A comprehensive review on Application of Nanotechnology in Food Industries

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Abstract.

Nanotechnology emerges as a ground breaking technology with applications across various industries like food, medicine, and agriculture. In the realm of food industry advancements, nanotechnology plays a pivotal role. Its utilization in food processing enhances the quality of food by amplifying taste, flavour, and bioavailability. Moreover, it contributes to prolonging the shelf life of products. Within the domain of food safety, nanotechnology bolsters barrier properties significantly, aiding in the identification of infections and toxins in food items. Additionally, it is instrumental in crafting intelligent packaging solutions while performing antibacterial functions in food packaging. Despite its myriad benefits, there exists a potential risk associated with nanoparticle exposure to human health. Thus, establishing a robust regulatory framework is crucial to mitigate any adverse effects linked to nanotechnology applications. This comprehensive evaluation focuses on categorizations, safety considerations, and the role of nanotechnology in ensuring food safety and packaging integrity.

Key Words: Nanotechnology, Manufacturing, Processing, Packaging,

Introduction.

Nanotechnology is an interdisciplinary field encompassing biology, chemistry, mechanical engineering, and electronics. Its aim is to comprehend, manipulate, and design devices with extraordinary properties at the atomic, molecular, and supramolecular levels (Bumbudsanpharoke, 2015). Structures and materials within the nanoscale range of 1-100 nm are crafted, analysed, manufactured, and controlled in this area of technology (Chaudhry, Castle, & Watkins, 2017). When particles shrink below this threshold, their physicochemical properties are drastically varied from those of larger-scale materials with the same composition (Chaudhry & Castle, 2017). Nanoparticles are deemed to possess distinctive characteristics that lead to a novel level of performance as individual entities (Bhattacharyya, A., & Debnath, K. 2020). Due to their increased surface area and mass transfer rates, nanoparticles display enhanced chemical and biological activity, catalytic behaviour, permeability, enzymatic activation, and quantum properties compared to larger particles (Qureshi, A. 2017). Nanomaterials are categorized based on their configuration, size, and properties (Khare & Kukkar, 2019). The advantageous physical and chemical properties of nanoparticles include solubility, bioavailability, diffusion capability, optical properties, colour variations, mechanical strength, magnetic properties along with thermodynamic features (Gupta, R., &

Xie, H. 2018).Nanotechnology has introduced alternative techniques to food processing in terms of both improving physicochemical qualities and increasing nutrient stability and bioavailability (He & Hwang, 2016). Because of their remarkable mesoscopic properties—such as their greater surface area, high reactivity, small particle size, high strength, quantum effects, and ductility—nanoparticles are employed in many different industries (Chaudhry et al., 2016). An efficient method is to use Nano-antimicrobial agents directly applied to food or through antimicrobial packaging (Singh, P., & Bhushan, B. 2017). The food system will be impacted at every stage, from food production to processing, packaging, transportation, storage, security, safety, and quality, as a result of the predicted rise in the application of nanotechnology by the food and food-related industries (Gupta & Xie, 2018).

Food Additives for Taste, Texture, and Colour.

The food industry is starting to use nanotechnology to create ingredients at the nanoscale to enhance food's flavor, texture, and colour (Singh, P., & Bhushan, B. 2017). Food additives include amorphous silica, TiO_2, and SiO_2 nanoparticles (McClements, D. J. 2016). The powdered sugar coating on doughnuts contains TiO_2 as a colouring agent (Chen & Yada, 2015).

Food Processing and Packaging

The incorporation of nanomaterials into food packaging provides numerous benefits (Unagwu, B., & Ude, C. 2018). These include enhanced mechanical barriers, the ability to detect microbial contamination, and potentially even improved nutrient absorption (Kumar, R., Munstedt, H., & Silver, S. 2017). This application of nanotechnology is widely employed in the food and related industries (Brody et al., 2018). Within the food sector, a variety of nanocomposites are used. These involve polymers with embedded nanoparticles for materials that interact with food, as well as for packaging purposes (Maurya & Bhattacharya, 2015). ZnO and MgO nanoparticles have been identified for use in food packaging (Khare, et al., 2019). Food containers often contain amorphous silica (Zhang et al., 2017).Engineered water nanostructures in aerosol form have proven effective in eliminating harmful bacteria such as Salmonella, Listeria, and Escherichia coli from steel food preparation surfaces (Wang & Xiao, 2017). However, it is essential to ensure regulatory compliance due to the potential migration of these nanomaterials from packaging into the food itself for widespread adoption in the industry (Peters et al., 2016).

Food-related Nano sensors

Nanomaterials play a crucial role as sensors in monitoring the food environment and detecting contaminants (Singh & Bhushan, 2017). They have the ability to spot various food pollutants and microorganisms, making them valuable tools in both and food production facilities (McClements, D. J., 2016). These nanomaterials can oversee the transportation and storage of food products effectively (Bhattacharyya & Debnath, 2020).Moreover, they can also pinpoint edible plants that lack essential nutrients, allowing for timely supplementation when needed (Bumbudsanpharoke & Ko, 2015). The food industry stands to benefit significantly from leveraging the vast capabilities of nanomaterials as Nano sensors and tracers (Kumar, et al., 2017).

Packaging made of edible thin films

Preservation of food stability and prevention of microbial contamination when storing are major concerns (McClements, et al., 2016). Over time, food composition changes due to environmental factors and processing methods affecting proteins, carbs, lipids, and fat content (Lethuaut, et, al., 2018). The degradation of food can be delayed by utilizing edible packaging or thin films to extend shelf life and enhance quality (Peters, et al., 2016). Bioplastics used in edible packaging thin films consist of blends like carrageenan, starch, sodium caseinate, chitosan, polylactic acid, gelatine, alginate, and polyglycolic acid (Huang & Wang, 2017). These components serve as active packaging materials boosting barrier protection against damaging gases such as ethylene and oxygen (Unagwu, et al., 2018). They safeguard meats, vegetables, chocolate, fruit, candies, and some baked goods while maintaining product appearance intact (Kumar, et al., 2017).

Non – Edible Packaging

Nanotechnology plays a crucial role in reducing environmental pollution through the development of biodegradable packaging (Rehman, et al., 2018). The mechanical and barrier properties of biodegradable materials are initially inadequate but can be significantly enhanced (Qureshi, A. 2017). By incorporating nanostructures like layered silicates, the mechanical strength of biodegradable materials can be improved, making them suitable for packaging applications (Unagwu, B., & Ude, C. 2018). A recent review highlighted the unique characteristics of Nano-bio composite films that enhance gas, vapour, and UV resistance, as well as preserve active ingredients in food bio packaging (Sekhon, 2016). One prominent company has introduced a "hybrid system" packaging film called Durethan KU2-2601, which is infused with numerous silicate nanoparticles (Chaudhry, Castle, & Watkins, 2017). These nanoparticles effectively prevent food spoilage by limiting the ingress of oxygen, carbon dioxide, and other gases while allowing for moisture removal (Khare & Kukkar, 2019). Another innovative nanostructure used in packaging is silicate layers, which when incorporated into a polymer matrix, enhance the material's barrier properties and enable controlled diffusion rates (Unagwu & Ude, 2018). A composite material consisting of Gelidium corneum and gelatin with attached nano clay exhibited excellent antibacterial properties in a study involving chicken breast packaging (Wang & Li, 2016). The thymol-containing composite film effectively inhibits microbial growth during storage, ensuring food safety and quality (Chaudhry et al., 2017).

Related Health Concerns, Security Concerns, and Regulatory Aspects

Poor packing performance can lead to health risks when consuming food in contact with nano packaging (Bhattacharyya, et al., 2020). The food might absorb particle nanomaterials from the packaging, depending on factors like ingestion rate, migration degree, packaging matrix type, and nanomaterial toxicity (Gupta, R., & Xie, H. 2018). Inhaling nanoparticles poses health risks, with overconsumption bioaccumulation, and increased activity of nanotechnology-based products affecting safety and health (Peters, et al., 2016). High concentrations of these substances through inhalation or skin absorption could lead to serious safety issues requiring thorough risk assessment for long-term toxicity (Gupta & Xie, 2018). Research suggests that food packed with silver nanoparticles may migrate into food consumed by humans (Chaudhry, Castle, & Watkins, 2017). Nanotechnology application has drawn attention from policymakers, ethical consumers, regulatory bodies, and other stakeholders (Singh, P. et al., 2018). The complexity of Nano, bio, and ecology interactions makes it challenging to trace and monitor nanoscale material characteristics (Bumbudsanpharoke & Ko, 2015). Developing regulations without sufficient scientific research and case studies is difficult due to variations in nanomaterial behaviour in different products and processing conditions (Zhang, et al., 2017).

Difficulties and Technical Limitations.

There exist many challenges in the path of nanotechnology's ability to develop innovative food-related products and processes (He & Hwang, 2016). The main issue is creating edible delivery systems with efficient formulation for human consumption while ensuring safety and utilizing cost-effective processing methods (Zhang, et al., 2018). A major concern is the migration and leaching of nanoparticles from packaging materials into food products to maintain food safety (Chaudhry, 2016).Sometimes nanoparticles from other sources are unintentionally introduced, either directly or indirectly (Chaudhry & Castle, 2016). At the nanoscale materials behave differently, and our understanding of their analysis is still limited (Akter, et al., 2018). A comprehensive understanding of the toxicities and nanoscale functions of nanoparticles will improve safety standards and practical applications (Ray, et al., 2011).It is essential to investigate the impacts of nanoparticles, potential risks, toxicological issues, and environmental challenges (Zhang, et al., 2016). There have been reports of nanoparticles penetrating cells and organs by overcoming biological barriers. Chemical processes used to synthesize nanoparticles can also have adverse effects, producing harmful by products that pollute the environment significantly.Therefore, when processing, packaging, and consuming food products based on nanotechnology, factors such as public demand, regulatory policies, biosafety, risk assessment programs need consideration.(Kamran et al., 2023). Additionally, before commercial use and developing environmentally friendly antibacterial nanoparticles, research involving interactions of nanoparticles with biological organisms both in vitro and in vivo is crucial.

Prospects for the Future and the Possibility of Commercialization

Nanotechnology plays a crucial role in enhancing food science and research. By aiding in tracking, tracing, and monitoring, nanotechnology contributes to ensuring food quality preservation and detecting poisons, diseases, and pesticides. Cost analysis, labour availability, and equipment acquisition do not pose obstacles to the application of nanotechnology.
Various Nano systems are still in their early of development as potent nanocomponents. The future holds promising prospects for the creation and preparation of functional foods using nanotechnology. Effective regulations and laws tailored to address safety concerns are essential for nanotechnology to dominate the food processing industry.Forecasts suggest that by 2050, nanotechnology will emerge as a cutting-edge technology with exponential growth potential. Its ability to find collaborative solutions at both micro and macro levels is set to revolutionize industrial and societal challenges.

Conclusion

Nanotechnology in the food industry provides numerous benefits that enhance food quality, safety, and shelf life. It marks a significant advancement in food processing, safety, and packaging. By improving the taste, texture, and availability of food additives, this innovative technology offers creative options. For instance, nanoparticles like titanium dioxide and amorphous silica are already enhancing the flavour, colour, and texture of food products. The use of nanotechnology has revolutionized food packaging by creating stronger materials that enhance food safety and prolong product shelf life. Nanocom containing nanoparticles such as ZnO and MgO improve the mechanical and barrier properties of packaging materials. These advancements help maintain food quality during storage and transportation while protecting it from microbial contamination.Intelligent packaging equipped with Nano sensors plays a crucial role in ensuring food safety throughout the supply chain by detecting microbial contamination and environmental changes. Edible thin films and biodegradable packaging are two significant innovations driven by nanotechnology. Edible films made from bioplastics like chitosan, starch, and polylactic acid extend the shelf life of food products by serving as active packaging that preserves chemical-physical stability and hinders microbial growth. Non-edible biodegradable packaging materials benefit from the addition of nanostructures like layered silicates to enhance mechanical strength and barrier properties significantly.Despite these advantages, there are concerns about using nanotechnology in the food industry. The possibility of nanoparticles migrating from packaging into food raises health and safety issues due to their potential accumulation in organs when consumed or inhaled. Therefore, thorough risk assessments and strict regulations are necessary to address these challenges. Extensive research is still required to understand the long-term effects of nanoparticles on human health as well as their toxicity. One major challenge facing nanotechnology in the culinary field is the technical limitations in producing affordable edible delivery devices that are both effective and safe. Additionally, understanding how nanoparticles interact with each other requires further study for safe utilization of these particles. Addressing environmental impacts from nanoparticle synthesis is crucial for eco-friendly applications, especially concerning toxic byproducts from chemical processes.The future outlook for nanotechnology in the food industry appears promising with continuous breakthroughs expected to enhance food quality, safety, and functionality. Successful commercialization of nanotechnology-based food products hinges on robust regulatory frameworks and safety standards to mitigate potential risks. Integrating nanotechnology into food science is set to drive innovation towards creating functional foods that meet consumer demands for sustainability, quality, and safety.In conclusion, while nanotechnology offers unparalleled opportunities for the food sector, it is crucial to address health, safety, and environmental concerns through stringent regulations, ethical practices, and extensive research. Achieving a balance between safety measures and innovative solutions is essential for harnessing the benefits of this cutting-edge technology without compromising public health or environmental integrity in our food systems.

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