Review:
Nanotechnology in Food Industry

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Research question:

Does Nanotechnology in food industries beneficial or noxious

Highlights:

- Detailed elaboration of various types of nanostructures leveraged in the food industry.
- A brief study on the preparation techniques of nanostructures.
- Critical discussion on the toxicological effect of nanostructures used in the food sector.

Summary:

Nanotechnology nearly covered every single aspect of the food industry including packing and processing of food, it affects contribution, development, and sustainability in the food sector by advanced technology. Nanotechnology uses materials and structures at the nanometer scale. The application of nanotechnology enables food preservation, increases the expiration date, and facilitates nutrition enrichment. Despite the benefits of nanotechnology, there are vital concerns regarding its usage, since the buildup of nanoparticles (NPs) in humans and the environment may result in various safety and health hazards. The toxicological basics and risk evaluation of nanomaterials should be thoroughly investigated in novel foods. A lot of work is needed to raise community awareness about the usage of nanoparticles in food and their impact on health.

Keywords: *Nanotechnology, Nanoparticles, Their impact, Food industry*

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Preface

Nanotechnology is advanced technology enabling assistance, development, and sustainable impact on medicine, agriculture, and food. Food nanotechnology is an emerging field of interest that opens up new possibilities for the food industry. Nano foods were in grown, processed, or packaged with nanotechnology to increase the self-life, preventing contamination, and production of enhanced food quality **(Nile et al., 2020)**. Nanotechnology widely uses in daily lives and is changing the entire society. Since the United States Department of Agriculture released its first road map on September 9, 2003, it has entered the agriculture and food industries **(Wani KA and Kothari R (2018)**.

Aim of review

The aim of this review is to shed light on the uses of nanotechnology in the food industry and its impact on human health.

Objectives

- Spot the significance of nanotechnology in the food industry.
- Identify some applications of Nanotechnology in the food industry.
- Recognize and evaluate the toxicological effect of nanostructures used in the food industry.

METHODS

Online data collection from MEDLINE/PubMed, Scopus and the academic search engine Google Scholar.

Elaboration of various types of nanostructures leveraged in the food industry:

Nanotechnology has several applications in the food industry, and it significantly helps in the characterization, fabrication, and manipulation of nanostructures. The nanostructures improve the solubility of food ingredients *in vivo*, along with enhancement in their bioavailability and controlled release at the target site. These nanostructures also serve as anticaking agents, nano-additives, delivery systems for nutraceuticals. (**Sahani and Sharma, 2020)**.The literature review highlighted the application of various types of nanostructures in the food industry

The use of nanotechnology in various industries has been so rapid and widespread due to its wide-ranging applications in daily lives. Nutrition and food service is altogether one amongst one of the largest industries to be influenced by nanotechnology in all areas, changing even the character of the food itself. Whether it is farming, food packaging, or the prevention of microbial within the food industries have seen dramatic changes due to nanotechnology. The inception of nanotechnology amazed the full universe with several new possible adventures in food science and technology. Gradually this became a boon to the food industry with some astonishing applications to simulate improved taste, flavor, color, texture, and the durability of food products (**Gupta et al., 2016**). Additionally to the superb absorption capacity of bioactive compounds (e.g., flavonoids and vitamins), polymeric nanoparticles are found to be suitable for the encapsulation of bioactive compounds to guard these compounds to focus on functions, thus enhancing their nutrition value **(Langer and Peppas, 2003).** Also, food antimicrobials, long-lasting food packaging materials with improved mechanical strength and anti-microbial properties, beside nano-sensors for traceability of health hazards, bio-nanosensors to test food quality during transport and storage together with encapsulation or coating of food components or additives (**Bieberstein et al., 2012; Singh et al., 2017**). Therefore, nanotechnology has given a replacement perception to the research fraternity to dive deep inside the substance at the nano level. Nanotechnology in food science **(Nile et al., 2020)** appear in (Figure 1).

Several studies investigated novel techniques for the direct application of nanotechnology within the food industry (**He and Hwang, 2016**). There are two preferential methods for nanomaterials, fabrication of nanostructures i.e. top-down, and bottom-up approaches. Nanotechnology within the food industry has developed two broad applications of nanostructures i.e. food ingredients and sensors within the food industry, nano-food ingredients cover a large utility area ranging from food processing to food packaging. In food processing; nanostructures act as anticaking agents, antimicrobial agents, Nano-additives, Nano-carriers, and Nanocomposites, while in food packaging; they potentially function as Nano-sensors to watch the food quality (**Ezhilarasi et al., 2013**).

The nanomaterials are proven to be as great enzyme-supports by their large surface-to-volume ratios as compared to the traditional macro-sized support systems. It makes the enzymes hyperactive, durable, and cost-effective. Recent Nano-carriers developed by Nano techniques have the potential to act as selective and exclusive delivery systems to move the food additives into food ingredients with no disturbance in their basic physicochemical properties and morphology. Here, particle size is the factor that affects the delivery rate of a bioactive compound to the target sites *in vivo* as only submicron NPs maybe assimilated in some cell lines efficiently or larger size micro-particles are not allowed to undergo **(Fathi et al., 2012; He and Hwang, 2016; Singh et el., 2017)**.

Preparation techniques of some nanostructures used in food industry:

- ***Preparation methods of bio-polymeric nanoparticles (NPs)***

Inceptively, biopolymer NPs were made up of albumin, non-biodegradable polyacrylamide, and poly (methyl acrylate) **(Pathakoti et al., 2017)**. Protein and polysaccharide-based NPs are prepared by several methods i.e. emulsification, desolation, and electrospray drying techniques. Chronic toxicity results from overloading of non-degradable polymers (polyacrylamide and polymethyl acrylate) NPs were realized and limitation on their use was imposed **(Pathakoti et al., 2017)**. Consequently, synthetic biodegradable polymers received tremendous attention in food processing. There are some synthetic biodegradable polymers such as polyalkylcyano acrylate; poly (lactic-co-glycolic acid) and polyanhydride are used in food processing and food sensing. Polylactic acid is one of the most common biopolymers used by manufacturers in the food industry for the encapsulation of bioactive ingredients and drug delivery **(Kumar et al., 2015)**.

1) Nanoliposomes and nanoemulsions

Complete nutrition provides several bioactive compounds to the body permanently health in an exceedingly controlled manner. Nano liposome has shown exciting opportunities within the food sector like encapsulation and controlled release of food materials, bioavailability, stability, and higher quality durability **(Karimi et al., 2019; Zarrabi et al., 2020 and Arshed et al., 2021)**. Nano liposomes are utilized in the food sector for enhancement in nutrient content and flavors. Recently, they have been explored for their capacity to assimilate antimicrobial properties against microbial contamination **(Khosravi-Darani et al., 2016**). Nano liposomes are found to be a number of the foremost promising lipid-based carriers for antioxidants. Nano liposomes provide the controlled and specific delivery of nutraceuticals, nutrients, enzymes, vitamins, antimicrobials, and additives. Liposomes are an appropriate carrier for a good sort of substances to biological, biochemical, pharmacological, and agricultural targets **(Khorasani et al. 2018; Karimi et al., 2019). Jafari and McClements (2017)** showed that the bioavailability of a nutrient is the fraction of ingested bioactive ingredient, which is absorbed and consequently used for the essential physiological functions of the body. The bioavailability of bioactive compounds like vitamins (A, D, and E), carotenoids, curcumin, conjugated linoleic acids, omega-3 fatty acids, and coenzyme Q10 reduces after oral ingestion **(Zhang and Mc-Clements, 2016)**. It happens because physiological and physiochemical factors like bioavailability, absorption, and transformation (**Figure 2**). NPs based delivery systems are applied to raise the bioavailability with suitable encapsulation of micronutrients (hydrophilic and hydrophobic) as pictorial in **Figure 3 (McClements and Xiao, 2014).** Therefore, nano-encapsulation of nutraceuticals could boost their positive effects on human health, thus reducing their side effects. In order to be applied in food and nutraceutical fields, food-grade material for the fabrication of nanoparticles must be used **(Wei et al., 2020)**. Among the food-grade material is used zein, a maize protein **(Yuan et al., 2020),** chitosan **(Xiong et al., 2020),** and gelatin **(Feng et al., 2020),** which were mainly used recently for the encapsulation of nutraceuticals (**Figure 4).**

Nanoemulsion may be a high-energy or non-equilibrium system, which is generated by supplying external energy driving forces as its formation, disturbs the equilibrium from a stable energy level. Nanoemulsions are formulated by either high-energy or low-energy techniques. The operating thermodynamic conditions in both techniques critically affect the particle size and composition of the resulting Nanoemulsion (**Pisoschi et al. 2018**). In high-energy techniques for Nanoemulsion formation, energy-supplying devices apply the energized disruptive forces and permit extensive mixing with the simultaneous addition of a surfactant (5–10%). This results in the formation of small droplets with a particular size of nano-emulsions (**Pisoschi et al. 2018**). While in low energy approaches, the formation of little oil droplets in diphasic systems depends on environmental temperature and composition affecting the dimensions of the formed drops in Nanoemulsions (Figure 5).

2) *Nanocomposites and inorganic nanoparticles*

Sharma et al., (2017) reported that the Nanocomposite substances have evinced themselves as possible alternatives in food packaging due to their working and cost. **Bratovcic et al., (2015)** said the Nanocomposites are polymer matrices incorporated by inorganic or organic Nanofillers with geometries (fibers, flakes, spheres, whiskers, sheets) having any of their three dimensions in the Nano range. There are several Nanofillers explored so far i.e. clays, metal oxides, carbon nanotubes, and cellulose fibrils of the Nano dimension **(Sharma et al., 2017).** Especially inorganic NPs are noticed as impeccable Nanofillers for nanocomposite formation. Besides, Inorganic NPs have tremendous utility, especially in the catalytic application of organic synthesis. Inorganic NPs are also found as an efficient adsorbent in a variety of applications of the food industry **(dos Santos et al., 2020).** Various metals and metal oxide-based NPs have been utilized either in the coating or in the packaging of food materials (Figure 6).

The active mineral either directly interacts with food contents or performs the function of antimicrobial activity. The possible phenomenon happening in antimicrobial action might be direct contact with the microbial cell body, break cell envelope and electron transfer; oxidizing cell components, formation of secondary reaction species, which in the end destroy the microbial cell. Sundry synthetic polymers with natural polymers have been used within food packaging for decades. The filler material acquires a higher surface area, and their reinforcing properties.

Critical discussion on toxicological effect of nanostructures used in food sector:

Nanomaterials have unique properties like high surface area, which make them more chemically active than bulk material in order that they could participate in most biological reactions that will have a harmful effect on human health or the environment. Nanostructures in nutrition or related industries must not create any direct or indirect damage to human health. Some features of nanoparticles are more important in unintentional side effects observed (Figure 7). Food and related industries like agriculture, packaging, and food processing have seen huge changes due to the unique properties of nanomaterials. Nevertheless, these unique properties may occasionally cause ambiguous and sometimes dangerous side effects to ecosystems and even in people.

The main role of nanotoxicology is to produce clear guidelines and roadmaps for reducing risks within the optimal use of nanomaterials. Exposures routes in industrial workers and consumers of food products that contain nanomaterials must be studied carefully. A particular understanding of the properties of nanomaterials like size, dose, surface chemistry, and structures, will enable us to induce safe food products. These novel chemical and physical properties have an impact on different ways through interaction with biological components, their uptake, accumulation, and clearance through the body, and interaction with the environment at large. These factors govern the toxicity of nanoparticles shown in Figure 7.

In the food industry, tested nanomaterials comprise organic (natural product nanoparticles), inorganic (metal and metal oxide nanoparticles), and both organic and inorganic as an example clay. Amongst all-metal nanoparticles, the gold nanoparticle is usually considered as a detector /sensor whereas silver nanoparticle due to their anti-microbial action utilized mostly for commercial purpose. For flavor enhancing, disinfecting and food additives, titanium dioxide nanoparticles are widely applied. Natural product nanoparticles are used as constituents or enhancements within the food industry **(Yogita et al., 2021; Monalisa et al., 2021).**

Various NPs have revealed great possibility and capability in every single phase of the food industry and agriculture. Within several facets of commodity, food nanotechnology has penetrated as an example food conservation, packing, and supplements or additives. In safeguarding food safety, nanotechnology has progressed the food treatment and storing processes **(Monalisaet al., 2021)**. On a nanometer scale, various chemicals supplemented as food additives or packing ingredients are found to partially exist. As an example, within the nanometer range, food-grade TiO_2NPs are found up to roughly 40% **(Dudefoi et al., 2017).** Although TiO2 NPs are usually acknowledged as lesser toxic at ambient conditions, long-term contact with such NPs may cause unfavorable effects **(Dorier et al., 2017; Mateja et al., 2021).**

The major bases for regulation and legislation on food nanotechnology are the US Food and Drug Administration (U.S. FDA) and European Commission (EC) supported risk evaluation of the particle size of a substance, EC and US FDA make some authorizations. Under research and development (R&D), some applications also are comprised to designate possible future applications.

Toxicological fundamentals and risk evaluation:

Despite the enormous advantages of NPs within the food sector, there is immense concern associated with their toxicity and noxious effect on the environment. The prime aspects associated with the behavior, fate, **Klaine et al, (2008),** described biological accessibility, disposal, and harmfulness of NPs to the environment**.** NPs are purposefully supplemented as food additives, or coincidentally introduced through migration in various food products according to **Hannon et al., (2016).** Upfront exposure of buyers to NPs utilized in the food sector jeopardizes the health of humans (Figure 8). Exposure is restricted until the NPs' remaining food packing. Nevertheless, there are high risks related to the passage of NPs to humans by ingestion of food. **Teow et al, (2011),** stated the impact of NPs on the health of humans and safety associated with the usage of NPs they described the entries of NPs, their distribution, and absorption in human bodies, emphasizing the cytotoxicity and genotoxicity. **Stark, (2011)** discussed the mode of action, behavior, and functioning of NPs in living systems, to develop safe nanotechnology.

The toxic effect of NPs on human organs relies on their physicochemical features like biological distribution and availability, concentration in food products, and quantity of food ingested **(Wani and Kothari, 2018**). NPs like asbestos could activate immunologic response or settle down within the brain **(Scrinis, 2008).** The reactivity of nanoparticles and the multiple entry routes aggravate the matter (Figure 8). These particles can move great distances facilitated by Brownian movement and are likely to urge deposited into air sacs **(Chidambaram and Krishnasamy 2012).** Nanoparticle toxicity has approaches kind of like conventional toxicity analysis. Most of the studies have suggested oxidative stress as a parameter for nanotoxicity analysis **(Donaldson et al., 2006).**

Toxic assessment of metal NPs was studied by **Schrand et al., (2010),** they stated that as NP size reduces, its toxic level is enhanced. Small NPs having high reactivity and therefore the capability to traverse membranes and capillaries could compile within the central system nervous **(Borm and Kreyling, 2004).**

Interaction of NPs with enzymes and proteins could trigger oxidative stress and production of Reactive oxygen species (ROS) inducing damage to mitochondria and cells, resulting in death. Over a generation of ROS could damage neurons, acute DNA damage, autophagy carcinogenesis, and age-related illnesses in groups of people **(Khan et al., 2012).**

TiO_2 NPs could trigger tumor-like alterations in cells of human beings **(Botelho et al., 2014)** and anti-caking silica NPs might be cytotoxic in lung cells (**Athinarayanan et al., 2014)**. Silver NPs affect fibroblast in human lungs by enhancing ROS, reducing ATP level, inducing chromosomal anomalies, and damaging mitochondria and DNA **(Kim et al., 2007).** Carbon

Nanotubes, generally utilized in food packing have toxic effects on human lungs and skin **(Mills and Hazafy, 2009)**. Accumulation of TiO_2 NPs in human bodies by eating chewing gums containing TiO2 NPs was reported by **Jovanovic (2015).** Similarly, **Athinarayanan (2014)** reported the buildup of SiO_2 NPs in gut epithelia after eating food-having E551. Various Metal NPs like Cu O, Ag, and Zn O could have harmful effects on food stimulants by increasing intracellular ROS triggering peroxidation in lipids, and damaging DNA (**Fukui et al., 2012; Karlsson et al., 2013; McShan et al., 2014).**

Furthermore, there is less toxicological research on NPs utilized in edible coatings and food packing. Hence, **Siddiqui, (2021)** showed that the danger assessment research to identify the harmful and noxious effects of NPs on human health must be crucially investigated (Figure 9).

CONCLUSION

There is no doubt that the utilization of nanotechnology within the food industry is developing at an incredible speed and carries many benefits to the buyer. It also, unfortunately, carries some health hazards. However, there are limited documented studies on the potential toxicity of Nanoparticles on human health. Hence, risk assessment research to identify the harmful and noxious effects of NPs on health must be crucially investigated. To assist to develop standardized protocols for regulating issues of safety and risk assessment for the usage of NPs within the food sector to confirm products safety, create a healthy food culture, and enhance the nutritional quality of food.

RECOMMENDATION

- *In vitro* and *in vivo* analyses are required to standardize protocols for regulating safety issues and risk assessment related to the usage of NPs in the food sector.
- Increase community awareness including health sectors about usages of nanoparticles in the food

industry and their impact on health.

Declaration of Competing Interest

This article was introduced to the Egypt Board of Clinical Nutrition for completing a clinical Nutrition fellowship. The authors and supervisors declare that they have no competing financial interests or personal relationships that could influence this review.

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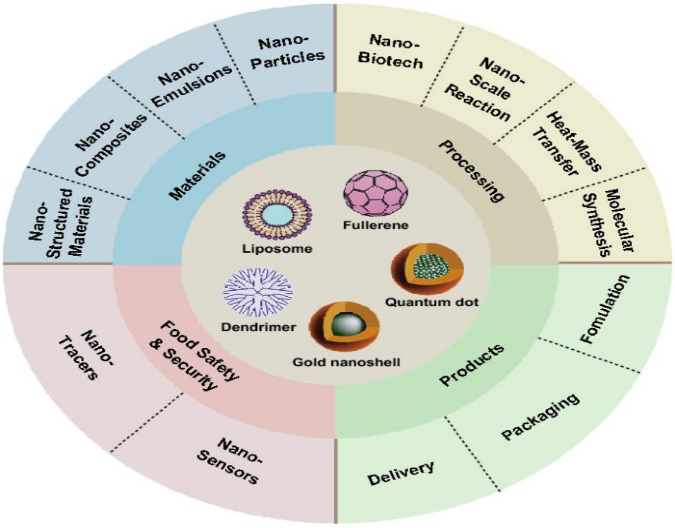

Figure 1: Nanotechnology in food science **(Nile et al., 2020)**

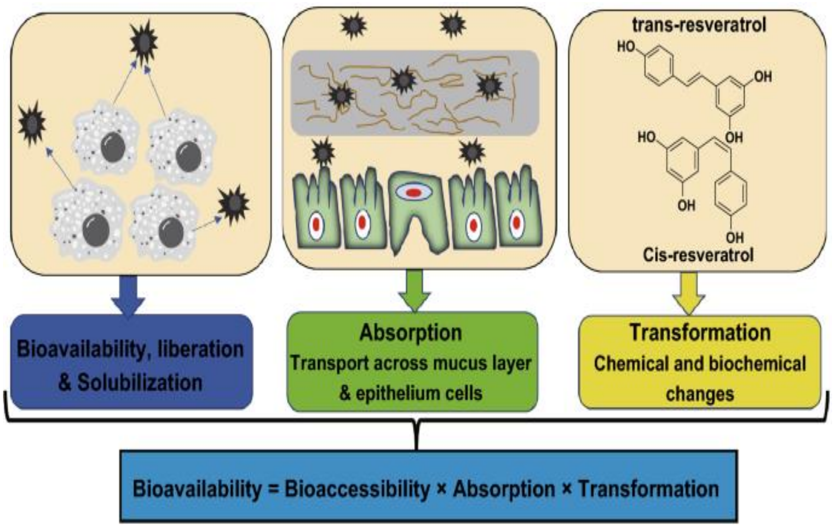

Figure 2: Mechanism of micronutrient bioavailability in the human body **(Arshad et al., 2021)**

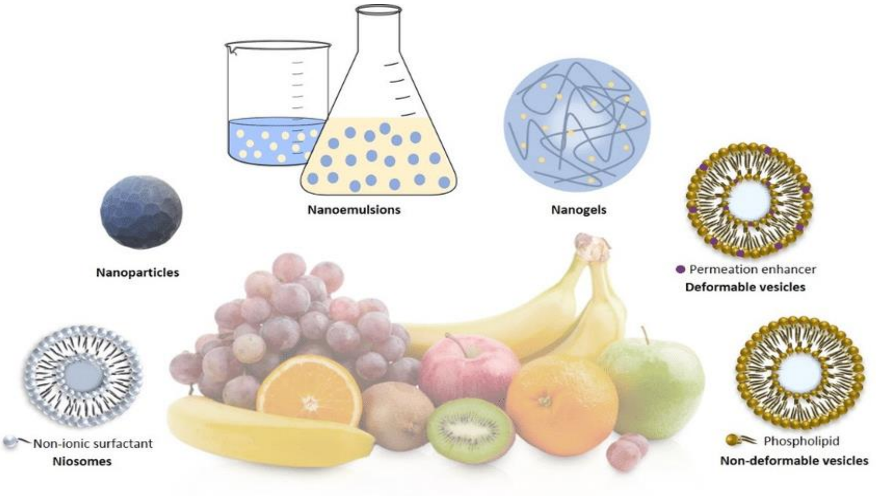

Figure 3: Examples of Different nanobased delivery systems to improve the bioavailability of encapsulated micronutrients **(Arshad et al., 2021)**

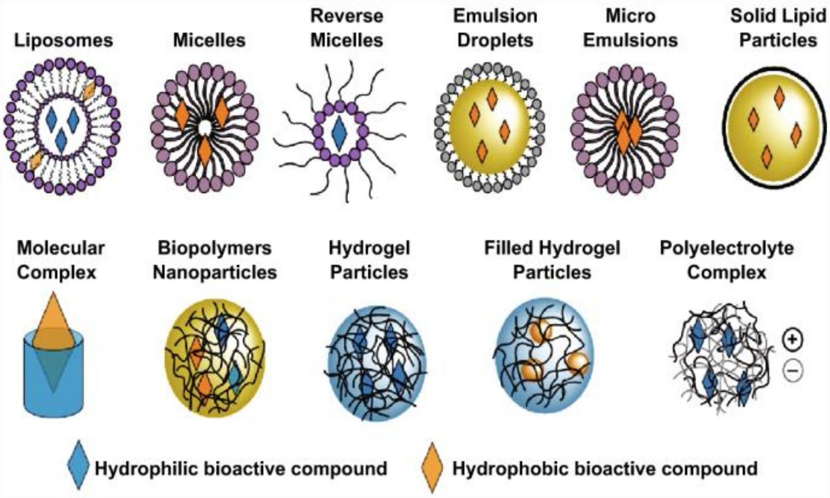

Figure 4. In this picture, some nanocarriers used for the delivery of nutraceuticals are represented (**Paolino et al., 2021**)

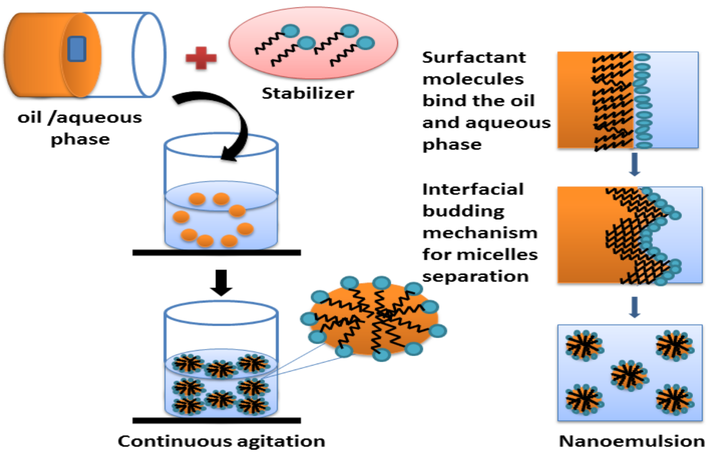

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Figure 5: Schematic diagram of nanoemulsions synthesis

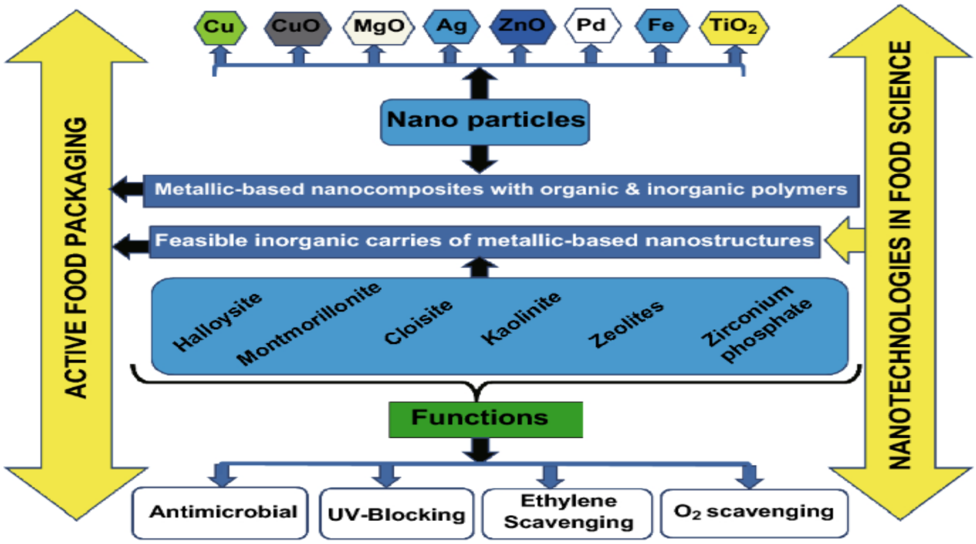

Figure 6: Potential for the development of metallic-based nanocomposites in active food packaging (**Hossain et al., 2021**)

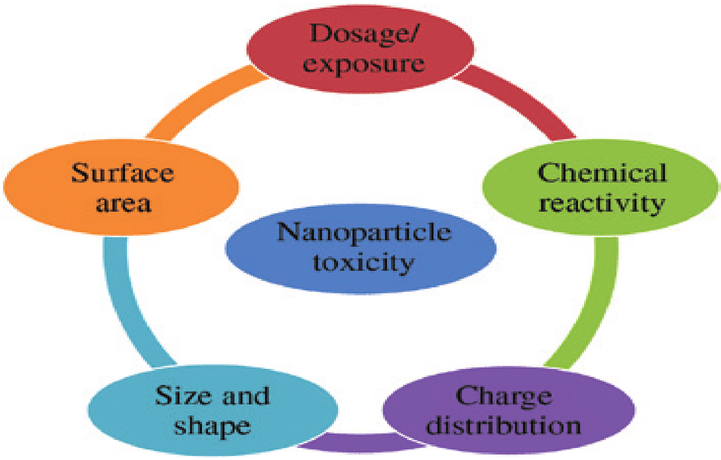

Figure 7: Different factors that may affect the overall toxicity of a nanoparticle **(Naseer et al., 2018)**.

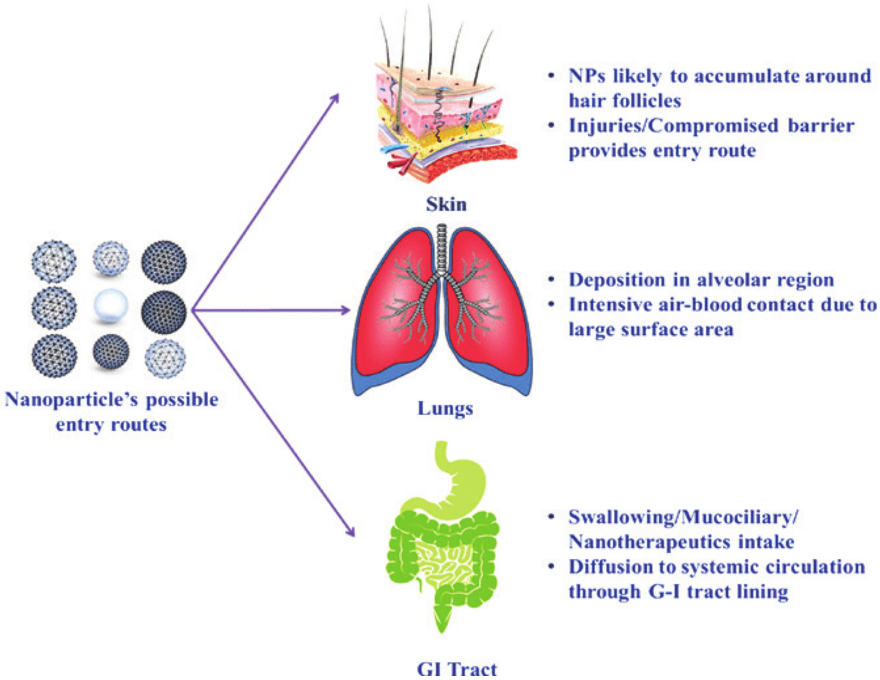

Figure 8: Possible routes of entry of a nanoparticle into the body **(Naseer et al., 2018).**

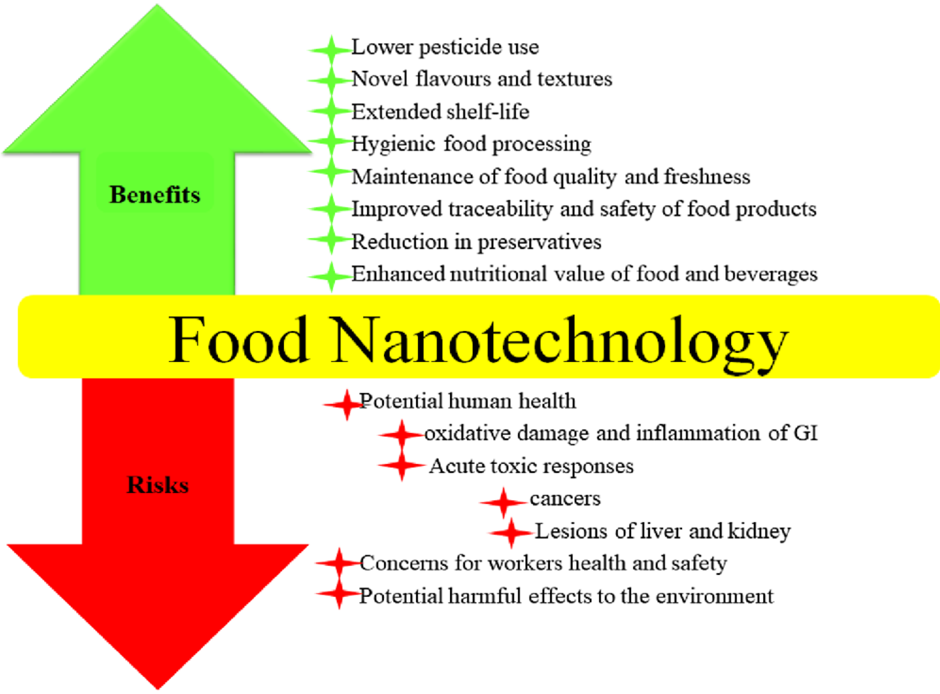

Figure 9 From: Nanotechnology: current uses and future applications in the food industry (**Thiruvengadam et al., 2018)**

Review: Nanotechnology in Food Industry

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تقنية النانو في صناعة الاغذية

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الملخص العربي

شملت تقنية النانو تقريبًا كل جوانب صناعة الأغذية بما في ذلك تعبئة الأغذية ومعالجتها ، كما أنها تؤثر على المساهمة والتنمية والاستدامة في قطاع الأغذية من خلال التكنولوجيا المتقدمة. تستخدم تقنية النانو مواد وهياكل بمقياس نانومتر. يتيح تطبيق تقنية النانو حفظ الطعام ، ويزيد من تاريخ انتهاء الصلاحية ، ويسهل إثراء التغذية. على الرغم من فوائد تقنية النانو ، إلا أن هناك مخاوف حيوية بشأن استخدامها ؛ نظرًا لأن تراكم الجسيمات النانوية (NPs) في البشر والبيئة قد يؤدي إلى العديد من مخاطر السلامة والصحة. يجب فحص أساسيات السموم وتقييم مخاطر المواد النانوية بدقة في الأطعمة الجديدة. هناك حاجة إلى الكثير من العمل لزيادة وعي المجتمع حول استخدام الجسيمات النانوية في الغذاء وتأثيرها على الصحة.

الكلمات المفتاحية: تقنية النانو، جسيمات النانو ، صناعة اغذية ، تأثيرها