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IMPLICATION OF NANOTECHNOLOGY IN FOOD INDUSTRY

Raghav Garg[1]*, Sudhanshu Maheshwari[2], Dr. Reshu Rajput[3]

[1,2,3]NH-05, Ludhiana - Chandigarh State Hwy, Sahibzada Ajit Singh Nagar, Punjab,*
Email id:raghavgarg4469@gmail.com, somani.sudhanshu@gmail.com,
reshu.e10479@cumail.in

Corresponding Author: -
raghavgarg4469@gmail.com

Abstract: -

The rapid and broad adoption of nanotechnology in multiple industries is due to its numerous uses in our daily lives. Food and nutrition delivery is one of the most affected sectors by nanotechnology in all aspects, impacting even the structure of food itself. Whether it's farming, packaged food, or microbial contamination prevention, the large food sectors have seen substantial changes as a result of nanotechnology. This review discusses the implications of nanotechnology on functional foods and the effects of antimicrobial nano- structured materials on bacteria. It also emphasises the properties of food nanotechnology, as well as its current and potential future food science applications. The possibilities for nanomaterials to use in the food business to provide consumers with secure, decontaminated food and to raise food acknowledgement due to improved functional properties.

Keywords: - *Nanoparticle, Food processing, Nanotechnology, Food packaging, Nanocarriers, Encapsulation, Nano emulsion.*

1. INTRODUCTION

Magical spells have the capacity to turn anything into gold; one that spell is "Nanotechnology," which is having mysterious power to revolutionise any field it touches. The food industry is currently being conquered by nanotechnology, which holds excellent potential. (Chellaram et al., 2014) (Fathi et al., 2012). The definition of nanotechnology is the invention, integration, and modification of substances, machines, or system at the nanoscale size. Nanoparticles are typically described as substances that are smaller than 100 nm, and they differ from their macroscale counterparts in a number of ways, including high surface to volume ratios and novel physicochemical characteristics including colour, solubility, and thermodynamics. [Motao et al., 2012]. The uses of nanotechnology in food are characterised by their functionality. Due to their characteristics and intended uses, functional food additives can affect the bioavailability and nutritional value of the food. Application of nanotechnology in the food industries include encapsulating and transfer of chemicals to specific places; enhancing flavour; adding antimicrobial nanoparticles to food; extending storage life, detecting impurity, better food shelf life, tracing, tracking, and copyright. [Ingale et al., 2018]. In addition to altering the nutritional content of food and removing pollutants or pathogens, nanotechnology is also used in food processing and product development. Nanotechnology-based food packaging materials have the strength to upgrade food concern, lengthen the shelf life of food due to high barrier packaging, mend packaging tears, and release additives to prolong the shelf life of food inside the container. The main purpose of this research is to highlight the maximum applications of nanotechnology in food delivery, packaging, and encapsulation to ensure the safety of food items. (Yu et al., 2018a).

2. History

New science and technology are frequently the result of human dreams and creativity. These aspirations gave rise to the 21st century frontier of nanotechnology. Its singular phenomena make way for cutting-edge applications. Although there has always been some human exposure to nanoparticles, throughout the industrial revolution there was a huge rise. It is not new to examine nanoparticles. Richard Zsigmondy, a chemistry Nobel Prize winner in 1925, was the one who initially coined the term "nanometer." In order to define particle size, he precisely developed the term "nanometer," and he was the first to use a microscope to determine the size of particles like gold colloids. He introduced the idea of atomic-scale manipulation of matter. (*Home | National Nanotechnology Initiative*, n.d.). With this innovative approach, new methods of thinking were presented, and Feynman's theories were later found to be true. For all these reasons, He is regarded as the father of modern nanotechnology. The term "nanotechnology" was first used to represent semiconductors operations that took place on the basis of a nanometre by a Japanese scientist named Norio Taniguchi, nearly 15 years after Feynman's presentation. He promoted the idea that using just one atom or one molecule, materials might be manipulated, isolated, stabilized, and deformed. [Norio, 1974]. The new disciplines of nanoscience and nanotechnology drew more attention towards the start of the 21st century. Feynman's influence and the idea of manipulating matter at the atomic level had a significant impact on the development of national science priorities in the United States. [NSTC, 2015] (Hulla et al., 2015). As the idea of nanotechnology started spreading, it conquered all the fields of science, likewise it is also being used in the food sector which is discussed in this paper.

3. Categorization of nanocarriers –

Colloidal drug carrier systems with submicron particle sizes, generally less than 500 nm, are known as nanocarriers. (Neubert, 2011). Nanocarriers have been actively researched in recent decades due to their immense promise. (Mishra et al., 2010). Nanoparticles might be broadly categorised as organic based, inorganic based, or a mix of the two. Organic nanoparticles include lipid-based nanoparticles like liposomes and nano emulsions as well as polymeric nanoparticles and carbon based nanocarriers. Inorganic nanocarriers include metallic nanostructures such as quantum dots. [Dinesh Mishra et al., 2018].

3.1 Organic Nanoparticle:

3.1.1. Polymeric Nanoparticle: The base of polymeric nanoparticles is a biocompatible and biodegradable polymer that may be found in both natural and manmade sources. The majority of synthetic polymers used in sustainable polymers, including poly (lactic acid), polyglycolic acid, poly (lactic-co-glycolic acid), polymethyl methacrylate, poly(caprolactone), and poly (amino acid). (Li & Tuan, 2005). Polymeric nanoparticles' flexibility and chemical characteristics make them excellent for integrating with biomaterials such as genetic materials and growing factors and for aim distribution to promote tissue regeneration. (Saravanan et al., 2017)

3.1.2. Liposomes: Over the past few decades, liposomes have drawn a lot of interest. (Lee et al., 2015). Concentric lipid-bilayer nano carriers called liposomes have an aqueous core that is surrounded by a surfactant made of phospholipids that can be either natural or manufactured. According to their structural characteristics, liposomes may be divided into 3 groups: multilamellar vesicles (MLVs), oligo lamellar vesicle (OLV), and unilamellar vesicles (ULVs). Small unilamellar vesicles (SUVs) have a diameter of 20 to 100 nm, medium unilamellar vesicles (MUVs), large unilamellar vesicles (LUVs) have a diameter of 100 nm or more, and giant unilamellar vesicles (GUVs) have a diameter of 1,000 nm or more. Liposome-based carrier systems with biocompatible lipid bilayers include immunoliposomes, virosomes, stealth lipid membranes, and archaeosomes, and archaeosomes, which may enhance the solubility and stability of the core substance. (Alavi et al., 2014; Fleddermann et al., 2016; Merino et al., 2018; Mineart et al., 2018)

3.1.3. Dendrimers: Dendrimers are usually branching macromolecules with several arms extending from the core. (Newkome et al., 2001). Typically, they are created utilising substances like sugars, nucleotides, and amino acids, whether they are natural or manufactured. With the aid of their stepwise synthesis, they may modify molecules with an incredibly consistent tree pattern, a specific molecular mass, and a characteristic amount of peripheral groups. (*Dendrimers and Dendrons: Concepts, Syntheses, Applications | WorldCat.Org*, n.d.). Through the use of divergent or convergent polymerization, dendrimers can be built from monomers. When employing various units, including chitin, melamine, polyamidoamine, poly L-glutamic acid, polyethylene glycol, and polypropylenimine, it is possible to show that the target size and form of a dendrimer depends on the repeating unit's percentage of branching units. (D'Emanuele & Attwood, 2005; R. Duncan & Izzo, 2005).

3.1.4. Carbon based Nanocarrier - Carbon nanotube is a carbon-based tube-like structure that is structured in the form of a graphene layer that has been coiled into a cylinder or closed at both ends, to create a buckyball form. (R. Duncan & Izzo, 2005) Single-walled nanotube and multi-walled nanotube are the two carbon-based structures. Multi-walled nanotubes are made up of more than 2 circular cylindrical shells of graphene layers surrounding a central hollow core, as opposed to SWNTs, which are made up of a single graphene cylinder. (Keservani et al., 2017). The formation further divides the nanotubes into target-based, ligand-attached, solvent-dispersed, and surfactant-grafted categories. Fullerenes are typical carbon-based nanocarriers with geometric prison-like structures made of pentagonal and hexagonal carbon faces, in addition to tubular varieties. (Ezzati Nazhad Dolatabadi et al., 2011).

3.2 Inorganic nanoparticle:

3.2.1 Quantum Dots: Quantum dots, which have a size range of 2-10 nm, are nanoparticles of synthetic fluorescent semiconducting atoms. Cadmium selenide is a semiconducting material that comprises a core and an aqueous zinc sulphide shell that inhibits the core to improve optical characteristics. Quantum dots could be built to emit light with wavelengths ranging from UV to infrared. The wavelengths emitted are strong enough to be identified at the microlevel (Qu et al., 2017). Furthermore, because biomolecules can be bonded to the outer aqueous shell, quantum dots offer a steady and inert delivery mechanism (Mo et al., 2017).

3.2.2. Nanoemulsion: For specific applications in food and beverage goods, nanoemulsions have several potential advantages over regular emulsions. Nanoemulsions are more resistant to particle aggregation and mechanical separation than conventional emulsions (Tadros et al., 2004). Nanoemulsions are droplets with sizes ranging from 10-100 nm that are classified into two categories based on the mutual spatial arrangement of the water and oil phases. (McClements & Rao, 2011). O/W nanoemulsion is typically kinetically stable and mildly turbid to transparent. Because of the low light scattering of particles in nanoemulsion, they are appropriate for integration into optically transparent goods such as fortified soft drink and waters, whitening cosmetics, and soups (Boonme et al., 2009; Lane et al., 2013; Wang et al., 2016; Silva et al., 2011).

3.2.3. Hydrogel Nanoparticle: Hydrogels are 3-D polymer network capable of absorbing vast amounts of water or biological fluid. The presence of hydrophilic groups determines the hydrogels' ability to absorb water (e.g., -OH, -CONH-, -CONH2-, and –SO3H) (Pachioni-Vasconcelos et al., 2016). Physical connections or crystallites, as well as chemical tie-points and junctions, are two types of crosslinks (Peppas et al., 2000). Polymers such as alginate, chitosan, poly (vinyl alcohol), poly (ethylene oxide), and poly-N-isopropylacrylamide are commonly utilized to create cross-linked networks in drug delivery systems. The electric field, light intensity, pH, and temperature all have an effect on these networks (Lin et al., 2009; Xiao et al., 2016).

Table 1. Methods for preparing nanocarriers traditional and developing (Yu et al., 2018b)

Preparation methods	Merits	Demerits
1. Conventional method		
High homogenization	Good adsorption efficiency, large-scale manufacture	Base element inactivation in nanocarriers
Reversed - phase evaporation	Better absorption performance, low cost	Organic solvent residues are hazardous to fragile structures and food components.
Solvent-emulsification	Entrapment efficiency is high.	Fragile, multivesicular
2. Emerging methods		
Microfluidic channel technique	Monodisperse nanocarrier creation, excellent entrapment efficiency	Fabrication can be complicated and should be optimised.
drying by spray	High encapsulation efficiencies and an environmentally sustainable process	Cost and time commitment
Membrane contactor technique	Nanocarriers are uniform and tiny in size, with great encapsulation efficacy and ease of scale-up.	Water - soluble drug entrapment needs improvement

4. Process to structure nano food particles - There are various established and new technologies for producing nanocarriers. The most popular ways are based on emulsification technology, although particular procedures for each type of nanocarrier must be developed.

4.1. Conventional method:

4.1.1. High-pressure Homogenization: It's commonly employed in the production of lipid-based nanocarriers such as nanoemulsion and solid lipid nanoparticles. High shear stress generates high pressure (100-2,000 bar), leading in particle breakup into the nanoscale range. A liquid product is subjected to extremely shear stress during high-pressure (valve) homogenisation, resulting in the creation of extremely small emulsion droplets. The shear is created by a high-pressure flow restriction through a restrictive valve. (Serdaroğlu et al., 2015). This technique is split into two phases: thermal homogenization and cooled homogenization. The former produces smaller particles because of the reduced fluidity of the phase at increased temperatures, but it can result in an accelerated breakdown rate of substratum in the nanocarriers. (Mishra et al., 2010).

4.1.2. Solvent emulsification diffusion: The most popular approach for producing lipid- and polymeric-based nanoparticles is solvent emulsification-diffusion. The polymer is in an organic solvent in the oil phase, while the stabiliser is in water in the aqueous phase. When water and organic solvent are combined, the organic solvents diffuse, which results in the creation of nanoparticles (Mishra et al., 2010). The solvent used in the nanoparticle preparation process must be eliminated. Furthermore, emulsification procedures for producing more complicated nanocarriers necessitated a double emulsion (Maciej Serda et al., 2001).

4.1.3. Injection method: The lipids are dissolved in C_2H_5OH using the ethanol injection method (Pons et al., 1993). Several lipid solution injections can raise the large proportion of the core components in the aqueous phase (Jaafar-Maalej et al., 2010). The two injection methods used to prepare lipid-based nanocarriers use ether or C_2H_5OH. Diethyl ether and ether-methanol solutions are commonly used for lipid dissolution (Deamer, 1978). The lipid-ether mixture is delivered into the aqueous medium, resulting in the formation of nanocarrier vesicles. (Dua et al., n.d.; Samad et al., 2007)

4.2 Developing technologies.

4.2.1. Microfluidic-channel methods: 2 silicon wafers, such as polydimethylsiloxane, are vertically joined together in the microfluidic channel method (Song et al., 2010). When preparing liposomes, a lipid mixture is injected into the central aqueduct, while aqueous mixtures are injected into the outer inlet, which cross with the central position. Liposomes form as a result of the various shear forces generated at liquid integrations by the altering flow rate ratio. A lipid-dissolved solvent stream is passed among two aqueous systems in a microfluidic channel. At the liquid interfaces, mixing occurs, leading to the formation of nanocarriers (Shi et al., 2008, 2009).

4.2.2. Supercritical fluid method: It is a technique in which super - critical fluid is used as a separation medium and target components are extracted based on variations in solubility. This method can be utilized as a medium for particle design and synthesis. The RESS process can be used to create microspheres or microcapsules of an active ingredient contained within a carrier. (Jung & Perrut, 2001). Under conditions beyond its thermodynamic crucial moment of temperature and pressure, a supercritical fluid can be either a gas or a liquid including such water or CO_2. This method is classified into 2 types: rapid expansion and antisolvent precipitation (Mishra et al., 2010). When compared to RESS, modified RESS inhibits particle expansion in the development jet and results in smaller nanoparticles (Meziani et al., 2004). Reduced environmental impact and improved particle morphology design are two benefits of these methods over traditional ones. This method's drawback is its limited ability to scale for industrial production, which could lead to variable particle characteristics (Lesoin et al., 2011).

5. Application of Nanotechnology in the food sector: There are innumerable application of nanotechnology in food sector which includes food processing, food packaging, barrier protection, monitoring of food quality, physical properties of food, protection against chemical ingredients and microbes.

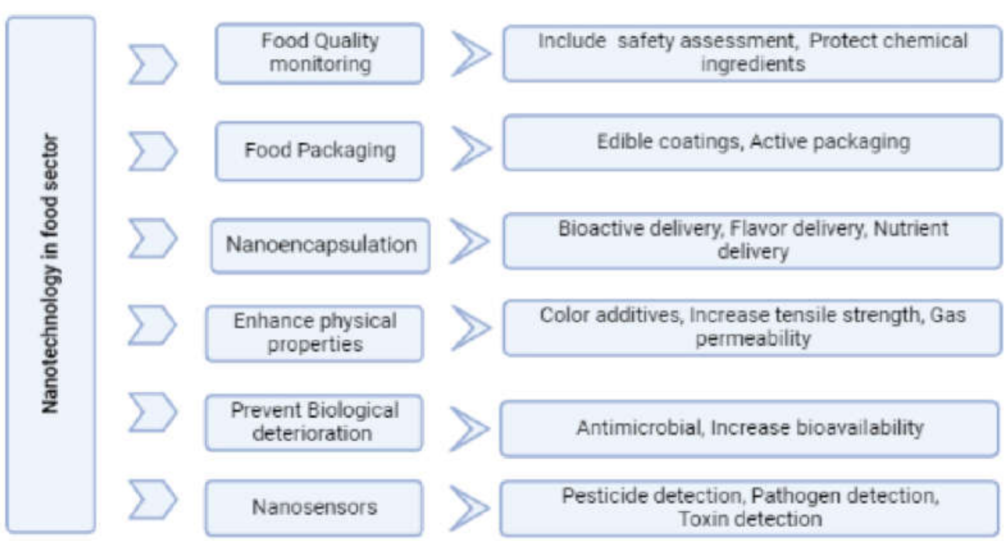

Fig 1. Application of nanotechnology in food industries

5.1. Food Packaging: Food packaging needs to be safe, tamper-resistant, and meet specific physical, chemical, or biological requirements. Additionally, it displays the product's label, which includes any nutrition facts for the food being consumed. The packaging plays a significant role in keeping the food fresh and marketable. Packaging innovations have produced high-quality packaging, consumer-friendly methods for estimating shelf lives, biodegradable packaging, and many others (*[PDF] New and Emerging Applications of Nanotechnology in Our Food Supply - Free Download PDF*, n.d.). For the preservation of food products, silver nanoparticles are used in packaging materials. These particles can kill bacteria in under 6 minutes. The packaging of alcoholic beverages is another typical use for multi-layered PET bottles (*Chasing Nanocomposites | Plastics Technology*, n.d.)

5.1.1. Antimicrobial packaging: A natural nanoparticle is one of the barriers, which helps to regulate microbial growth that can produce pathogens or spoilage. In all kinds of products, such as electrical appliances, kitchenware, and biotextiles, silver nanoparticles are used. In bulk form, silver nanoparticles act as needed, and its ions can stop a variety of bacterial biological processes (T. v. Duncan, 2011). One of the most popular nanomaterials used as antimicrobials in the food industry is silver nanoparticles and nanocomposites. The U.S. FDA has authorised the use of twelve silver containing zeolites or other products as food contact materials with the goal of decontamination. To ensure food safety, the nano - structured film can possibly block bacteria from getting into food (Asadi & Mousavi, 2006).

5.1.2. Smart packaging: Sensors are tools that convert the measured value of substances into signals that can be read by observers. They are utilized to control the internal ecosystem of food products, and sensors are regularly used to sense their properties. According to a recent report, oxygen scavengers, moisture absorbers, and barrier packing products account for 80% of the market share in the current smart packaging segment. However, to date, the most nano-enabled packaged food technology has been used for meat and bakery products. Thus, the use of intelligent sensors benefits both consumers and producers by allowing for faster distribution and decent quality proof of identity of food products (Chellaram et al., 2014).

5.1.3. Bioavailability: Some studies have explored the use of nano - materials as drug carriers to increase the biocompatibility of bioactive components as nutritional supplements. Bioactives have undertaken extensive testing in nano delivery systems, including coenzyme Q10, nutrients, iron, calcium, curcumin, and so on (Oehlke et al., 2014).

5.1.4. Edible film packaging: The use of comestible thin film or packaging can prolong food's storage life and improve quality. Chitosan, gelatin, polyglycolic acid, sodium caseinate blends, poly lactic acid, poly glycolic acid, alginate, and others are materials utilized in the bioplastic manufacturing process for packaging made of edible thin film (Arvanitoyannis et al., 1998; Lagaron & Lopez-Rubio, 2011).

5.2. Enhance of physical properties:
5.2.1. Color additives: Food colour additives are approved by the Office of Cosmetic products and Shades inside the Center for Food Safety and Applied Nutrition, the U.S. FDA, in accordance with legal requirements, and they can only be used in accordance with the approval uses, requirements, and limitations. With the development of nanotechnology, numerous nanoscale colour additives are currently being researched and produced. The use of specific nanomaterial products as food colour additives, which are essential to the emotional appeal of consumer goods, has recently received approval. With the restriction that the ingredient should not be more than 1% w/w, the U.S. Received FDA approval TiO_2 as a meal colour additive, and it is now exempt from certification. In addition to TiO2, SiO_2 and/or Al_2O_3 may be used as dispersing aids in colour ingredient mixtures for food use, but not in excess of 2% overall. However, it is no longer permitted to use carbon black as just a colourant additive (*U.S. FDA Color Additive Requirements - Registrar*, n.d.)

5.2.2. Anticaking agents: Silicon dioxide is utilized to coagulate pastes, to add anti-caking ingredients to powdered goods, and to transfer flavours and fragrances in both food and non-food related products. In the European Union, this is listed as a food additive. It has been discovered that some SiO_2 found in food ingredients is nano-sized. According to data, eating foods exposes the gut epithelium to nanosized SiO_2. Despite the fact that nanoparticles can be toxic to cells to human lung cells when exposed, they are frequently used (Athinarayanan et al., 2014; Peters et al., 2012).

5.3. Flavour control: Flavors are regarded as essential components in all foods because they have a big impact on sensory quality and how much people eat. The strength and suitability of the food are related to the growing interest in the stability of flavours in various types of food (Estevinho & Rocha, 2017). The solubility of the flavour and the carrier's physical and chemical characteristics should be taken into consideration when developing an encapsulation system (viscosity). The carriers in particular shouldn't react to the flavours (Gharsallaoui et al., 2007).

5.4. Encapsulation of Bioactive compounds: The solubility, bioavailability, and reliability of vital nutrients and bioactive compounds have all been improved by nanotechnology during computation, storage, and distribution. Beta-carotene from carrot, lycopene from tomato, beta glucan from oats, conjugated linoleic acid from cheese, isoflavones from soybeans, and other bioactive compounds are highly nutritious components that are typically present in foods in trace amounts. [Hongda et al., 2006]. Antimicrobial peptides enclosed in liposomes demonstrated advantages over free bacteriocins and increased food shelf life, demonstrating an intriguing method of delivery to the food industry (da Silva Malheiros et al., 2010).

5.5. Nanosensors: Due to their potential for nondestructive detection and measurement of very minimal concentrations of pathogenic organisms, Other chemicals and organic compounds, nano sensors have a significant role to play in agriculture. The nano sensor has been used to identify organophosphate pesticides in water, plants, and fruit. The high water solubility, high toxicity level and widespread use of pesticides in agriculture make extremely sensitive and specific analysis techniques for trace analysis of these pollutants essential (Otles & Yalcin, 2010; Valdés et al., 2009)

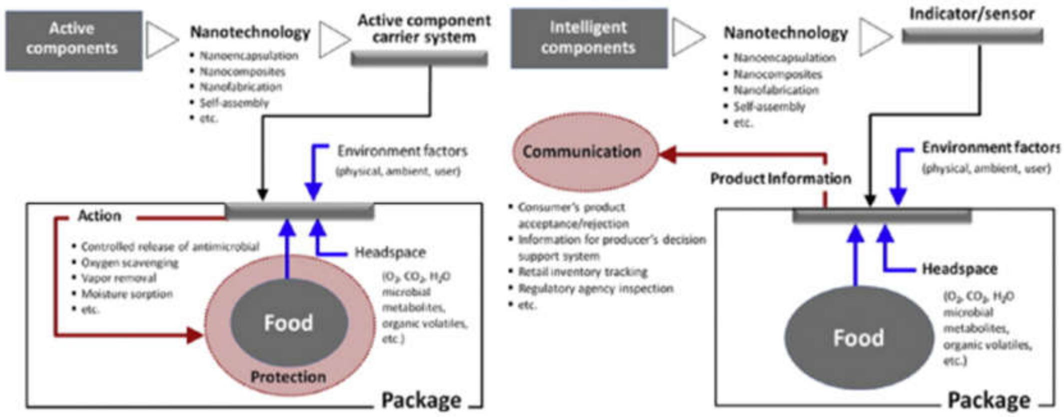

Fig. 2. Action of Nanosensors (*E Development of Nanotechnology and Its Application in Active and... | Download Scientific Diagram*, n.d.)

6. Current scenario of nanotechnology: Packaged foods, preservatives, and preservation of food are just a few of the areas where food nanotechnology has impacted consumer goods. Food storage and processing have advanced to ensure food safety thanks to the acknowledgement of this novel technology. Additionally, it has been discovered that a large number of conventional chemicals used as food additives or packaging materials are partially present at the nanometer scale. In the nanometer range, for instance, food-grade TiO2 NPs have now been discovered up to about 40% (Dudefoi et al., 2017; Weir et al., 2012). Despite the fact that at ambient temperatures, nanoparticles like Tio2 are typically regarded as being low toxic, prolonged exposure to these nanomaterials may result in negative side effects. The use of food supplement nanotechnology and the existence of nanoscale chemicals have also drawn public attention to the risks they may face.

7. Challenges for nanotechnology: Despite the fact that nanotechnology has the capability to develop novel food-related processes and products, it faces numerous challenges. The main thing is to develop edible delivery methods that are cost-effective to produce and safe for human consumption. (Dupas et al., 2007). The leaching & migration of nanomaterials from packaging into foodstuffs is a major concern for food safety. Nanoparticle consequences, potential risks, toxicity issues, and environmental concerns must be addressed. It has been reported that nanoparticles can cross the biological shield and enter cells and organs (*Quantum Dot Biolabeling Coupled with Immunomagnetic Separation for Detection of Escherichia Coli O157:H7 - PubMed*, n.d.). The synthesis of nanomaterials using various chemical methods has negative consequences and produces hazardous non-eco-friendly byproducts that cause serious environmental pollution. Furthermore, prior to large-scale application and for the production of antibacterial nanoparticles with environmental friendliness properties, in vivo and in vitro research studies nanoparticle interactions with living organisms are required. (Cha & Chinnan, 2004).

8. Safety concerns: Despite its numerous benefits, the rapid spread of nano-biotechnology in food technology has sparked concerns about safety of people, ecological, ethical, strategy, regulatory requirements. Nanomaterials may have significantly different biological and physicochemical characteristics than their traditional counterparts, and these unidentified properties may pose unpredictable hazards. Even though the food industry has extensively studied nanoencapsulation technology for bioactive compounds, the possible risk of physical touch of nanomaterials with living beings by means of oral consumption remains a concern. The organic solvents should be eliminated through an evaporation process, but this step may leave unanticipated residual solvents in the finished product, which could have negative effects on safety if their composition is unknown. Organizations like the World Health Organisation (WHO), the Food and Drug Administration (FDA), and the European Food Safety Authority have identified safe usage levels for emulsifiers and solvent, which has been labelled as harmful (EFSA).

9. Future prospective: There are many toxicity issues and potential risks related to the use of nanomaterials, and these issues need to be addressed. These microscopic particles have unpredictable effects on people, animal life, and the surroundings because their properties change over time. To get to specific organs and cells, some nanoparticles can pass through biological problems like the blood-brain barrier. Scientists must develop the best and many more nanoparticles with the improved absorption while attempting to regulate the flavour, texture, and appearance of the food as carrier integration progresses. The concept of smart packaging, in which antigen specific indicators are utilized to create nanocomposite packaged foods and films via nanoparticle inclusion, should be fully realised. Advances in food, efficiency, storage life performance, and safety will usher in a fresh tech era defined by nanotechnology engineering's applications. These breakthroughs, collectively known as big data information, enable software innovations that will progressively affect all aspects of society. Reacting to breakouts linked to foodborne illness is highly difficult because of the globalization of food supply networks. data related to the food business could help improve world food safety and security. Employees in the food industry should have greater access to these types of sources of information in the future. The WHO recently adopted a big data knowledge attitude towards food security outcome, likely to result in the formation of a new forum for food precautionary measures known as "FOSCOLLAB," which collect data from various routes and areas. (Jagtiani, 2022; *WHO | Food Safety Collaborative Platform*, n.d.)

10. Conclusion: Nanotechnology has fueled tremendous growth in the meal industry by improving food quality. Consumers benefit from nanomaterials and nanosensors because they provide data on the condition of the food inside. Food bioactives with anti-disease properties are hydrophobic in nature, with low bioavailability and stability. Nanotechnology is a new field of science, and the benefits and drawbacks of its application in the food sector are not completely understood at this time. There is a convergence of the food industries in the growing functional foods market as the relationship between food and health becomes clearer. Finally, nanotechnology allows for modifications to existing food production and processing in order to ensure product safety, promote healthy traditional food, and improve food nutritional quality.

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