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Review article

An overview on the applications of nanotechnology for improving the safety of food products

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ABSTRACT

The rapid spread of nanotechnology has led to the application of this technology in different sectors of the food industry such as processing, packaging, storage, transport, and safety. One of the most important areas in which nanotechnology can help is the safety of food products. Today, food quality and safety control is done with a preventive approach from the farm to the consumer table. The ideal scenario is defined based on minimizing the risk of food contamination without compromising organoleptic properties and food quality. Nanotechnology using various nanostructures can be employed to achieve this ideal scenario. A very wide range of nanostructures such as metal oxides, inorganic metals, and nanocomposites containing biologically active compounds have been used in food products. Nanostructures can help improve the food safety in a variety of ways, such as identifying pathogens, producing active, smart, and antimicrobial edible films, protecting against allergens and biofilms, and other applications. However, there are concerns about the potential dangers of using engineered nanomaterials for human, animal, and environmental health, so careful assessments are needed before the arrival of any of these nanotechnology-based products to gain the satisfaction and trust of the target community. This study suggested that the nanotechnology can be considered as an efficient strategy to improve the safety of food products.

Keywords: Nanotechnology; Nanostructures; Food safety; Consumer health

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1. Introduction

The issue of food safety has become a global public health concern. Food safety is used as a scientific discipline describing handling, preparation, and storage of food in ways that prevent food-borne illness (Griffith, 2006).The first goal of food safety is to ensure that the food does not cause any harm to the consumer during preparation and consumption. Food must be protected from any contamination, including physical, chemical, and biological. Today, due to rapid changes in dietary guidelines and habits, the issue of food safety has attracted more attention (Wesley et al., 2014; Singh et al., 2017). Pathogens, toxins, and other food contaminants can pose serious health risks to consumers. However, the methods used to detect pathogens and toxins are time consuming and require a lot of labor. Therefore, today, a lot of attention has been paid to nanotechnology-based methods to improve food safety, which will be discussed in this review paper (Inbaraj & Chen, 2016). Food nanotechnology is an area of emerging interest and opens up a whole universe of new possibilities for the food industry. Nanotechnology has different applications in the food industry such as for the detection of bacteria in packaging, or for the production of stronger flavors and color quality, and safety by increasing the barrier properties

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(Sekhon, 2010). The use of nanotechnology in the food industry can lead to the development of devices and methods that can help improve food safety. In this review article, various applications of nanotechnology in improving food safety are examined and discussed thoroughly.

2. Nanotechnology and food safety

As shown in Fig. 1, according to the previous studies and literature, the nanotechnology can lead to the manufacture and production of different nanostructures and nanomaterials that these nano-scaled structures can be employed to improve the safety of food products in various aspects, which will be discussed in the following sections.

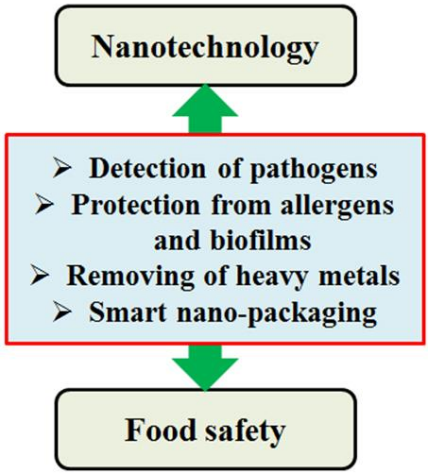

Fig. 1. Applications of nanotechnology in food safety.

2.1. *Nanoparticles for detecting of pathogens*

Nanosensors are systems that are designed using a variety of nanostructures and bioreceptors in an integrated system. Various nanosensors have been developed to detect pathogens and contaminants in different food products. Surface enhanced Raman scattering (SERS) is a method for the production of nanosensors with rapid pathogen detection power (Kahraman et al., 2008). Silver nanoparticles are commonly used in these systems because can increase the Raman signal. In addition to silver nanoparticles, graphene oxide, magnetic beads, carbon nanotubes, plasmonic gold, and silver nanoparticles are also used to detect pathogenic bacteria in food products. Synthetic DNAs called nano-barcodes are also used to detect food pathogens (Li et al., 2004). Some of the nanoparticles which have been used to detect the food-borne pathogens are shown in Table 1.

Direct detection of *Escherichia coli* in food samples and products is possible by measuring and detecting the light scattered by cells. These sensors work by attaching to a specific protein that is placed on a silicon chip and can then attach to *Escherichia coli* bacteria in the food (Battacharya et al., 2007). In this regard, researchers used liposomal nanocarriers to detect *Escherichia coli*, *Salmonella* and *Listeria monocytogenes* in single and mixed cultures (Chen & Durst, 2006). The researchers reported that the carrier was able to successfully detect pathogens simultaneously and could be used as universal agents in immunological tests. Another types of nanosensors used to detect pathogens are nano-cantilevers, which use silicon materials to detect proteins. In these systems, pathogens are detected based on different vibrations at different frequencies that depend on the amount of cell mass (Jain, 2003). Another diagnostic system used in the rapid detection of pathogens is lateral-flow immune test strips. For example, researchers have developed a strip system containing palladium nanoparticles to detect *Klebsiella* (Tominaga, 2018). Therefore, these results showed that the nanoparticles can be considered as efficient and promising systems for the detection of pathogens in the food products which can improve their safety.

2.2. *Nanoparticles for protection from allergens*

Nanotechnology can be used as a basic tool to control and manage food allergens. Polymer-based nanoparticles are often used for this purpose because other nanoparticles themselves can cause allergies or harmful side effects. For example, it has been reported that silica oxide nanoparticles themselves can cause allergies in human body (Yoshida et al., 2011). It has also been reported that the use of nanoparticles such as aluminum hydroxide in the treatment of allergies can cause harmful side effects such as inflammation (Vogelbruch et al., 2000). Therefore, researchers used polymer nanoparticles, especially protamine-based nanoparticles, to manage food allergens. Protamine is a peptide with a molecular weight of 4 kDa that is rich in arginine and is found in salmon sperm. The protamines are biodegradable and are used in surgery to reverse heparin activity (Schulman & Bijsterveld, 2007). In addition, heparin-based nanoparticles have been shown to have the ability to suppress allergen-induced reactions and can therefore be used as a new carrier to treat allergies. Therefore, researchers predict that in the near future, polymeric-based nanoparticles will play an important role in the treatment of food allergies which can improve the food safety as well as the health of consumers (Pali-Scholl et al., 2013).

2.3. *Nanoparticles for removing of heavy metals*

Release of heavy metals from nanomaterials poses a serious risk of toxicity. Release of these metals in food can also cause harmful effects on the product if accumulated. Nanomaterials based on metals and metal oxides such as zinc oxide, silver, and copper oxide can increase lipid peroxidation and damage DNA. In this regard, various compounds are used to recycle these nanomaterials from the environment, the most important of which are magnetic nanoparticles (Amin et al., 2014). For example, researchers recently used magnetized amino iron nanoparticles to remove heavy metals in water (Lin et al., 2017). In another study, researchers used sol-gel-synthesized magnesium oxide nanoparticles to remove heavy metals in contaminated water. Their results showed that these nanoparticles have a high potential for being used in food products because they have high efficiency, low cost, and fast preparation and are also environmentally friendly (Cai et al., 2017).

Table 1. Some examples of nanoparticles employed for the detection of foodborne pathogens.

Nanoparticle	Pathogen	Detection limit	Ref
Gold nanoparticles	*Salmonella enterica*	98.9 CFU/mL	Vikeslan et al. (2010)
Gold/silicon nano-rod	*Salmonella enterica*	Not reported	Dungchai et al. (2008)
Magnetic bead	*Escherichia coli*	10^3 CFU/mL	Yang et al. (2006)
Single walled carbon nanotube	*Escherichia coli*	Not reported	Zhao et al. (2004)
Magnetic nanoparticle	*E. coli, S. aureus, S. epidermidis*	Not reported	Zhao et al. (2004)
Liposome nanoparticles	*Salmonella typhimurium*	10^2 CFU/mL	Zhou et al. (2011)

2.4. *Nanoparticles to inhibit the formation of biofilms*

Biofilms are layers of bacterial cells that adhere to different surfaces to produce extracellular matrices that are highly impermeable. Biofilm formation begins with the attachment of airborne microorganisms to a surface through van der Waals bonds, which causes problems such as bio-deposition, corrosion, and accumulation of contaminants in the food processing industry (Shakeri et al., 2017). Nanomaterials can be used to destroy these biofilms. For example, researchers used nano-silver particles to prevent the formation of biofilms. Nickel oxide nanoparticles also have good antibacterial and tumor properties. Zinc oxide nanoparticles have also been employed well to prevent the formation of fungal biofilms in different surfaces (Gambino et al., 2017). Magnetic iron oxide nanoparticles have also been used to prevent biofilm formation by *Bacillus subtilis* (Ranmadugala et al., 2017). In fact, the researchers used the nanoparticles in a way that did not affect the positive function of the bacterium and only reduced its ability to form biofilms. The results showed that the use of magnetic iron oxide nanoparticles reduced the biomass of the bacteria well without negatively affecting the survival of the bacteria. Therefore, the researchers suggested that nanoparticles could be used in various industries such as the food industry to combat the formation of microbial biofilms. In another study, silver nanoparticles were used to reduce the formation of microbial biofilm, which changed the physical structure of the biofilm (Thuptimdang et al., 2017). However, it seems that much more studies are needed in this area to be able to use nanostructures more efficiently to reduce the formation of microbial biofilms in food industry processing.

2.5. *Nanotechnology and food packaging*

Nanotechnology can help to develop the production of active and intelligent edible packaging with improved mechanical and thermal properties to ensure better protection of food. The integration of clay nanoparticles in biopolymers improves the mechanical properties. Biopolymers containing clay nanoparticles are biodegradable and environmentally friendly, so they are considered as a suitable alternative to traditional plastic-based food packaging. In addition to strengthening the mechanical properties, this type of packaging can play a controlling role in gas exchange and increase the shelf life of the product by limiting the penetration of oxygen and preventing the leakage of carbon dioxide (Han et al., 2011). Nanoemulsions allow the integration of different biologically active molecules and nanoparticles to prevent oxidation and decomposition of food products. Activated oxygen species reduce the quality of food and can be inhibited by the use of selenium and cellulose nanoparticles in food packaging. Phenolic nanoemulsions also have the ability to protect against the degradation and breakdown of some foods, especially fatty foods. Other natural oils have the potential to blend in with nanofibers to extend the shelf life and keep food fresh (Spitia et al., 2019). Carbohydrate-based nanoparticles are among the new nanoparticles that have received a lot of attention in packaging. Nano-filters made from these nanoparticles are included as a reinforcing phase in nanocomposites. Also, carbohydrate-based nanoparticles are used as a base material in photo-catalytic polymers (Fathi et al., 2014).

3. Future trends and potential risks of nanotechnology

There have been many advances in the application of nanotechnology in the food science that are still ongoing. Nanotechnology helps to detect the pesticides, pathogens, and toxins and can be used to maintain the quality of food products. Nano-compounds can also be used to produce active and intelligent films which can improve the quality of the packaged foods (Tully et al., 2006). Along with the widespread use of nanotechnology in food products, there are a number of potential risks in the field of nanocomposites, nanostructures, and nanomaterials that need to be addressed. The effect of these nanoscale compounds on the humans, animals, and the environment is unpredictable because the properties of these materials change over time. Some nanomaterials can cross the blood-brain barrier and enter various cells and organs (Su & Li, 2004). Some research has shown that the inhaling nanoparticles can cause health problems. It has also been shown that some nanomaterial used in food products, such as nano-silver, have the ability to accumulate in the human body as well as in food products which can be harmful for the health (Kovanovic, 2015). Therefore, with the advancement of nano-science and nanotechnology, it is necessary to pay attention to its safety and also to give the necessary training to consumers in this field (Rhim et al., 2013).

4. Conclusion

A new era is emerging in the field of food safety and food quality assurance. Current methods for ensuring the safety of end materials in each aspect are inefficient and can be improved by using nanotechnology. A review of various studies showed that nanotechnology can help to improve the safety of food products in various fields, the most important of which are the use of nanotechnology in the detection of pathogens and toxic compounds, their use in the production of smart and active packaging as well as in preventing the formation of biofilms, removing the heavy metals, and also helping to protect against allergenic compounds. However, it seems that more research is still needed on the application of nanotechnology in food safety. Extensive research is also needed to study the safety of nanomaterials and nanostructures used in the food products to address the safety and toxicity concerns at the nanoscale.

Therefore, in the future studies, the potential risks of engineered nanomaterials to humans, animals, and the environment should be considered in parallel with the development of new nanomaterials and new nanotechnology approaches.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

Amin, M. T., Alazba, A. A., & Manzoor, U. (2014). A review of removal of pollutants from water/wastewater using different types of nanomaterials. *Advances in Materials Science and Engineering*, *2014*.

Bhattacharya, S., Jang, J., Yang, L., Akin, D., & Bashir, R. (2007). BioMEMS and nanotechnology-based approaches for rapid detection of biological entities. *Journal of Rapid Methods & Automation in Microbiology*, *15*(1), 1-32.

Cai, Y., Li, C., Wu, D., Wang, W., Tan, F., Wang, X., ... & Qiao, X. (2017). Highly active MgO nanoparticles for simultaneous bacterial inactivation and heavy metal removal from aqueous solution. *Chemical Engineering Journal*, *312*, 158-166.

Chen, C. S., & Durst, R. A. (2006). Simultaneous detection of Escherichia coli O157: H7, Salmonella spp. and Listeria monocytogenes with an array-based immunosorbent assay using universal protein G-liposomal nanovesicles. *Talanta*, *69*(1), 232-238.

Dungchai, W., Siangproh, W., Chaicumpa, W., Tongtawe, P., & Chailapakul, O. (2008). Salmonella typhi determination using voltammetric amplification of nanoparticles: a highly sensitive strategy for metalloimmunoassay based on a copper-enhanced gold label. *Talanta*, *77*(2), 727-732.

Espitia, P. J., Fuenmayor, C. A., & Otoni, C. G. (2019). Nanoemulsions: Synthesis, characterization, and application in bio-based active food packaging. *Comprehensive Reviews in Food Science and Food Safety*, *18*(1), 264-285.

Fathi, M., Martin, A., & McClements, D. J. (2014). Nanoencapsulation of food ingredients using carbohydrate based delivery systems. *Trends in Food Science & Technology*, 39(1), 18-39.

Gambino, M., Ahmed, M. A. A. A., Villa, F., & Cappitelli, F. (2017). Zinc oxide nanoparticles hinder fungal biofilm development in an ancient Egyptian tomb. *International Biodeterioration & Biodegradation*, *122*, 92-99.

Griffith, C. J. (2006). Food safety: where from and where to?. *British Food Journal*, *108*(1), 6-15.

Han, W., Yu, Y., Li, N., & Wang, L. (2011). Application and safety assessment for nano-composite materials in food packaging. *Chinese Science Bulletin*, *56*(12), 1216-1225.

Inbaraj, B. S., & Chen, B. H. (2016). Nanomaterial-based sensors for detection of foodborne bacterial pathogens and toxins as well as pork adulteration in meat products. *Journal of Food and Drug Analysis*, *24*(1), 15-28.

Jain, K. K. (2003). Nanodiagnostics: application of nanotechnology in molecular diagnostics. *Expert Review of Molecular Diagnostics*, *3*(2), 153-161.

Jovanović, B. (2015). Critical review of public health regulations of titanium dioxide, a human food additive. *Integrated Environmental Assessment and Management*, *11*(1), 10-20.

Kahraman, M., Yazıcı, M. M., Şahin, F., & Çulha, M. (2008). Convective assembly of bacteria for surface-enhanced Raman scattering. *Langmuir*, *24*(3), 894-901.

Li, Y., Tseng, Y. D., Kwon, S. Y., d'Espaux, L., Bunch, J. S., McEuen, P. L., & Luo, D. (2004). Controlled assembly of dendrimer-like DNA. *Nature Materials*, *3*(1), 38-42.

Lin, S., Xu, M., Zhang, W., Hua, X., & Lin, K. (2017). Quantitative effects of amination degree on the magnetic iron oxide nanoparticles (MIONPs) using as adsorbents to remove aqueous heavy metal ions. *Journal of Hazardous Materials*, *335*, 47-55.

Pali-Schöll, I., Szöllösi, H., Starkl, P., Scheicher, B., Stremnitzer, C., Hofmeister, A., ... & Jensen-Jarolim, E. (2013). Protamine nanoparticles with CpG-oligodeoxynucleotide prevent an allergen-induced Th2-response in BALB/c mice. *European Journal of Pharmaceutics and Biopharmaceutics*, *85*(3), 656-664.

Ranmadugala, D., Ebrahiminezhad, A., Manley-Harris, M., Ghasemi, Y., & Berenjian, A. (2017). The effect of iron oxide nanoparticles on *Bacillus subtilis* biofilm, growth and viability. *Process Biochemistry*, *62*, 231-240.

Rhim, J. W., Park, H. M., & Ha, C. S. (2013). Bio-nanocomposites for food packaging applications. *Progress in Polymer Science*, *38*(10-11), 1629-1652.

Schulman, S., & Bijsterveld, N. R. (2007). Anticoagulants and their reversal. *Transfusion Medicine Reviews*, *21*(1), 37-48.

Sekhon, B. S. (2010). Food nanotechnology–an overview. Nanotechnology, science and applications, 3, 1.

Shakeri, S., Kermanshahi, R. K., Moghaddam, M. M., & Emtiazi, G. (2007). Assessment of biofilm cell removal and killing and biocide efficacy using the microtiter plate test. *Biofouling*, *23*(2), 79-86.

Singh, T., Shukla, S., Kumar, P., Wahla, V., Bajpai, V. K., & Rather, I. A. (2017). Application of nanotechnology in food science: perception and overview. *Frontiers in Microbiology*, 8, 1501.

Su, X. L., & Li, Y. (2004). Quantum dot biolabeling coupled with immunomagnetic separation for detection of *escherichia coli* O157: H7. *Analytical Chemistry*, *76*(16), 4806-4810.

Thuptimdang, P., Limpiyakorn, T., & Khan, E. (2017). Dependence of toxicity of silver nanoparticles on Pseudomonas putida biofilm structure. *Chemosphere*, *188*, 199-207.

Tominaga, T. (2018). Rapid detection of Klebsiella pneumoniae, Klebsiella oxytoca, Raoultella ornithinolytica and other related bacteria in food by lateral-flow test strip immunoassays. *Journal of Microbiological Methods*, *147*, 43-49.

Tully, E., Hearty, S., Leonard, P., & O'Kennedy, R. (2006). The development of rapid fluorescence-based immunoassays, using quantum dot-labelled antibodies for the detection of Listeria monocytogenes cell surface proteins. *International Journal of Biological Macromolecules*, *39*(1-3), 127-134.

Vikesland, P. J., & Wigginton, K. R. (2010). Nanomaterial enabled biosensors for pathogen monitoring-a review. *Environmental Science & Technology*, *44*(10), 3656-3669.

Vogelbruch, M., Nuss, B., Körner, M., Kapp, A., Kiehl, P., & Bohm, W. (2000). Aluminium-induced granulomas after inaccurate intradermal hyposensitization injections of aluminium-adsorbed depot preparations. *Allergy*, *55*(9), 883-887.

Wesley, S. J., Raja, P., Raj, A. A., & Tiroutchelvamae, D. (2014). Review on-nanotechnology applications in food packaging and safety. *International Journal of Engineering Research*, *3*(11), 645-651.

Yang, L., & Li, Y. (2006). Quantum dot bioconjugates for simultaneous detection of Escherichia coli O157: H7 and Salmonella Typhimurium. *Analyst*, *131*(3), 394-401.

Yoshida, T., Yoshioka, Y., Fujimura, M., Yamashita, K., Higashisaka, K., Morishita, Y., ... & Kamada, H. (2011). Promotion of allergic immune responses by intranasally-administrated nanosilica particles in mice. *Nanoscale Research Letters*, *6*(1), 1-6.

Zhao, X., Hilliard, L. R., Mechery, S. J., Wang, Y., Bagwe, R. P., Jin, S., & Tan, W. (2004). A rapid bioassay for single bacterial cell quantitation using bioconjugated nanoparticles. *Proceedings of the National Academy of Sciences*, *101*(42), 15027-15032.

Zhou, L., Lv, S., He, G., He, Q., & Shi, B. I. (2011). Effect of PE/Ag_2O nano-packaging on the quality of apple slices. *Journal of Food Quality*, *34*(3), 171-176.