IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

RECENT TRENDS OF NANO-TECHNOLOGY IN PACKAGING

Dushyant Kumar

Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab 144411, India

Dushyant Kumar

School of Agriculture

Department of Food Technology and Nutrition

Lovely Professional University, Phagwara, Punjab, India-144411

ABSTRACT

Due to increasing demand for safer and hygienic foods has led to applying new technologies for food preservation. Active packaging enriched with antimicrobial agents is a good approach for enhancing the shelf-life of food produce. It promotes better food quality and stability by releasing of antimicrobial agents into food. Similarly, intelligent or smart packaging system uses the nano sensor technology to prevent food product from spoilage through analysis and detection of toxins. Nanotechnology has revolutionized the food packaging industry by introducing nanoparticles into food contact materials to preserve food for longer periods. Nanocomposite enriched packaging containing nanoparticles helps in eliminating the use of preservatives and also inhibit the growth of microorganisms. This review focuses on the applications of nanoparticles in food packaging along with their mechanism of action.

KEYWORDS: Nanotechnology, Packaging, Food, Active Packaging, Smart Packaging, Nanocomposite

INTRODUCTION

Nowadays, consumer demands for organic and safer foods, which led to develop new technologies (nanoparticles, intelligent or smart packaging and active packaging) for food preservation. Due to several foodborne diseases caused by different viruses, bacteria and fungi raised the food safety concern around the world (Bahrami et al., 2020). Therefore, to reduce the transmission of diseases, food packaging is the crucial target area for the preservation of food products. In the food industry, packaging of food provides protection against physiochemical damages, improve shelf-life and facilitate safe handling of the produce during storage or transportation (Dehnad et al., 2014; Pilevar et al., 2019). Nanotechnology with its novel and innovative approaches is playing a vital role in food and agricultural sectors. This technology contributes to enhance food quality and safety and promotes human health (Nile et al., 2020). Nanotechnology has revolutionized the packaging sector by improving mechanical properties of packaging materials, incorporation of antimicrobial-loaded nanocarriers into packaging structure and coating packaging with antimicrobials. (Bahrami et al., 2020). Similarly, the use of antimicrobial sachets in the package and the antimicrobial immobilization into packaging material (Limbo et al., 2015). Nanotechnology also offered an improvement over conventional packaging in which plastic used as barriers and its functional components such as antimicrobial activities aid in enhancing shelf-life of food product (Sekhon, 2010). Nanotechnology based active and intelligent packaging systems provides specific characteristics such as sensing, reporting, localization and remote control with enhanced efficiency and security to food items. Nanotechnology applications in food industry provides better security by using nanosensors for the detection of any pathogen and contamination in food (Nile et al., 2020). Furthermore, nanotechnology is involving application of nanomaterials of size range between 1-100 nm and these nanomaterials can be combined with polymers to produce nanocomposite (Uskoković, 2007). Nanomaterials have smaller size and having enhanced mechanical, barrier and thermal properties. These nanomaterials provide lower permeability to gases and water when incorporated into polymer matrix (Gracia et al., 2018).

RECENT TRENDS OF NANOTECHNOLOGY IN PACKAGING OF FOOD PRODUCTS

In recent years, advanced packaging such as active packaging and smart/intelligent packaging aids in maintaining quality as well as sensory characteristics of the food item over time (Bahrami et al., 2020). Active packaging involves controlled diffusion of desirable components such as antimicrobials compounds towards food, maintains the food quality as well as stability and also improve cost- effectiveness (Azeredo et al., 2019). Advanced packaging includes use of Nano sensors, they provide alarm for food spoilage and contamination to the consumers by detecting toxins, pesticides and microbial contamination in food product. These measurements are based on different parameters such as flavor production and color formation (He et al., 2019). Nanoparticles are act as a carrier to incorporate enzymes, antioxidants, anti-browning agents, flavors and other bioactive materials to enhance the shelf-life of the open or packaged food. Several metals and metal oxides nanoparticles such as zinc oxide, silver, gold and titanium oxides are widely used as antimicrobial agents in food packaging (He et al., 2019)

INTELLIGENT/SMART PACKAGING SYSTEM

Intelligent packaging system involves Nano sensors which responds to environmental stimuli by alerting the consumer regarding contamination (Le and Sheng, 2014). Nanoparticles are used in the development of Nano sensors. Application of Nano sensors involves food analysis, detection of flavors, colors, drinking water, toxins and food pathogens. Nano sensors in food packaging involves tracing the physical, chemical and biological modifications during food processing (Berekaa, 2015). Intelligent packaging system with time-temperature indicators also aids in tracking of packaged food during transportation (Augustin and Sanguansri, 2009). In the meat industry, the combined use of nano sensors and indicators are crucial for monitoring of freshness and time-temperature relationship of packaged food during storage or transportation. Freshness and time- temperature indicators both are monitored throughout the production and distribution chain to maintain the quality and to increase the shelf life of the produce (Branton et al., 2009).

Nano barcodes are developed with the help of nanoparticles and used as identification (ID) tags. Application of nano sensor gives details of enzymes produced during the degradation of food compounds, which makes food unfit for human consumption (Nile et al., 2020). Packaging act as a barrier for air, enzymes, enhance shelf life of the food product and serves as substitute for artificial preservatives. Similarly, it reported that intelligent packaging also prevents the production of ethylene (Nile et al., 2020). For example, a device known as electric nose, which used for determination of volatiles and to monitor the quality control process in the food industry. It works similar to human nose, it uses sets of chemical sensors attached to a data processing system (Varnamkhasti et al., 2018).

ACTIVE PACKAGING

Active packaging is another type of advanced packaging. This packaging has superior functions such as controlled atmosphere of packaging as well as growth of microorganisms (Duncan, 2011). Active packaging enhances the shelf life and safety of packaged food by eliminating foodborne pathogens (Bahrami et al., 2020). Active packaging is developed according to the purpose of storage, it consists of CO_2 scavengers, regulating agents, O_2 scavengers and antimicrobials. Modified Atmosphere Packaging (MAP), vacuum packaging, and bulk gas flushing systems are used for long-term chilled storage, while overwrap packaging system is used for short-term chilled packaging (Dias et al., 2013; Nile et al., 2020). Modified atmosphere packaging (MAP) is used widely for the storage, distribution and maintenance of packaged food (Kerry et al., 2020). Oxygen (O_2) and carbon-dioxide (CO_2) gases are used in modified atmosphere packaging. These gases are non-inert in nature and their profile changes over time due to some factors like type of product, respiration, size of packaging and storage conditions (Morris et al., 2020). Thermoplastic polymers such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC) are the common polymers used to produce the active packaging. These polymers play a crucial role in releasing of a substance from polymer into foods, due to their chemical nature and environmental issues, so they are now replaced by bio-polymers such as starch, cellulose and chitosan (Bahrami et al., 2020). Recently, use of bio-polymers based materials for production of active packaging has been increasing. These polymers are edible, environmentally friendly, flexible in nature and come from renewable resources. Furthermore, bio-polymers have poor mechanical properties, but this limitation can be overcome by using nano-technology (nanoparticles, nanocarriers, nanocomposite) (Khaneghah et al., 2018).

NANOPARTICLES USED IN PACKAGING

Nanotechnology has been applied in the production of nanocomposites. Nanocomposite are the fusion of a polymer and a nano-dimensional material that can be come in form of fillers. Fillers such as metals, metal oxides, silica, clay and carbon nano-tubes and their inclusion in nanoscale form enhance the mechanical strength of food packaging material (Munoz et al., 2019). Nanoparticles are tiny particles having size between 1-100 nm and are used in nanotechnologies of food science. They are used for production and processing of healthier, safer and quality food (Nile et al., 2020). Nanoparticles used for packaging have potential antimicrobial activity. And they also act as carrier for antimicrobial agents and protect against microbial spoilage. They are also used to incorporate enzymes, flavors, anti- browning agents, antioxidants and other bioactive compounds into produce (Cha et al., 2004; Weiss et al., 2006). According to a study, packaging materials consists of starch coating with antimicrobial agents, serves as a barrier to microbes through controlled diffusion of antimicrobials from packaged material (Nile et al., 2020).

Table 1 Nanomaterials and their applications in food product

Nanomaterials	Analyte	Samples	References
Zinc oxide	Decreases the oxygen flow inside the packed container	Food preservation and packaging	Nile et al., 2020
Titanium dioxide	Used as whitener in dairy products (e.g., milk and cheese)	Food preservation and packaging	Zhao et al., 2008
Silver nanoparticles	Acts as antibacterial agent, absorbs, and decomposes ethylene in fruit and vegetables	Food preservation and packaging	Acosta, 2009
Silicon dioxide	Act as food colorant, hygroscopic, anticaking, and drying agent	Food preservation and packaging	Jones et al., 2008
Gold nanoparticles AuNPs	Integration of DNA or enzymes or antibodies with Au NP	Food storage applications Meat and dairy industries Fruit juice	Ozdemir et al., 2010
Carbon nanotubes	Optical, electrical, mechanical, and thermal conductivity	Food inspection and vacuum proof food packaging	Yadav, 2017
Graphene	Nanoplate-based nanocomposites	Detects contaminants in food	Sundramoorthy et al., 2014

Metal Oxides Nanoparticles

Metal oxides plays their role as photocatalysts with antimicrobial activity. Their mechanism of action includes oxidative photocatalysis by production of highly reactive oxygen species such as ROS, inactivation of microbes by peroxidation of membrane phospholipids (Azeredo et al., 2019). According to a study, the incorporation of titanium oxide nanoparticles (TiO_2 NPs) into chitosan films made them active against grampositive, gram-negative bacteria and fungi. They facilitate enhancement in grapes stability, shows ethylene scavenging effects and effective in delaying ripening of climacteric fruits (Azeredo et al., 2019).

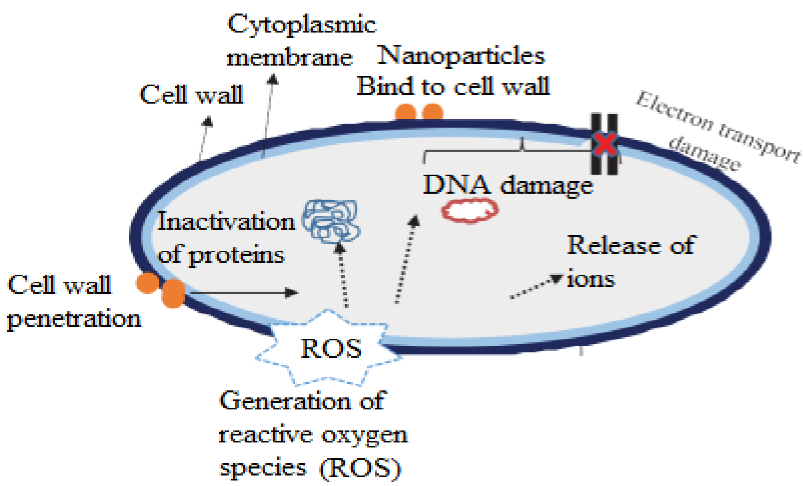

Figure 1. Possible mechanism of antimicrobial efficacy of Metal Oxides nanoparticles

Silver Nanoparticles (SiO_2 NPs) and their action of mechanism

Silver nanoparticles (SiO_2) are biocidal agents and prevent the infection rates. They have specific characteristics such as high thermal resistance and a wide variety of antimicrobial performances. Silver nanoparticles increase the shelf-life as well as prevent the microbial growth in perishable products (Hoseinnejad et al., 2017). Their antimicrobial effect depends on several factors such as shape, size, concentration, target species and the composition of the nanoparticles. Silver nanoparticles have been used in antimicrobial food packaging applications. And their mechanism of action includes penetration into outer and inner membranes of cells, disruption of barrier components of microbes and moulds. Furthermore, the inhibition of respiratory chain enzymes, disrupt the DNA replication and cellular protein activation processes. Moreover, silver nanoparticles also produce reactive oxygenated species that cause oxidative stress to microbial cells (Melini and Melini, 2018). According to a study, fabricated antimicrobial biodegradable starch-PVA-films enriched with silver nanoparticles (Ag NPs) showed substantial effect against *Listeria innocua*, *Escherichia Coli*, *Aspergillus niger* and *Pencillium Expansum* respectively (Cano et al., 2016).

Zinc Oxide Nanoparticles (ZnO NPs) and their action of mechanism

Zinc nanoparticles are antimicrobial agents having specific properties like low cost and toxicity and ultraviolet (UV) light blocking properties. And they are produced by mechanochemical processing and by the sol-gel method and spray pyrolysis (Gracia et al., 2018). Zinc nanoparticles (ZnO NPs) biocidal activity involves firstly, the effects of reactive oxygen species (ROS) on the performance of cells and secondly, the generation of electron-hole pair when expose to UV light and as a result formation of hydroxyl radicals takes place and these active uncharged molecules then damage the microbial cells and completely degenerate them

(Hseinnejad et al., 2017). According to a study, reported that zinc oxide nanoparticles showed biocidal effects against *Bacillus subtilis, Escherichia coli and Clostridium perfringens* due to the production of high amount of oxygen species from the surface of the zinc oxide nanoparticles which leads to the destruction of the bacterial through permeation of cell membrane (Nawaz et al., 2011).

Titanium Dioxide Nanoparticles (TiO_2 NPs) and their mechanism of action

Titanium nanoparticles (TiO_2 NPs) are having different characteristics such as photocatalytic antimicrobial properties, high stability, an extensive range of antibiosis and the generation of reactive oxygen species (ROS) when expose to UV light (Hoseinnejad et al., 2017; Gracia et al., 2018). Their action of mechanism involves peroxidation of lipids in the cell membrane and oxidation of proteins and DNA (Gracia et al., 2018). On the surface of titanium dioxide (TiO_2) several reactive oxygen species are produced such as superoxide anions, hydroxyl radicals and hydrogen peroxide. These reactive oxygen reactive species (ROS) trigger the peroxidation of polyunsaturated phospholipids which are present in the membrane of microorganisms. Among all of these ROS agent's hydroxyl radicals are the most efficient to inactivate *Escherichia coli* (Hoseinnejad et al., 2017). According to a study, the antimicrobial impact of titanium dioxide (TiO_2) prevents the proliferation of *Shewanella aneidensis* (Yadav et al., 2016; Maurer-Jones et al., 2013).

Gold Nanoparticles (Ag NPs) and their mechanism of action

Gold nanoparticles (Ag NPs) are good absorber of biomolecules without losing their biological functions. These particles have large surface per volume ratio and specific physical and chemical properties (Nile et al., 2020). Gold nanoparticles (Ag NPs) are act as a biocidal candidate with their antimicrobial functions. According to a study, gold nanoparticles showed substantial antimicrobial activity against *Pseudomonas aeruginosa*, *Escherichia Coli*, *Staphylococcus aureus*, *Bacillus subtilis* and *Klebsiella pneumoniae* (Hoseinnejad et al., 2017). There are two approaches used by gold nanoparticles to exhibit their antibacterial impacts. Firstly, the modification of membrane charge and suppressing ATP synthase activities so as to alleviate the ATP concentration and thus slow down the process of metabolism (Hoseinnejad et al., 2017). Secondly, the prevention of ribosomal subunit assembly for tRNA resulting in biological dysfunction. Major advantage of using gold nanoparticles over other antibacterial agents is their effective and safer mode of action of reactive oxygen species (ROS) independent strategy (Hoseinnejad et al., 2017).

CONCLUSION AND FUTURE PRESPECTIVE

Nanotechnology is being embracing by the food packaging sector as its applications provides substantial improvements in packaging materials and packaging technologies. Nanocomposites are better substitutes for conventional polymer structures currently used. As it provides stronger, lighter and more flexible films with enhanced oxygen and aroma barriers. Introduction of antimicrobial nanocomposites in food packaging can be used to create packages to increase microbiological shelf-life and safety of foods. In smart packaging, incorporation of nanosensors into food packaging provides information regarding state of packaged food during storage and transportation. In coming years, radio-frequency identification (RFID) techniques with its smaller and economical characteristics will replace the barcode system in packaging. In future more studies should be focused on the migration of nanoparticles from nanocomposites onto food matrix and their effects on consumer health. Furthermore, sustainability and recycling of nanopackages as well as regulatory information to evaluate the safety of nanocomposite applied to food packaging has to be considered. There is a void knowledge regarding safety regulations, standardization and toxicity characteristics of nanomaterials. Also, their physiochemical properties such as surface charges, particles size, reliable techniques for their characterization, identification in complex food matrices and their disposal techniques. Metal-oxide based nanocomposites such as titanium dioxide (TiO_2), zinc oxide (ZnO) has enhanced mechanical, barrier properties and antimicrobial effects against various bacterial strains. The incorporation of metal-oxide nanoparticles into biodegradable polymers improve their water and oxygen barrier properties as well as their mechanical strength. Most oxide-based nanocomposites still at the development stage due to lack of validated material to determine migration of nanomaterials from packaging. Natural antimicrobial agents are now promising candidates to be used as alternative for synthetic ingredients in formation of healthy foods and in food packaging system such as active packaging. Future studies should be focuses on the evaluation of the interaction between food components and antimicrobial-loaded nanocarriers. Antimicrobial packaging materials prevent food from spoilage and foodborne diseases through inhibiting microbial growth.

REFERENCES

Azeredo, H. M., Otoni, C. G., Corrêa, D. S., Assis, O. B., de Moura, M. R., & Mattoso, L. H. C. (2019). Nanostructured antimicrobials in food packaging—Recent advances. *Biotechnology journal*, *14*(12), 1900068.

Augustin, M. A., & Sanguansri, P. (2009). Nanostructured materials in the food industry. *Advances in food and nutrition research*, *58*, 183-213.

Acosta, E. (2009). Bioavailability of nanoparticles in nutrient and nutraceutical delivery. *Current opinion in colloid & interface science*, *14*(1), 3-15.

Bahrami, A., Delshadi, R., Assadpour, E., Jafari, S. M., & Williams, L. (2020). Antimicrobial-loaded nanocarriers for food packaging applications. *Advances in colloid and interface science*, *278*, 102140.

Berekaa, M. M. (2015). Nanotechnology in food industry; advances in food processing, packaging and food safety. *Int J Curr Microbiol App Sci*, *4*(5), 345-357.

Branton, D., Deamer, D. W., Marziali, A., Bayley, H., Benner, S. A., Butler, T., ... & Schloss, J. A. (2010). The potential and challenges of nanopore sequencing. *Nanoscience and technology: A collection of reviews from Nature Journals*, 261-268.

Cha, D. S., & Chinnan, M. S. (2004). Biopolymer-based antimicrobial packaging: a review. *Critical reviews in food science and nutrition*, *44*(4), 223-237.

Dias, M. V., Nilda de Fátima, F. S., Borges, S. V., de Sousa, M. M., Nunes, C. A., de Oliveira, I. R. N., & Medeiros, E. A. A. (2013). Use of allyl isothiocyanate and carbon nanotubes in an antimicrobial film to package shredded, cooked chicken meat. *Food chemistry*, *141*(3), 3160-3166.

Dehnad, D., Emam-Djomeh, Z., Mirzaei, H., Jafari, S. M., & Dadashi, S. (2014). Optimization of physical and mechanical properties for chitosan–nanocellulose biocomposites. *Carbohydrate Polymers*, *105*, 222-228.

Duncan, T. V. (2011). Applications of nanotechnology in food packaging and food safety: barrier materials, antimicrobials and sensors. *Journal of colloid and interface science*, *363*(1), 1-24.

Garcia, C. V., Shin, G. H., & Kim, J. T. (2018). Metal oxide-based nanocomposites in food packaging: Applications, migration, and regulations. *Trends in food science & technology*, *82*, 21-31.

Ghasemi-Varnamkhasti, M., Apetrei, C., Lozano, J., & Anyogu, A. (2018). Potential use of electronic noses, electronic tongues and biosensors as multisensor systems for spoilage examination in foods. *Trends in Food Science & Technology*, *80*, 71-92.

Hernández-Muñoz, P., Cerisuelo, J. P., Domínguez, I., López-Carballo, G., Catalá, R., & Gavara, R. (2019). Nanotechnology in food packaging. In *Nanomaterials for Food Applications* (pp. 205-232). Elsevier.

Hoseinnejad, M., Jafari, S. M., & Katouzian, I. (2018). Inorganic and metal nanoparticles and their antimicrobial activity in food packaging applications. *Critical reviews in microbiology*, *44*(2), 161-181.

He X, Deng H, Hwang HM. The current application of nanotechnology in food and agriculture. J Food Drug Anal. 2019 Jan;27(1):1-21. doi: 10.1016/j.jfda.2018.12.002. Epub 2018 Dec 24. PMID: 30648562.

Jones, N., Ray, B., Ranjit, K. T., & Manna, A. C. (2008). Antibacterial activity of ZnO nanoparticle suspensions on a broad spectrum of microorganisms. *FEMS microbiology letters*, *279*(1), 71-76.

Kerry, J. P., O'grady, M. N., & Hogan, S. A. (2006). Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A review. *Meat science*, *74*(1), 113-130.

Khaneghah, A. M., Hashemi, S. M. B., & Limbo, S. (2018). Antimicrobial agents and packaging systems in antimicrobial active food packaging: An overview of approaches and interactions. *Food and Bioproducts Processing*, *111*, 1-19.

Kannan, P., & Guo, L. (2020). Nanosensors for food safety. In *Nanosensors for Smart Cities* (pp. 339-354). Elsevier.

Limbo, S., & Khaneghah, A. M. (2015). Active packaging of foods and its combination with electron beam processing. In *Electron Beam Pasteurization and Complementary Food Processing Technologies* (pp. 195-217). Woodhead Publishing.

Li Z, Sheng C. Nanosensors for food safety. J Nanosci Nanotechnol. 2014 Jan;14(1):905-12. doi: 10.1166/jnn.2014.8743. PMID: 24730307.

Morris, M. A., Padmanabhan, S. C., Cruz-Romero, M. C., Cummins, E., & Kerry, J. P. (2017). Development of active, nanoparticle, antimicrobial technologies for muscle-based packaging applications. *Meat science*, *132*, 163-178.

Melini, V., & Melini, F. (2018). Strategies to extend bread and GF bread shelf-life: From sourdough to antimicrobial active packaging and nanotechnology. *Fermentation*, *4*(1), 9.

Nile, S. H., Baskar, V., Selvaraj, D., Nile, A., Xiao, J., & Kai, G. (2020). Nanotechnologies in food science: applications, recent trends, and future perspectives. *Nano-Micro Letters*, *12*(1), 1-34.

Ozdemir, C., Yeni, F., Odaci, D., & Timur, S. (2010). Electrochemical glucose biosensing by pyranose oxidase immobilized in gold nanoparticle-polyaniline/AgCl/gelatin nanocomposite matrix. *Food Chemistry*, *119*(1), 380-385.

Pilevar, Z., Bahrami, A., Beikzadeh, S., Hosseini, H., & Jafari, S. M. (2019). Migration of styrene monomer from polystyrene packaging materials into foods: Characterization and safety evaluation. *Trends in Food Science & Technology*, *91*, 248-261.

Sundramoorthy, A. K., & Gunasekaran, S. (2014). Applications of graphene in quality assurance and safety of food. *TrAC Trends in Analytical Chemistry*, *60*, 36-53.

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

Uskoković, V. (2007). Nanotechnologies: What we do not know. *Technology in society*, *29*(1), 43-61.

Weiss, J., Takhistov, P., & McClements, D. J. (2006). Functional materials in food nanotechnology. *Journal of food science*, *71*(9), R107-R116.

Yadav, S. K. (2017). Tissue science & engineering realizing the potential of nanotechnology for agriculture and food technology. *J. Tissue Sci. Eng*, *8*, 8-11.

Zhao, R., Torley, P., & Halley, P. J. (2008). Emerging biodegradable materials: starch-and protein-based bio-nanocomposites. *Journal of Materials Science*, *43*(9), 3058-3071.