Nanotechnology and Food Microbiology

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Abstract

Nanotechnology has emerged as a safer and more effective alternative to conventional food microbiology techniques used to assess pathogens or enhance shelf life of foods. Nanoparticles of silver, zinc oxide, and titanium are already being used as effective antimicrobial agents and are being incorporated in various food-related equipment and packaging materials. Nanoparticles can also be used in combination with polymers leading to formation of nanocomposites. These nanocomposites have enhanced antimicrobial properties and, when embedded in packaging material, provide better shelf life. Nanoemulsions formed from essential oils offer controlled release of these oils. This leads to prolonged antimicrobial activity from the oils without the risk of overpowering aroma or thermal destruction. Nanosensors offer a faster way to detect pathogens with minimum amount of sample. However, despite their manifold advantages, nanostructures are yet to be fully understood in terms of their biological safety. Many food safety agencies across the world are still in process in developing protocols to ensure better and safer use of nanotechnology-based products.

Keywords

Nanotechnology · Nanosensors · Nanoparticles · Nanocomposites · Nanoemulsions · Food safety

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7.1 An Overview of Nanotechnology

With his classic talk "There Is Plenty of Room at the Bottom," Richard Feynman envisioned the development of nanostructures with *atom-by-atom* design (Feynman 1960). The transformation of nanotechnology into a separate branch of science has been a rapid one and has led to its applications in all the major disciplines of science. According to the National Nanotechnology Initiative (Arlington, VA, USA), nanotechnology is defined as "the understanding and control of matter at dimensions of roughly 1-100 nm, where unique phenomena enable novel applications." In the nanodimensions (10^{-9} m), matter acquires some unique properties compared to the bulk counterparts due to increased surface area-to-volume ratio. The physical, optical, magnetic, thermodynamic properties of nano-materials show significant variations compared to bulk materials (Rai et al. 2009). Manufacturing of nanomaterials is accomplished by two approaches: "the top-down" approach and "the bottom-up" approach. The top-down approach involves breaking down of bulk material into nanodimensions through techniques like nano-lithography, milling, and precision engineering. The bottom-up approach deals with synthesis of nanomaterials from atoms or molecules, accumulated using crystallization, self-assembly, or microbial synthesis (Iqbal et al. 2012). Nanostructures can vary in their composition (monometallic, bimetallic, composite, hybrid, magnetic, metal oxides, semiconductors, etc.) and shapes and sizes (nanoparticles, nano-rods, nano-wires, nanofibers, nanotubes, nanofluids, nanocapsules, quantum dots, nanosheets, nanoribbons, etc.) (Nasrollahzadeh et al. 2019). These nanostructures have found remarkable applications in food industry, medicine, defense, electronics, textiles, agriculture, and cosmetics (Ozimek et al. 2010).

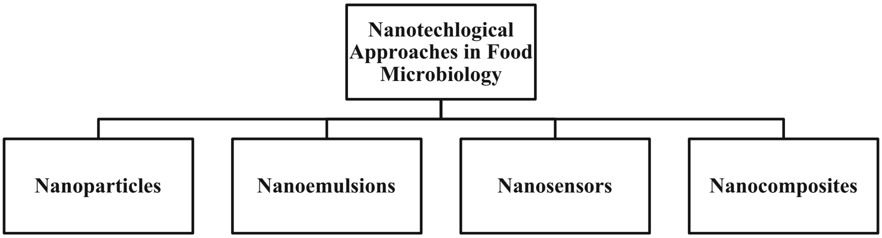
7.2 Role of Nanotechnology in Food Microbiology

As consumers are becoming more and more aware of food safety, focus of research and development in food sector has shifted toward advanced techniques for food preservation and quality enhancement.

The aim is to have safe, pathogen-free, and high-quality food products with zero defects. Traditional microbiological approaches are time and labor intensive. Therefore, many large food companies like Nestlé, Unilever, and Kraft have already started experimenting with the use of nanotechnology to prepare foods with enhanced quality and safety levels (Ozimek et al. 2010).

7.3 Use of Nanoparticles as Antimicrobial Agents

Nanoparticles can act as potent antibacterial agents and reduce the spoilage of food products. Silver nanoparticles are most commonly used in food products as antimicrobials. One of the major issues encountered by food microbiologists is development of biofilms. Microbial biofilms are impenetrable to most antimicrobial agents. Nano-silver can easily penetrate biofilms and is readily ionized into chemically active form (Zarei et al. 2014). Silver is a stable metal, and within FDA-recommended limit, it can be safely incorporated into packaging materials without posing any health risks. Silver nanoparticles have higher bactericidal effects toward Gram-negative bacteria than Gram-positive ones due to the thinner cell wall of the former. The mechanism of action of silver involves the disruption of ribosomal activity, thereby inhibiting the production of many important microbial proteins and enzymes. Other than silver, titanium dioxide, zinc dioxide, and chitosan nanoparticles can be used as antimicrobial agents in foods. Zinc oxide nanoparticles can be incorporated in polymeric matrices for preparation of antimicrobial packaging materials (Xie et al. 2011). ZnO nanoparticles have been identified as GRAS (generally recognized as safe) material by FDA. Titanium dioxide nanoparticles show photocatalytic activity and are only bactericidal under UV irradiation (Weir et al. 2012). Another way of using nanoparticles as antimicrobials is by loading them with antimicrobial agents. For example, pectin nanoparticles loaded with natural broad-spectrum antimicrobial agent, nisin, can be used as food additives to enhance microbiological safety of the foods (Krivorotova et al. 2016). Cadmium, telluride, selenium, copper, and copper oxide nanoparticles and carbon nanotubes have also shown antimicrobial activity.



7.4 Polymer-Based Nanocomposites for Barrier Applications

Nanocomposites are formed by a combination of polymers and nanoparticles. Nanocomposite formation enhances the activity of the polymer used. Nanocomposites are used in packaging materials (Llorens et al. 2012). They prevent the microbial infestation of food and do so in a controlled rate over a prolonged duration of time (De Azeredo 2009). Nano-laminates made up of polymers and nano-metals are used to coat meats, fruits, and vegetables and prevent microbial infestations. Nanoforms of zinc oxide, magnesium oxide, and silver have been successfully used in antimicrobial coatings made up of nanocomposites (Garcia et al. 2018). Bio-based nanocomposites offer a biodegradable and environmentally efficient way of food packaging. These are commonly made up of starch and cellulose derivatives (Rhim et al. 2013).

7.5 Nanoemulsions

Emulsions are created by dispersing two immiscible phases. Based on their physical and structural properties, emulsions can be microemulsions or nanoemulsions. While microemulsions are thermodynamically stable, nanoemulsions are only kinetically stable. Microemulsions are transparent, while nanoemulsions are opaque. Functional efficacy of nanoemulsions is increased owing to their decreased particle size. Due to their higher stability, hydrophobic active agents can be dispersed reliably through them (Salvia-Trujillo et al. 2014).

Nanoemulsions can be made through two kinds of techniques: high-energy and low-energy techniques. High-energy techniques are used when energy acts as a disruptive agent to create smaller particle size. These involve techniques such as high-pressure homogenization, microfluidization, and sonication. Low-energy approaches involve techniques such as spontaneous emulsification, emulsion inversion point, phase inversion composition, and phase inversion temperature (PIT). Nanoemulsions made up of essential oils have been used as antimicrobials to control foodborne pathogens like *Listeria monocytogenes*, *Salmonella typhi*, and *Escherichia coli* O157:H7 (Amaral and Bhargava 2015). A soybean oil-based nanoemulsion has recently been of interest due to its antagonistic properties against Gram-positive pathogens and enveloped viruses. It has also been found to be fungistatic.

7.6 Nanosensors

Nanosensors are nanoscale-based sensors that characterize chemical, mechanical, and optical properties of nanoparticles. These nanosensors are being developed with numerous food-based applications. In agri-food sector, it is used as gas sensors for detecting variation in temperature, pressure, and other processing parameters in food samples (Joyner and Kumar 2015). It can also be used for detecting foodborne pathogens, dangerous microorganisms, toxins, contaminants, and chemicals present in foods. These nanosensors have potential advantages over conventional sensors in terms of enhanced sensitivity, specificity, increased speed analysis, low cost, increased number of sample analysis, and less complexity in sample assay. These sensors require a very small amount of analyte in order to get a response that is largely due to small sensing surface area (Driskell and Tripp 2009). The small sensing surface areas lead to fabricate higher-density arrays. Therefore, it analyzes a maximum number of analytes (toxins, contaminants) which also reduces the complexity and cost by reducing the sample processing steps. Nanosensors are classified on the basis of external and internal food conditions. For external conditions of the food products, these sensors are able to detect atmospheric effect, while in internal conditions, these are able to detect certain foodborne pathogens and chemicals (Ramachandraiah et al. 2015). The crucial application of nanosensors is to reduce the pathogen detection time from days to minutes (Bhattacharya et al. 2007). These sensors would also act as “electronic tongue” or “noses” in the packaging material by detecting chemicals during food spoilage (García et al. 2006). On the basis of microfluidic devices, these are having potential applications in detecting food pathogens in less time with high sensitivity (Baeumner 2004). The nanosensor research has led to the development of scientific advancements in the field of nanotechnology that forms new generation nanomachines.

7.7 Risks Related to Use of Nano-products

Nanostructures can cross the cellular barriers and lead to complications at the molecular level. Some nanoparticles can attach to cellular receptors in cells of immune system and lead to their disruptions, cause degradation of cellular proteins, or increase oxidative stress in cells. They can also cause genotoxic and cytotoxic effects by disrupting the DNA of the cells. Consumption of nanoemulsions at a large scale can cause health-related problems as large amounts of surfactants are used to stabilize them. Nanoparticles can also adversely affect the environment. They can get washed away into the ocean where they can enter the plankton, thereby entering the entire aquatic food web.

Internationally, several agencies are in place to regulate the use of nanotechnology-based products in food sector. Some of these include the European Food and Safety Authority (EFSA), Environmental Protection Agency (EPA), Food and Drug Administration (FDA), National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), US Department of Agriculture (USDA), Consumer Product Safety Commission (CPSC), and US Patent and Trademark Office (USPTO).

7.8 Conclusion

An increased demand for biologically safe and eco-friendly methods of food safety is causing a surge in production of nanotechnology-based products in the food industry. Some of these products and technologies have successfully been able to control the foodborne pathogens and enhance the shelf life and safety of the food products. However, most government policies related to nanotechnology are still in their nascent phase as the field has grown at a rate much faster than anticipated. Lack of regulations can put consumers at risk and defeat the purpose in the process.

References

Amaral DMF, Bhargava K (2015) Essential oil nanoemulsions and food applications. Adv Food Technol Nutr Sci Open J 1(4):84–87

Baeumner A (2004) Nanosensors identify pathogens in food. Food Technol (Chicago) 58(8):51–55

Bhattacharya S, Jang J, Yang L, Akin D, Bashir R (2007) BioMEMS and nanotechnology-based approaches for rapid detection of biological entities. J Rapid Methods Autom Microbiol 15 (1):1–32

De Azeredo HM (2009) Nanocomposites for food packaging applications. Food Res Int 42 (9):1240–1253
Driskell JD, Tripp RA (2009) Emerging technologies in nanotechnology-based pathogen detection. Clin Microbiol Newsl 31(18):137–144
Feynman RP (1960) There's plenty of room at the bottom. California Institute of Technology, Engineering and Science Magazine
Garcia CV, Shin GH, Kim JT (2018) Metal oxide-based nanocomposites in food packaging: applications, migration, and regulations. Trends Food Sci Technol 82:21–31
García M, Aleixandre M, Gutiérrez J, Horrillo MC (2006) Electronic nose for wine discrimination. Sensors Actuators B Chem 113(2):911–916
Iqbal P, Preece JA, Mendes PM (2012) Nanotechnology: the "top-down" and "bottom-up" approaches. In: Supramolecular chemistry: from molecules to nanomaterials. Wiley, Chichester
Joyner JJ, Kumar DV (2015) Nanosensors and their applications in food analysis: a review. Int J Sci Technol 3(4):80
Krivorotova T, Cirkovas A, Maciulyte S, Staneviciene R, Budriene S, Serviene E, Sereikaite J (2016) Nisin-loaded pectin nanoparticles for food preservation. Food Hydrocoll 54:49–56
Llorens A, Lloret E, Picouet PA, Trbojevich R, Fernandez A (2012) Metallic-based micro and nanocomposites in food contact materials and active food packaging. Trends Food Sci Technol 24(1):19–29
Nasrollahzadeh M, Issaabadi Z, Sajjadi M, Sajadi SM, Atarod M (2019) Types of nanostructures. In: Interface science and technology, vol 28. Elsevier, Amsterdam, pp 29–80
Ozimek L, Pospiech E, Narine S (2010) Nanotechnologies in food and meat processing. Acta Sci Pol Technol Aliment 9(4):401–412
Rai M, Yadav A, Gade A (2009) Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv 27(1):76–83
Ramachandraiah K, Han SG, Chin KB (2015) Nanotechnology in meat processing and packaging: potential applications—a review. Asian Australas J Anim Sci 28(2):290
Rhim JW, Park HM, Ha CS (2013) Bio-nanocomposites for food packaging applications. Prog Polym Sci 38(10–11):1629–1652
Salvia-Trujillo L, Rojas-Graü MA, Soliva-Fortuny R, Martín-Belloso O (2014) Impact of microfluidization or ultrasound processing on the antimicrobial activity against Escherichia coli of lemongrass oil-loaded nanoemulsions. Food Control 37:292–297
Weir A, Westerhoff P, Fabricius L, Hristovski K, Von Goetz N (2012) Titanium dioxide nanoparticles in food and personal care products. Environ Sci Technol 46(4):2242–2250
Xie Y, He Y, Irwin PL, Jin T, Shi X (2011) Antibacterial activity and mechanism of action of zinc oxide nanoparticles against campylobacter jejuni. Appl Environ Microbiol 77(7):2325–2331
Zarei M, Jamnejad A, Khajehali E (2014) Antibacterial effect of silver nanoparticles against four foodborne pathogens. Jundishapur J Microbiol 7(1):e8720