's ability to act as a nano-vehicle has been successfully applied to the transport, trapping, and preservation of delicate hydrophobic nutraceuticals into food items [4].

The gastrointestinal tract uses a process known as nanofabrication to absorb the necessary nutrients. This natural nanomaterial exists in our body systems as micelles or nanofibres. Although food nanoparticles are a legacy, it might be difficult to introduce them in new forms for safety and nutritional benefits. With this entire in mind, it is essential to combine technological improvements with advances in the science of nanomaterials. Indeed, nanoparticles are not a new phenomenon for the biological system [34].

Every breath we take might contain millions of tiny particles, according to scientists. When created at the nanoscale, some materials do have unique characteristics. Therefore, nanoparticles' focus in reacting to nanotechnologies is not on the material's size but rather on substances that, if included in the final diet, may have a distinct biological or chemical effect. For instance, nanocapsules are frequently utilized in the food processing industry because of their better stability, capacity to resist oxidation, and improved ability to retain volatile chemicals [30]. They are widely recognized for their pH-triggered controlled release, which provides long-lasting flavor and nutritional bioavailability [35]. Other forms, such as nanoliposomes (zein fibers filled with gallic acid), are utilized to provide enzymes, additives, vitamins, and other nutrients to meals. Parallel to this, nanoencapsulation uses a variety of nanoparticles, such as archaeosomes [36], nanocochleates (soy-based phospholipids), and colloidosomes [37, 36] archaebacterial membrane lipids [38], nanoceuticals [39].

6. Utilization of nanotechnology for human food

Since nanotechnology is the most promising technology to emerged in last few years, the food sector has chosen to employ it. Engineered nanomaterials are defined as "any intentionally produced material that has one or more dimensions of the order of 100 nm or less or that is composed of discrete functional parts, either internally or at the surface, many of which have one or more dimensions of the order of 100 nm or less, including structures, agglomerates, or aggreg[s]" in the context of food by Regulation (EU) No. 2015/2283 of the European Parliament and of the Council of November 25, 2015 on novel. According to potential market developments, this definition may change [41].

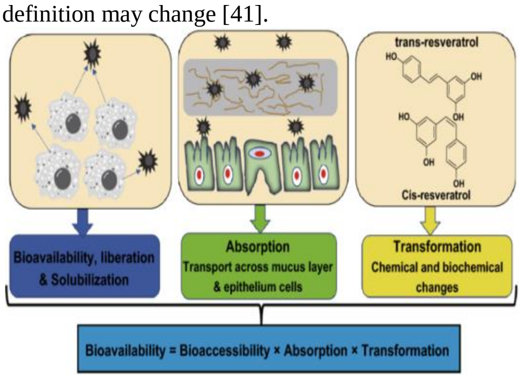

Fig. 4: Bioavailability mechanisms of nano-particles. [40].

6.1. Agriculture

The usage of nanoparticles may have advantages as well as disadvantages. Changes in the aforementioned attributes on various scales may result in environmental harm, toxicity issues for people and animals, and other issues [42]. All of these factors make nanotechnology a topic of intense research today. The use of nanotechnology as "nano-inside" (component of the diet) or "nano-outside" (does not become a component of the processed food and do not get into the body) may have different effects on people's perceptions. Studies on public perceptions of nanotechnology in the food sector have been conducted in several nations to date [43].

The term "nano-food" describes food that has been produced utilizing nanotechnology for food processing, production, security, and packaging. In the preparation of post-harvest food, nanotechnology offers enormous promise. It alters the potential cluster formation, size distribution, particle size, , and surface charge of food while enhancing food bioavailability (Fig. 4), taste, texture, and consistency, or masking the disagreeable flavor or aroma [44]. Also, edible nano-coatings (5 nm thin coatings) could be employed for meat, fruits, vegetables, cheese, fast food, baked goods, and confectionery products as gas and moisture barriers. Additionally, they provide manufactured goods with taste, color, enzymes, antioxidants, anti-browning ingredients, and a longer shelf life. Several baked items are available in edible antibacterial nano-coating [45]. Without boiling, nanoscale filters aid in the bacterial removal from water and milk. Milk and beer may be filtered using the same nanomaterials that were used to create nanosieves [46,47]. To prevent food-borne illnesses, better foods with less salt, sugar, and fat are produced using nanotechnology. A research found that titanium dioxide (TiO_2) and silicon dioxide (SiO_2) were widely used as food additives. (E551 and E171, respectively) [48]. Also, bio nano encapsulated quercetin (biodegradable poly-D, L-lactide), which has improved the shelf life of tomatoes, is recommended to extend shelf life of fruits and vegetables [49].

The most widely used commercialized nanotechnology-based goods on the market include:

- Nano green-tea.
- Neosino capsule.
- Canola oil.
- Aquanova (Vit. Mixtures: A, C, D, E, and K).
- Beta-carotene.
- Omega-3 fatty acids).
- Nutralease (nutraceuticals and drugs).
- Fortified fruit juices.
- Nananoceuticals slim shakes.
- Oat nutritional beverages containing tuna fish oil in breads.

6.2.Food Processing

The term "nano-food" describes food that has been produced utilizing nanotechnology for food processing, production, security, and packaging. In the preparation of post-harvest food, nanotechnology offers enormous promise. It alters the surface charge, potential cluster, size distribution and particle size formation, and of food while enhancing food bioavailability, taste, texture, and consistency, or masking the disagreeable flavor or aroma [30].There are several different types of nanocolloidal materials, including polymeric or biopolymeric nanoparticles (proteins), nanoemulsions, liposomes, and nanocomposites. (i) Liposomes (100-400 nm), which are small, spherical synthetic vesicles mostly consisting of lipid bilayers; (ii) Nanoparticles (20-200 nm), which are often built of biodegradable polymers for long-term medicine or antioxidant release; and (iii) Surfactant-stabilized micelles (10-100 nm), which are amphiphilic particles capable of encasing either lipophilic or lipophobic medications; (iv) Nanocapsules (10-1000 nm): These tiny containers may hold large amounts of drugs and nucleic acids, such as DNA, microRNA, shRNA, and siRNA; (v) Nanoconjugates, which are polymers covalently attached to drug molecules; (vi) Dendrimers (3–20 nm): These monodisperse macromolecules can be utilized to covalently couple drugs, imaging agents, and targeting moieties [51]. The physical method for creating nanoparticles frequently uses mechanical forces and evaporation. Pulse laser ablation, wire discharge, mechanical/high ball milling, physical vapor deposition with consolidation, mechanical chemical synthesis, etc. are examples of physical methods used to create nanomaterials [24, 52].

The terms "nanoceuticals" and "nutrition-be-nanotech" are used to describe dietary supplements. Nanochelates are utilized to effectively distribute nutrients without altering their color or flavor, while nano-sized powders are employed to improve nutrient absorption. Another dietary supplement is vitamin sprays containing nanoparticles that are disseminated. Zinc and Iron nano-particles target essential probiotics and substances that enter the human body via encapsulation methods [6].

6.3.Packaging nanomaterials in food

Food package materials have a great attention in recent years as a result of being the main defines from spoilage. The big great challenge is to prepare antimicrobial and antioxidant films and coating for wrapping paper used safely in contact with different food products, extending the shelf life as well as keeping good quality attributes. Nanotechnology applications in food packaging provide fresh possibilities for improving the efficacy of food items. Nanofillers are also employed in food packaging as a result of their beneficial qualities and functions. The use of packaging material properties by nanofillers in biosensors not only shields food from the elements but also expands the variety of possibilities for food packaging [54].

7. Applications of nano- forms in food

We can classify nanomaterials in food according to their formality as follows:

7.1.Nano-metals

To coat or package food items, a variety of metals and metal oxide-based nanoparticles have been used [55]. A particular antibacterial effect is carried out by the active metal, or it directly interacts with food components. Possible antimicrobial action include contact directly with the microbe's cell, damage of the mitochondrial cell membrane plus transport of electrons, cell components oxidizing, or the generation of secondary reaction products that finally kill the microbial cell. Due to their potent antibacterial action against a variety of pathogens, including viruses, bacteria, and fungi, silver nanoparticles are the most remarkable metal nanoparticles. Through direct binding with essential cell constituents, silver nanoparticles impair cellular processes. Second, several structural variations of TiO_2 was investigated for their potential anti-bacterial effects [56]. It's well-known that antimicrobial ability is restricted to UV light. Additionally, TiO2 has a biocidal action related to its attack to the cell membrane and producing oxidative substances (hydroxyl radicals), which altered the function of Coenzyme A-dependent enzymes and DNA damage. Additionally, other metal oxides such as SiO2, ZnO, MgO, and others are employed to create nano-composites. Also, ZnO, MgO, and CaO have demonstrated anti microorganism efficacy for disease management [57]. Recently, the food industry has also made use of calcium phosphate or hydroxyapatite's biocompatibility as nano-fillers. In comparison to single-metal nanoparticles, such as Fe nanoparticles or Cu nanoparticles, bimetallic copper and iron nano particles have been found to improve the inactivation effects on both E. coli and MS2 coliphages [58]. Due to their exceptional optical qualities, including great sensitivity, photostability, high selectivity, and resolution, quantum dots (QDs), and fluorescent nano-crystalshave recently attracted substantial attention [58]. Anticancer medications and other useful substances can readily functionalize them.

7.2.Nano-tub

According to [60], there are two main categories of carbon nanotubes: single-wall and multi-walled nanotubes. One carbon atom is all that separates the single-walled nanotube from the multi-walled nanotubewhich is seen (Fig. 5), as a flock of concentric tubes. These carbon tubes have remarkable tensile strength extremely high aspect ratios and elastic moduli. It is also known that carbon nanotubes have antibacterial qualities. Due to their incredible strength, carbon nanotubes have been widely used in packaging methods. Additionally, carbon nanotubes serve as sensors for bacteria, dangerous proteins, and food deterioration systems. With the least physicochemical change, a nano-composite material made of carbon nanotubes and allylisothiocyanate demonstrated good preservation of shredded cooked chicken flesh for 40 days [61].

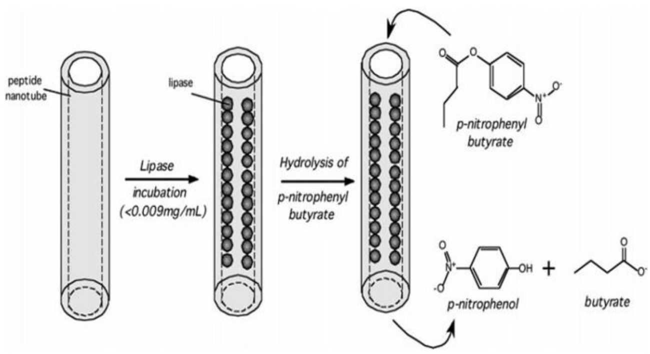

Fig. 5: Nanotube utilizing in food system[59].

7.3.Nano-biosensors

A sensor is a device that is used to quantitatively assess the test substance (analytic) in a sample. Such a gadget should ideally be able to respond continuously, be reversible, and not harm the sample. A system that uses at least one nanostructure to detect gases, chemicals, biological agents, electric fields, light, heat, etc. is referred to as a nanosensor. The sensitivity of the system is greatly increased by the addition of nanoparticles. In biosensors, a biological component (such as an entire cell, DNA strand, enzyme, or antibody) is employed as the component of the system to connect to the analyte and precisely detect it. The "Nano Biosensors" (Fig. 6) series examines a range of biosensor and biochip types (including a variety of biosensors), highlighting the importance of nanostructures created for use in biology and medicine. Nano Biosensors Electrochemical sensors are sensors that employ an electrode as a transducer and a biological element as a diagnostic component. In these systems, nanostructures are typically used to bridge the nanoscale gap between the converter and the bioreceptor. Potentiometry, chronometry, voltammetry, impedance measurement, and field effect transistors (FET) are popular electrochemical methods used in sensors. The development of high sensitive sensors with decomposition power has resulted from the simultaneous use of the benefits of nanostructures and electrochemical methods [62]. Typically, nanostructures are used in these sensors to bridge the nanoscale gap between the converter and the bioreceptor. Nanoparticles, nanotubes, and other forms of nanostructures created for use in biology and medicine. Electrochemical sensors are sensors that employ an electrode as a transducer and a biological element as a diagnostic component. In these systems, nanostructures are often used. Self-adhesive monolayers, nanocomposites, nanowires, and nanopores may all be employed to enhance the functionality and effectiveness of sensors [62].

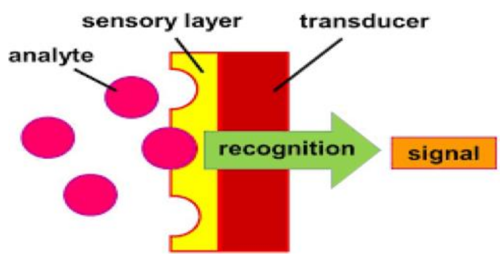

Fig. 6: Nano sensors in food processing [63].

7.3.1.Types of Nanosensors used in food

- Mycotoxin detection using nano biosensors
- Using nano biosensors to find antibiotics
- Nano-biosensor-based detection of microbial foodborne diseases
- Using nano biosensors to find pesticide residues in food
- Nanosensors to identify food additives and adulterants
- packaging for food using nanosensors

7.4.Nano-emulsion

Colloidal suspensions of 50 nm to 1000 nm in size are called nano-emulsions (Fig. 7). They are used for many different things, such as flavoring food components and drinks, enhancing flavor, decorating food, and fortifying it [64]. Emulsions provide several advantages since they don't alter the physicochemical makeup or flavor of food ingredients. The supply of necessary minerals, vitamins, antioxidants, steroids, and other bioactive compounds in vivo is carried out by these self-assembled nano-emulsions. Nano-emulsions are a mixture of evenly dispersed colloidal phases made up of an oil phase dispersed in water. Here, emulsifying molecules encircle each drop of oil to create an interface layer with particles that range in size from 50 to 500 nm [65]. Depending on the type of phase used, there are two different forms of nano-emulsions: oil/water and water/oil. Although they may be employed to create edible coat by integrating different hydrophobic components bound in a lipophobic polymeric matrix, oil- and water-based nano-emulsions are given higher importance [58]. For the creation of nano-emulsions, a variety of lipophilic materials have been described, including quinines, fatty acids [66], carotenoids, antioxidants, phytosterols, and essential oils produced from plants [67]. For their usage as possible delivery systems, nano emulsions are stabilized by the inclusion of natural biopolymers as they're thermodynamically unsteady as a result of coalescence, aggregation, Oswald's maturation, floating, and the effects of gravity over time [68]. These nano emulsions are stabilised by the addition of organic biopolymers, making them potentially useful as delivery systems [69].

7.4.1. Micellus

By combining an aqueous and an organic phase, spontaneous emulsification is used to create nanoemulsions. According to [70], the organic phase is made up of oil, a lipophilic surfactant, and a water-miscible solvent. The aqueous phase is made up of water and a hydrophilic surfactant (Fig. 7). This technique involves emulsifying both of aqueous solution and organic solvent at high agitation, which produces nanoparticles between 50 and 100 nm and causes hydrophobic material to dissolve. The organic solvent is then removed, keeping produced nano-particles in a steady dispersion. The need for an organic solvent is a significant drawback of this technology since organic solvent residues may be harmful when used biologically [71].

7.4.2.Liposomes

Bioactive substances with a variety of advantageous health effects are provided by a complete diet. About the encapsulation and regulated release of food ingredients, bioavailability, stability, and increased durability, nanoliposomes have demonstrated interesting potential for the food industry. Nutraceuticals, minerals, enzymes, vitamins, antimicrobials, and additives may all be delivered in a regulated and targeted manner using nanoliposomes [72, 71]. For a wide range of chemicals intended for biological, biochemical, pharmaceutical, and agronomic goals, liposomes have proven to be an effective transporter. The liposomes (Fig.7), often referred to as proteoliposomes, contain one or more proteins. Because of their fundamental spherical form, liposomes are frequently referred to as spherulites. It is made up of either a single layer of amphiphilic shells or several layers. Small unilamellar vesicles are liposomes with a single bilayer shell and a diameter of less than 30 nm or substantial unilamellar vesicles (30–100 nm), as appropriate [73, 71]. Applications of nanoliposomes in the food sector have provided fascinating and novel qualities for the defense of delicate and fragile food components. Nanoliposomes' increased efficacy has also sped up the production of several foods, including cheese and other auxiliary food items. Fish oil liposome-encapsulated to efficiently fortify yogurt was reported by [75] and they discovered the combination was more effective than fish oil alone. Zatariamultiflora essential oil included in liposomes showed a noticeably increased antibacterial activity, according to [76]. These few noteworthy instances highlight the potential use of nanoliposomes in the food and pharmaceutical industries.

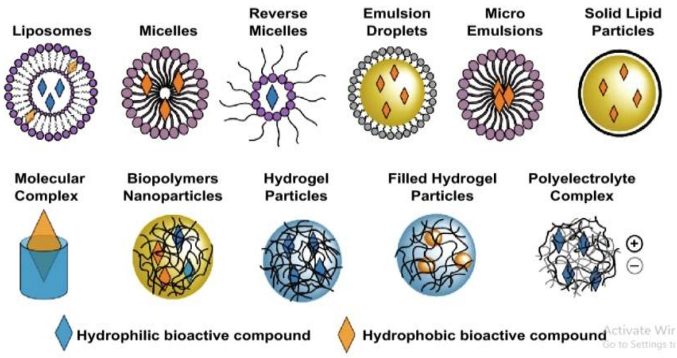

Fig. 7: Nano form of bioactive compounds [74].

7.5.Nano-capsules

Encapsulation is a technique that involves encasing an active substance—such as a medicine, probiotic, vitamin, antioxidant, or live cell—within a carrier matrix (a mixture of carbohydrates, proteins, lipids, or polymers). Increased biocompatibility, bioavailability, and controlled release of active ingredients are all made possible via encapsulation. Additionally, it offers materials that are flavorless and odorless [77]. For 60 years, the field of food science has been very interested in encapsulation techniques. A perfect encapsulation should protect the active substance from environmental factors including pH, temperature, and ion concentration while allowing for regulated release of the active substance. Numerous methods have been documented in the literature to create micro- or nano-encapsulated particles. For instance, the emulsion procedure produces nanoparticles in the liquid phase that require the best drying method to create powdered nanocapsules (Fig. 7). Similar to electrospray, electrospinning is a simple, one-step process for creating micro- and nanocapsules from powder. There are two ways to create structures that are nanoencapsulated. These are nanoparticles made of biopolymers and lipids as vehicles. Additionally, food grade components which like, substances that are generally-recommended-as-safe (GRAS) should be present in the encapsulating materials intended for food integration [78]. Because of their biocompatibility and bioavailability, proteins, polysaccharides, and natural biopolymers are frequently utilized to encapsulate active substances. According to [79], When encapsulated particles are between 0.2 and 5000 nm in size, they are categorised as microparticles, beyond 5000 nm as macroparticles, and under 1 nm as nanoparticles. To increase the bioavailability, stability,biocompatibility and solubility of active compounds capsules, multifunctional micro/nanocarriers such as emulsions, microcapsules, polymer gels, core-shell capsules, and self-assembling structures are frequently used. The choice of the micro/nanoencapsulation process is determined by the physicochemical properties both ofactive compounds (antioxidants, vitamins, and peptides) and the carrier materials matrix Coacervation, phase separation, and emulsion are examples of physico-chemical encapsulation techniques. Spray drying, electrospray, and electrospinning are examples of physico-mechanical encapsulation techniques.

To create biocompatible, biodegradable, and food-grade encapsulations of active particles, electrospray, and electrospinning techniques are frequently utilized [80,82]. The production of micro- and nanofibers and nanoparticles is accomplished using electrostatic forces. The basis for both approaches is the same. The process is determined by the end product's shape and polymer content. When the solution concentration is high, the Taylor cone is stable and the nozzle tip elongates, which causes the formation of nanofibers on the collector. According to [83], when concentrations of polymer is low, polymer jet destabilizes and produces micro- and nanoparticles. Electrical forces atomized polymer solution, including active materials in the electrospray method. As the micro- and nanoparticles move through the collector, the solvent evaporates. Compared to spray drying, the electrospray approach may create nanosized particles [84, 66]. According to reports [85], whey protein concentrate and isolate and gelatin are often employed as protein source. Because these processes don't involve heat, which might denature the protein structure, they are excellent choices for protein encapsulation. Calamak, (2021) [86] demonstrated that the electrospray approach may be used to create micron- and submicron-sized whey protein concentrate-based particles. The characteristics of the encapsulating material may have a synergistic impact and boost the active chemicals' bioavailability. For instance, -carotene's oxidative and light stability was improved by electrospunzein fibers [87]. Curcumin's increased free radical scavenging activity and sustained release capabilities were further improved by its encapsulation in 310 nm zeinnanofiber [88]. Also, Nanocapsules are used in the delivery of drug, with considering its content of bioactive compounds used either as targeting materials or protecting materials [89].

7.6. Nano-composites

Due to their performance and inexpensive price, nanocomposites have established themselves as promising substitutes in food packaging [54, 90]. According to [91], nano composite is a polymer matrice that include both organic and inorganic nano filler with certain geometry (sheet, flake, thread sphere and whisker) having three dimensions in the nano range. Clays, carbon nanotubes, metal oxides, and nano cellulose fiber is a few of the nanofillers that have been studied thus far [16]. Natural and manmade polymers have both been utilized for many years in food packaging. Biodegradable and natural biopolymers, however, are the main emphasis due to environmental concerns. Biodegradable and natural biopolymers are prioritized, nonetheless, due to concerns about their effects on the environment. Many biodegradable synthetic polymers, including polyvinyl alcohol, polylactide, and polyglycolic acid, are now popular for the creation of nanocomposites.

Types of Nano-fillers (hydrogel):

- Clay and Silicate Nano-platelets
- Cellulose
- Carbon Nanotubes
- Starch
- Chitosan
- Pectin
- Gelatin
- Gum.

7.8.Nano Package materials

7.8.1.Activenano-package

Active nanoparticles are used in packaging to prolong the shelf life of food by the interaction between the environment and food and thwarting the bacterial growth (Fig. 8). Examples include oxygen scavengers and antimicrobials. Nanomaterials such as carbon nanotubes, nano silver, nano Tio_2, nanoMgO, nanoCuO, and nanoTio_2 can all be employed in active packaging as antibacterial materials [92]. These containers prevent microbiological development, respiration rate, moisture migration, and oxidation, which aids in food preservation. Also, zinc oxide nano composite is used in active food packaging. Zinc oxide is an antioxidant that helps keep food fresh. Antioxidants are added to the packaging material in the active packaging method for sustaining food product preservation. The use of nanocomposites and nanolaminates is common in nanoparticles and antimicrobial food packaging [54]. They shield food goods from harsh temperature changes and mechanical trauma, lengthening their shelf life [93].

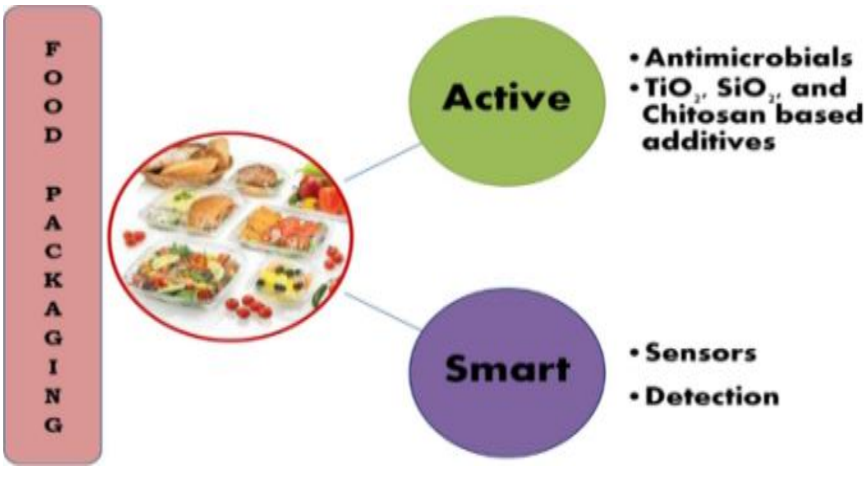

Fig. 8. Nano packaging for food industries, source:

7.8.2.Smart nano-package

Food products are wrapped in nanomaterials to enhance their shelf life without changing them unintentionally.

Nanotechnology can offer solutions to issues with food packaging by altering foil penetration activities, raising mechanical, chemical, and microbiological barriers, and boosting heat resistance [94].

Intelligent or clever nanopackaging (Fig. 8). The inside environment of food and its properties are routinely observed using sensors. Sensors measure drug concentrations and translate them into observable, readable numbers. Solutions for barrier packaging, moisture absorbers, and oxygen scavengers make up approximately 80% of the current smart packaging market. Packaging for meat and bread goods is nano-enabled [95]. Nanosensors are used to monitor pathogens, oxygen levels, temperature and shelf life in the food environment by altering foil penetration activities, raising mechanical, chemical, and microbiological barriers, and enhancing heat resistance. Here are a few instances: Food quality evaluation by fish and meat spoilage gas sensing gaseous amines emitted using nano fibrils of perylene-based fluorophores and microbial detection using nano-gold particles incorporated enzyme are three methods of detecting contamination. Due to their extended lifespan, silver nanoparticles are advantageous for material packaging. As a result, these particles coat objects that are shielded from pollution [86].

7.8.3.Intelligent-package materials

The development of numerous different indicators, including time temperature integrators (TTT's), food spoilage indicators, and chemical indicators, is currently being researched in view of customer demands for food security and the potential use of some specific "intelligent" packaging as a tracking device. There are TTIs for enzyme-catalyzed reactions that may be purchased. Nano-sensors, which are used in food monitoring systems, will act as electronic barcodes when incorporated into food products as small chips. They give out a signal that makes it possible to track food, if it is still fresh, or has been sitting on market shelves, to generate more palatable, marketable goods and fewer product get-back. Nanosensors for packaging materials and effective anti-microbial activators are needed for food that is stored in supermarkets for extended periods. To increase food shelf life and quickly identify food spoiling, these devices emit nano-anti-microbes [6].

8. Food Nanotechnology: benefits and hazards

In terms of enhancing physicochemical properties and enhancing nutritional stability and bioavailability, nanotechnology has brought alternative ways to food processing (Fig. 9) [97]. One of the potential areas for increasing food production and creating new products for use in agriculture, food, water, the environment, medicine, energy, and electronics is nanotechnology. To increase the quality, health benefits, safety, and affordability of food products, the food industry may apply nanotechnology in a number of different ways. Some nanomaterials are used to develop delivery systems for nutrients, the benefits of which are difficult to explain and their pure forms have a low bioavailability. Furthermore, nanotechnology has occasionally been applied to enhance the rheological, optics, and flow properties of food products [98].

The health of the general populace is seriously threatened by nanotechnology. Although many food components and constituents contain nanostructures, adding synthesized nanoparticles to the food system might cause dangerous contaminants to deposit in foods, endangering both human health and the environment. The Scientific Committee has released a scientific consultation. It was concluded that the substance's nano-specific properties are likely to have an influence on the toxicokinetics and human hazard assessment factors of degradation, genotoxicity, accumulation, and immunotoxicity. These factors should thus come first in the evaluation of the risks associated with nanomaterials [99]. Conceptually, nanoparticles can migrate to packaged food; however, migration tests and risk assessments are currently lacking.Migrations into food may be thought of as a process of mass transfer in which components with lower molecular masses are caught in packaging and subsequently released into the packed substrate. It was therefore originally believed to be a diffusion process that could be explained by Fick's second law, making it one of the most important potential dangers [101]. They hypothesised that this was caused by a dearth of sufficient analytical methods for recognising nanoparticles with lower concentrations and smaller dimensions, and they fervently advocated repeating any experiments that had previously shown no sign of migration. In particular, it was found that various experimental studies had not been able to offer a compelling answer on the possibility of nanoparticles migration across the packaging of food to foodstuffs [102].

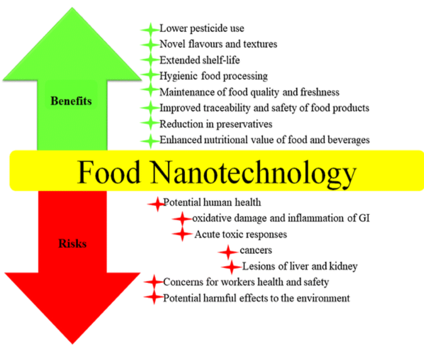

Fig.9 : Food nanotechnology: advantages and disadvantages [100].

9. Toxicological Aspects of Nanomaterials in Food

There are several uses for nanoparticles, nanocomposites, and nanolaminates in the packaging of food products. They have been widely utilized in the antimicrobial packaging of food products in recent years. According to [103], nano-composites are mostly utilized to protect food from mechanical and high-temperature shock and to lengthen its shelf life.

Although food nanotechnology has advanced quickly, little is understood about the origin, course, and toxicity of nanoparticles. Food component, additive, and contact material developed from nanotechnology have discussed in regard to possible effects on consumer safety and governmental oversight [104].

Dynamic, kinetic, and catalytic features as well as functionalization, net particle reactivity, agglomeration, and functional environment all promote nanoparticle-mediated toxicity [105]. Although nanoparticles at the package material surface may not pose a threat to humans, their migration through the environment and assimilation into food may. Before, it was discussed how NP enters the body through various routes, is absorbed, and is distributed throughout the body [106], with a focus on their cytotoxicity and genotoxicity (Fig. 10). Through skin contact, ingestion, inhalation, intravenous injections, or implanted medical devices, nanoparticles enter an animal's system where they interact with biological macromolecules. The persistent, non-dissolvable, and non-degradable character of the NP is primarily responsible for its toxicokinetic difficulties [107]. A deeper comprehension of nanomaterial-based toxicity characterization and regulatory processes is necessary given the absence of detection techniques, government regulations, policies and consumer awareness and for risk assessment of nanotechnology. As the size of the metal-based NP shrinks, the toxicity rises [108]. Because they easily pass through capillaries and membrane barriers, nanoparticles have unusual toxico-kinetic and toxico-dynamic features. Some nanoparticles attach to protein and enzyme, which stimulates the oxidative stress response and the formation of ROS (Fig. 10). Apoptosis and mitochondrial degeneration are brought on by a buildup of ROS. The majority of NP-imposed toxicity experiments conducted on animals showed that NP might cause serious harm to the immune system, liver, and kidneys, among other organs. Lack of research about how NP affects human health justifies conducting significant research. Only a small number of in-vivo toxicological investigation of silver NP has been carried out using models (such as rat and mice), despite the fact that silver NP has been employed in several commercial nanoproducts. Human cells exposed to TiO_2 NP had tumor-like modifications. For the assessment of nanomaterial-induced toxicity under in vitro circumstances, several lung, GI tract, and skin cell lines were utilized [109].

Genotoxicity, which may be divided into primary and secondary genotoxicity, is a result of the absorption of exogenous materials, including nanomaterials, which caused genetic harm in the cell and animal system. Primary genotoxicity refers to the direct interaction of the NP with the genomic DNA without the triggering of inflammatory responses. Crystalline silica, particle asbestos, and some particular nanosilver compounds have all been linked to this [110]. The production of ROS in nanopartical induced target cell or the decline in intra-cellular antioxidants are two indirect methods of primary genotoxicity. The formation of peroxy-nitrite by TiO_2 and C60 fullerenes, as well as changes in the levels of hydroperoxide, ROS, (MDA) malondialdehyde concentration, and the activity of lactate dehydrogenase (LDH), which led to DNA fragmentation, were all responsible for the primary genotoxicity caused by quartz particles [111]. At the secondary geno-toxicity, nanomaterials stimulate macrophages and neutrophils, which lead to inflammatory responses along with genetic damage. DNA damage linked with inflammation is brought on by reactive oxygen species (ROS), reactive nitrogen species (RNS), and phagocyte mediators [112]. Increased inflammatory responses and genotoxicity are brought on by the oxidative and nitrative stressors brought on by ZnO and TiO_2 NP in human monocyte cells. Chronic inflammation and secondary genotoxicity are brought on by the biopersistent particles application of long- term nanoscale granular [113].

At the food sector, nanoparticles are employed for food packaging, smart packaging, and nutritional supplements because of their antibacterial properties. To solve the issues related to nanotechnology in the food sector, it is important to thoroughly investigate the bioavailability, destiny, behaviour, disposition, and toxicity of NP in the environment [114].

Lipids, proteins, and/or carbohydrates make up organic nanoparticles, which at room temperature can be liquid, gel, crystalline, or amorphous. These often take the shape of nanofibres and spherical morphologies, which aid in their penetration. However, based on their makeup, their behavior inside the GI tract may change. Organic nanoparticles are digested in the stomach, making them less harmful and non-persistent. The solubility, biosorption, and bioaccumulation of inorganic nanoparticles in the host, on the other hand, are influenced by their varying diameters, interfacial characteristics, aggregation state, food matrix effects, and GIT effects [115].

Due to their ability to adsorb and huge surface area beside, denature digestive enzymes found in the gastrointestinal fluid, these nanoparticles may interfere with the GI tract's ability to operate [116]. This would reduce the enzymes' ability to carry out their intended role of digestion. There may be a decrease in the digestion of lipids, proteins, or starches as a result of the large amount of indigestible organic nanoparticles at GI tract. Gupta and Xie (2018) [117], studied the oxidative stress and inflammation in the GI tract can occasionally be brought on by nanoparticles entering the body through immunological reactions. Even though the collection and aggregation of nanoparticles in many tissues and cells is a key factor in toxicity, the nanomaterials used for food or nano foods are digestible by nature and provide the least hazard. The carcinogenic or genotoxic consequences of nanoparticles used in food are also not substantial due to minimal accumulation in the body [118].

In addition, strong chemicals are frequently utilized in the methods used to create nanoparticles, which might result in severe toxicity in vivo. The usage of various ionic and non-ionic surfactant types in nanoemulsions is the main factor contributing to toxicity. Additionally, the creation of nanoliposomes calls for the use of organic solvents, which must be chosen carefully because of their potential for severe toxicity. Additionally, some indigestible protein and carbohydrate-based nanoparticles may affect how other proteins, starches, and fats are absorbed and so represent a health risk [119]. When digestible lipids are enclosed in nanolaminate fibers, their digestion is delayed and sluggish in the GI upper tract. This causes a larger concentration of lipid to pass into the colon, where they are fermented and cause issues of GI. When high amounts of some nanoparticles carrying nutraceuticals with antibacterial characteristics that are not digested in the upper GI tract reach the colon, they change the colon's microbiome and have harmful consequences [117]. The safety and toxicity of food-grade materials has been the subject of several investigations; as a result, all these variables should be taken into account when creating nano-formulations for dietary use.

10. Food nanotechnology and the legislation and laws

Ingredients, packaging, and food product analysis are just a few of the many applications of nanotechnology in the food sector. In addition to its potential applications, their connection with the food chain raises questions regarding the health of both people and animals. No conventional regulatory standards addressing the use of nano-formulated goods in the food and Agri sectors have yet been developed, even though they are harmful to plants and animals. As a result, strong regulations and rules are needed for the food business to use nanoparticles safely. In the USA, food packaging and nano foods are regulated by the regulatory organization USFDA. The Food Standards Code's regulatory agency, Food Standards Australia and New Zealand (FSANZ), actively engages at the regulation of nano-food ingredients and additives in Australia [120]. In the European Union, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) assesses the risks associated with nanotechnology. Before being approved for use by humans, food components based on nanotechnology should pass a safety evaluation [121]. According to the European Food Safety Authority's (EFSA) re-evaluation plan, food packaging materials and nano additives that were allowed before 2009 should be handled by the program. Despite being the two nations that produce the majority of nanomaterials, Japan and China lack the necessary rules for this field [122]. Additionally, Egypt does not yet have laws or standards for regulating nanofood. Lack of knowledge regarding exposure, accessibility, and human toxicity is the cause of the absence of food restrictions in several nations. Several nations have sought a regulatory structure for managing the dangers linked with nano foods as a result of the rising regulatory issues. For lawful nanotechnological uses, strict toxicological screening procedures are crucial because there are no formal regulations or laws in place [30].In addition, strong chemicals are frequently utilized in the methods used to create nanoparticles, which might result in severe toxicity in vivo. The usage of various ionic and non-ionic surfactant types in nanoemulsions is the main factor contributing to toxicity. Additionally, the creation of nanoliposomes calls for the use of organic solvents, which must be chosen carefully because of their potential for severe toxicity. Additionally, some indigestible protein and carbohydrate-based nanoparticles may affect how other proteins, starches, and fats are absorbed and so represent a health risk [119]. When digestible lipids are enclosed in nanolaminate fibers, their digestion is delayed and sluggish in the upper GI tract. This causes a larger concentration of lipids to pass into the colon, where they are fermented and cause GI issues. When high amounts of some nanoparticles carrying nutraceuticals with antibacterial characteristics that are not digested in the upper GI tract reach the colon, they change the colon's microbiome and have harmful consequences [117]. The safety and toxicity of food-grade materials have been the subject of several investigations; as a result, all these variables should be taken into account when creating nanoformulations for dietary use [124].

11. Future perspectives of nanotechnology in food

Although nanoparticles are produced all around the world, relatively few nations have the requisite regulatory framework in place to use nanotechnology in food items. Nanotechnology holds a lot of potential for producing unique products and processes in the food business, there are still many obstacles to be addressed. Therefore, if handled and regulated properly, the use of these nanotechnologies may significantly contribute to enhancing food processing and product quality, which will enhance human health and well-being. As research on food nanotechnology develops societal concerns about the safety of nanotechnology products for human use and consumption increase. Consequently, a detailed analysis of potential risks to human health is necessary before the release of nano-food items for commercial sale. The use of nanoparticles in food packaging has fewer health risks than using them as food ingredients. There is always a chance that nanomaterials, which may cause DNA damage, cell membrane rupture, and cell death, will find their way into the food chain through the air, water, and soil during their production and use. There hasn't been much in vivo research done yet to determine how nano-foods affect both human and animal health.

Several environmental, moral, and safety regulations have been raised in response to the disintegration of these nanoparticles. To assess the threshold levels of toxicity to environmental biota, safety standards, and regulations must be made mandatory. By using edible biopolymers as the framework of nanostructures, the drawbacks of nanotechnologies in the food industry may be minimized, such as the influence of eco-toxicity and bioaccumulation. However, the kind, size, and penetrating capacity of the nanoparticles determine their toxicity. It is crucial to keep an eye on how nanoparticles are migrating in packaging materials and biosensors. Metals and metal oxides have been cited in several in vitro and in vivo investigations as biocompatible compounds with low toxicity but the potential to cause pro-inflammatory reactions. Therefore, consistent operational procedures must be created to study nanoparticle toxicity reliably and practically. To reduce the negative impacts on health, the food safety standards established by agencies like the World Health Organization (WHO), the Food and Drug Administration (FDA), and the European Food Safety Authority (EFSA) should be stricter. Future studies should focus on how nanoparticles employed in food packaging and sensing interact, associate, and dissolve with biological systems including the gastrointestinal tract. To ensure food safety, it is important to advance the procedures for validating chronic exposure to these food contact nanomaterials. To promote consumer acceptance, there should be proper labeling and laws for the marketing of nano foods. However, there isn't currently a formal universal standard for evaluating the safety of nanomaterials in meals. The primary challenge is creating ingestible delivery methods that are both affordable to create and secure for use by people. The migration and absorption of nanoparticles from packaging materials into foodstuffs is a significant issue for ensuring the safety of meals.

•***Some proposed methods for detecting the presence of food content modified into nanoparticles:***

1. Surface plasmon resonance (mass fraction)-based imaging and analytical devices are one way to test for cadmium.
2. spectroscopy (dimensioning of nanoparticles).
3. radiotracking using positron emission tomography.
4. dynamic light scattering (distribution of particle sizes).
5. mass spectroscopy (to determine the makeup of test materials).
6. optical emission spectrometry for elemental analysis at the trace level.
7. Test materials are gathered by the Raman Nano Chip TM food safety detecting device employing nanorods and molecular interactions with adsorption on the nano surface structure. A Raman spectrum is created by analysing the computer analysis to separate food components from a database based on scattering intensity at the nanosurface.

Foods that have undergone nanotechnology should thus go through the necessary testing before being allowed for sale. New approaches and standardized test methods to look at how nanoparticles affect live cells are urgently needed for the evaluation of potential dangers related to human exposure to nanoparticles. People are expected to have more access to food items made feasible by nanotechnology in the future years.

12. Conclusions

The application of nanotechnology in the field of food and food manufacturing is considered one of the most important revolutions that represent a major shift in food production technology. Nanotechnology allows food to improve functional properties as well as control flavor and color as desired. Unfortunately, this technological revolution lacks many studies on its toxicity, the extent of its impact on human health, and its interactions and absorption within the human body. Also, until now, there are no international laws and legislation that govern their use and set quality standards for these foods. Therefore, there is an urgent need to create regulations, legislation, and standard specifications that govern and regulate the circulation of these foods. Research must also be directed to studying the absorption and path of these nanoparticles within the human body and the harm they cause. There is also an urgent need for methods to detect and analyze foods containing nanoparticles.

13. Conflicts of interest

"There are no conflicts to declare".

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