

# Chapter: 07

## NANOTECHNOLOGY IN FOOD PACKAGING

**MOHD BABU KHAN\***

\*Correspondence- Assistant Professor, Glocal School of Science and Technology,  
Glocal University, Saharanpur, U.P. – 247121, India

**RUKAIYAA PARVEEN**

Student, Glocal University, Saharanpur, U.P. – 247121, India

**SOURABH KUMAR**

Student, Glocal University, Saharanpur, U.P. – 247121, India

**SHIKHA DEVI**

Student, Glocal University, Saharanpur, U.P. – 247121, India

**KASHFA AZEEM**

Student, Glocal University, Saharanpur, U.P. – 247121, India

*Email: [babu@theglobaluniversity.in](mailto:babu@theglobaluniversity.in)*

*DOI: <https://doi.org/10.52458/9788196897437.nsp.2023.eb.ch-07>*

*Ch.Id:-GU/NSP/EB/RTFP/2023/Ch-07*

## **ABSTRACT**

*The burgeoning field of nanotechnology-enabled food packaging offers two pivotal avenues: enhanced packaging materials bolstering barrier properties and active packaging where AgNPs directly interact with food to enhance its protection. AgNPs, renowned for their remarkable antimicrobial efficacy, owe their success to their large surface area and high-temperature stability. As the utilization of nanomaterials in food packaging continues to evolve, it promises to extend the shelf life of perishable goods, reduce food waste, and revolutionize food preservation and safety. However, addressing potential health and environmental concerns while responsibly regulating nanomaterial use is paramount for harnessing the full potential of this transformative technology in the food industry.*

## **1. INTRODUCTION**

Nanotechnology, a transformative interdisciplinary field, operates at the nanoscale, where materials and systems exhibit unique and novel properties, often markedly different from their bulk counterparts, defined as the manipulation and engineering of matter at the atomic and molecular level, nanotechnology represents a profound convergence of science, engineering, and innovation. The essence of nanotechnology lies in its capacity to precisely control and manipulate matter at the nanoscale, typically involving structures and systems with dimensions ranging from 1-100 nm [1-5]. At this minuscule scale, quantum mechanical effects become dominant, affording materials with extraordinary properties that can be engineered to achieve specific desired outcomes. Nanotechnology offers unprecedented opportunities for the design, synthesis, and customization of nanomaterials, nanodevices, and nanosystems with exceptional precision, enabling innovations with far-reaching implications [6]. As we embark on this journey into the realm of nanotechnology, we will delve into its profound impact on diverse sectors, revealing its potential to reshape industries, enhance scientific understanding, and usher in a new era of innovation.

Nanotechnology in food packaging refers to the application of nanoscale materials and technologies to enhance the properties and functionality of packaging materials used in the food industry. At the nanoscale, materials exhibit unique properties and behaviors, which can be harnessed to improve various aspects of food packaging. This section will provide an in-depth explanation of what nanotechnology in food packaging entails, including the use of nanoparticles, nanocomposites, and nanocoatings. It will also explore the fundamental principles and materials involved in nanotechnology, establishing a solid foundation for the subsequent discussions [6]. Numerous advantages have been reported, such as enhanced barrier properties, antimicrobial effects, improved shelf life, and real-time monitoring capabilities. It will

highlight how nanotechnology can address critical issues in the food industry, such as food safety, quality preservation, and sustainability. By elucidating the significance of this technology, readers will gain insight into why nanotechnology is a promising and transformative approach in the field of food packaging. The purpose of this chapter is to provide a comprehensive overview of nanotechnology in food packaging, covering its fundamentals, applications, challenges, and future prospects [Fig. 1]. The structure of the chapter is designed to facilitate a systematic exploration of this topic [5]. It will include sections on the fundamentals of nanotechnology, nanotechnology-based materials used in food packaging, safety and regulatory considerations, practical applications, challenges, case studies, and future trends. This structured approach will enable readers to grasp the breadth and depth of nanotechnology's role in food packaging, fostering a deeper understanding of its potential and limitations in the food industry.

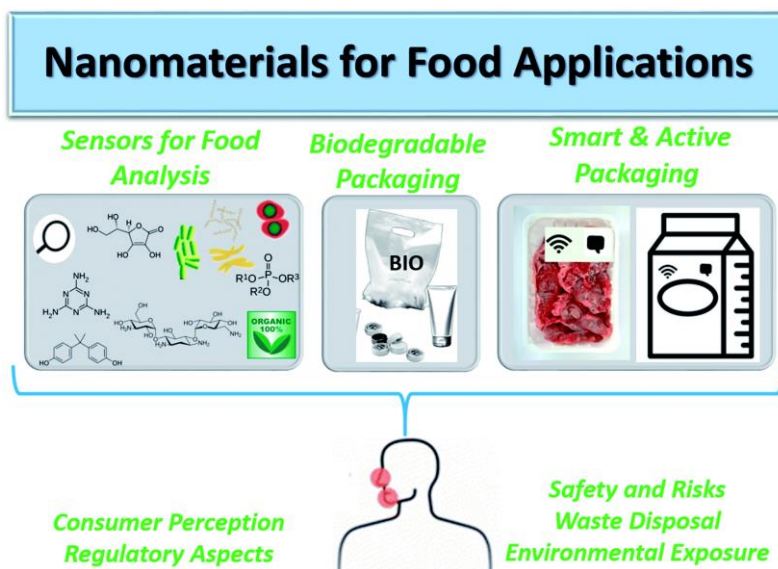


Fig. 1. Schematic representation of applications of nanomaterials in the food sector (Reproduced from ref. [5] under CC-BY Copyright, The Royal Society of Chemistry 2020).

## 2. NANOTECHNOLOGY-BASED MATERIALS

### 2.1. Silver Nanoparticles (AgNPs)

Silver nanoparticles have gained considerable attention in food packaging due to their remarkable antimicrobial properties. At the nanoscale, silver exhibits potent bactericidal and fungicidal activity [5-8]. AgNPs can be incorporated into packaging

materials to inhibit the growth of harmful microorganisms, thus extending the shelf life of perishable food products. Their versatility enables them to combat a broad spectrum of pathogens while minimizing the risk of microbial resistance. Silver nanoparticles can be immobilized within packaging films or coatings, providing a continuous release of silver ions to maintain food safety and quality. AgNPs have garnered widespread attention for their antimicrobial prowess in food packaging. They offer a versatile and potent means of inhibiting the growth of harmful microorganisms, effectively extending the shelf life of perishable products [9]. Incorporating AgNPs into food packaging materials brings forth a myriad of advantages. These nanoparticles enhance the barrier properties of packaging materials, preventing the ingress of oxygen and moisture, thereby preserving food quality. Moreover, they bolster the mechanical integrity of packaging, ensuring the protection of food during transit and storage. The antibacterial properties of AgNPs also mitigate the risk of foodborne illnesses, contributing to enhanced food safety. Recognizing the growing importance of AgNPs in food packaging, regulatory bodies such as the United States Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA) have taken measures to oversee their use.

## **2.2. Zinc Oxide Nanoparticles (ZnO-NPs)**

Zinc oxide nanoparticles are another nanomaterial with notable antimicrobial attributes. ZnO-NPs possess the ability to damage bacterial cell membranes, disrupt microbial metabolism, and inhibit microbial proliferation. They can be integrated into food packaging materials to create surfaces that actively deter microbial contamination [1,5]. Zinc oxide nanoparticles are particularly effective against various foodborne pathogens and are considered safe for use in food packaging applications. In the pursuit of enhancing food safety and extending the shelf life of perishable products, nanotechnology has introduced innovative solutions to the field of food packaging. Zinc oxide nanoparticles (ZnO-NPs) have emerged as a noteworthy nanomaterial with diverse applications in this context.

ZnO-NPs exhibit remarkable antimicrobial properties, making them an attractive candidate for incorporation into food packaging materials. Their ability to damage bacterial cell membranes and disrupt microbial metabolism has been harnessed to inhibit the proliferation of foodborne pathogens. When integrated into packaging, ZnO-NPs create surfaces that actively deter microbial contamination, contributing to food safety. Nanocomposites comprising ZnO-NPs dispersed within packaging polymers have been developed to enhance the barrier properties of food packaging materials. These nanomaterials act as an effective shield, preventing the ingress of

oxygen and moisture into packaged foods [10-12]. The enhanced barrier properties of ZnO-NP-based packaging materials extend the shelf life of products, reduce food spoilage, and maintain product freshness. Beyond their antimicrobial and barrier-enhancing properties, ZnO-NPs can also play a role in preserving the quality of packaged foods. These nanoparticles can be integrated into food packaging to mitigate the impact of external factors such as light exposure, which can lead to the degradation of food quality, particularly in light-sensitive products.

### **2.3 Barrier Enhancement with Nanomaterials**

Nanotechnology facilitates the development of high-performance barrier materials for food packaging. Nanocomposites, comprising nanoscale particles dispersed within packaging polymers, can enhance gas barrier properties, effectively preventing the ingress of oxygen and moisture. This barrier enhancement extends the shelf life of packaged products, reduces food spoilage, and maintains product freshness [13]. Nanomaterials such as layered silicates and clay nanoparticles have been instrumental in this regard. Nanosensors offer the capability to monitor food quality and safety in real-time. These nanoscale devices can detect specific molecules or changes in the environment within the packaging, such as gas composition, temperature, and pH. Nanosensors provide valuable data throughout the supply chain, enabling timely interventions to maintain product integrity and safety.

### **2.4 Nanocoatings for Improved Shelf Life**

Nanocoatings, comprising thin layers of nanomaterials, can be applied to food packaging surfaces to enhance functionality. These coatings can provide moisture resistance, improve printability, and offer antimicrobial protection. Nanocoatings contribute to the extension of shelf life, preservation of product appearance, and prevention of moisture-related quality issues [14]. Nanocoatings, consisting of thin layers of nanomaterials applied to food packaging surfaces, have garnered significant attention for their capacity to enhance food preservation and extend shelf life. These innovative coatings offer a multifaceted approach to improving the quality, safety, and longevity of packaged food products.

**Here, we delve into the key aspects of nanocoatings and their pivotal role in food packaging:**

- **Enhanced Barrier Properties:** Nanocoatings are designed to provide superior barrier properties, serving as a protective shield against external factors that can compromise food quality. These coatings can effectively block the ingress of oxygen, moisture, and other gases, which are primary culprits in food

degradation. By reducing the exposure of packaged foods to these environmental elements, nanocoatings help maintain product freshness and extend shelf life.

- **Moisture Resistance:** Moisture is a common cause of food deterioration, leading to texture changes, microbial growth, and chemical reactions. Nanocoatings with hydrophobic properties create a moisture-resistant barrier, preventing water vapor from penetrating the packaging. This feature is particularly beneficial for items like cereals, snacks, and baked goods, which are sensitive to moisture-induced quality deterioration.
- **Preservation of Product Appearance:** The visual appeal of food products significantly influences consumer choices. Nanocoatings can play a pivotal role in preserving the appearance of packaged foods. These coatings can protect against color fading, discoloration, and the formation of unsightly surface blemishes caused by factors like light exposure.
- **Minimization of Flavor and Odor Transfer:** Nanocoatings can reduce the migration of flavors and odors between packaged foods, preventing cross-contamination of taste and smell. This is crucial in situations where distinct food items are packed together, such as in pre-packaged meals.
- **Reduced Food Waste:** By extending the shelf life of products and maintaining their quality, nanocoatings contribute to reducing food waste. Consumers can enjoy fresher products for more extended periods, resulting in fewer discarded items and a more sustainable approach to food consumption.

## **2.5 Nanotechnology enabled-smart Packaging**

Smart packaging systems leverage nanotechnology to enhance consumer engagement and product integrity. The utilization of nanomaterials has witnessed substantial growth across various domains. In particular, their application in the realm of food packaging has seen a significant upswing over the past decade. Nanotechnology-enabled food packaging can be delineated into two pivotal categories: firstly, the realm of "improved packaging" where nanomaterials are seamlessly blended into the polymer matrix, bolstering gas barrier properties, as exemplified by polymer/clay nanocomposites; secondly, the paradigm of "active packaging," where nanoparticles engage directly with the food or its environment, facilitating enhanced food protection. Notably, silver nanoparticles (AgNPs), celebrated for their potent antimicrobial efficacy, have earned a prominent role as "active packaging" components. Metal nanoparticles endowed with biocidal attributes, including copper (Cu), zinc (Zn), gold (Au), titanium (Ti), and silver (Ag), have emerged as pivotal candidates in this

domain. Among these, silver nanoparticles (AgNPs) have demonstrated unparalleled bactericidal prowess against a wide spectrum of pathogenic microorganisms encompassing bacteria, yeasts, fungi, and viruses. AgNPs' exceptional antimicrobial properties can be attributed to their remarkably expansive surface area, facilitating enhanced interaction with microorganisms [15]. Additionally, their stability at elevated temperatures and low volatility render them especially suitable for diverse food packaging applications. AgNPs can be seamlessly integrated into various matrices, including polymers and stabilizing agents such as citrates and long-chain alcohols, employing diverse strategies such as coating, absorption, or direct incorporation within the synthesis processes [16].

Nano-assemblies demonstrate exceptional versatility by seamlessly integrating into various matrices, including polymers, employing diverse strategies such as coating, absorption, or direct incorporation within synthesis processes. This adaptability extends to stabilizing agents like citrates and long-chain alcohols, crucial for ensuring homogeneity and stability within the matrices. The integration of nano-assemblies with polymers enhances material properties, offering improved strength, durability, and customizable functionalities. The diverse strategies employed, such as coating for protective enveloping, absorption for homogeneous distribution, and direct incorporation for molecular-level blending, provide researchers and industries with flexible options to tailor composite materials for specific applications. This versatility holds significant implications across industries. In medicine, nano-assemblies integrated into polymeric matrices enable advanced drug delivery systems, ensuring controlled and targeted release. Meanwhile, in materials science, the integration of nano-assemblies into polymers paves the way for the development of lightweight, robust materials with applications in the aerospace and automotive sectors. The seamless integration of nano-assemblies into matrices emerges as a transformative avenue, offering unprecedented opportunities for material design and functionality at the nanoscale.

Therefore, these applications underscore the transformative potential of nanotechnology-based materials in food packaging, offering innovative solutions to enhance food safety, quality, and consumer satisfaction while addressing critical challenges in the food industry.

### **3. CONCLUSION**

The integration of nanomaterials, particularly silver nanoparticles (AgNPs), into food packaging represents a pivotal advancement with significant potential for enhancing food safety and quality. The burgeoning field of nanotechnology-enabled food packaging offers two key avenues: improved packaging materials that bolster

barrier properties and "active packaging" where nanoparticles like AgNPs directly interact with the food to provide enhanced protection. AgNPs, in particular, stand out for their exceptional antimicrobial efficacy, attributed to their large surface area and stability at high temperatures. As the application of nano-based materials in food packaging continues to evolve, it holds promise for extending the shelf life of perishable goods and reducing food waste, ushering in a new era of food preservation and safety. However, the responsible and regulated use of nanomaterials, along with addressing potential health and environmental concerns, will be imperative in realizing the full potential of this transformative technology in the food industry.

## REFERENCES

1. Craster, B., and Jones, T.G.J. *Permeation of a range of species through polymer layers under varying conditions of temperature and pressure: in situ measurement methods. Polymers*, **2019**, *11*, 1056.
2. Yusuf, M. *Food Packaging and Preservation: Handbook of Food Bioengineering*, eds. Grumezescu, A.M. & Holban, A.M., Chapter 12 (Academic Press, London UK), **2018**, p. 409-438.
3. Francis, F. J. *Encyclopedia of food science and technology*. (2nd. ed.), New York: Wiley. 2000.
4. Bi, L. J. *Research on corrugated cardboard and its application. Adv. Mater. Res.*, **2012**, *535*, 2171-2176.
5. Mustafa, F. and Andreescu, S., 2020. *Nanotechnology-based approaches for food sensing and packaging applications. RSC advances*, *10*(33), pp.19309-19336.
6. Yusuf, M.; Khan, S.A. *Biomaterials in Food Packaging*, Jenny Stanford Publishing USA, 2022.
7. Yusuf, M.; Shabbir, M.; Mohammad, F. *Natural Colorants: Historical, Processing and Sustainable Prospects. Nat. Prod. Bioprospect.*, **2017**, *7*(1), 123-145.
8. De Tandt, E., Demuytere, C., Van Asbroeck, E., Moerman, H., Mys, N., Vyncke, G., et al. *A recycler's perspective on the implications of REACH and food contact material (FCM) regulations for the mechanical recycling of FCM plastics. Waste Manag.*, **2021**, *119*, 315-329.
9. Diggle, A., and Walker, T. R. *Implementation of harmonized extended producer responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. Waste Manag.* **2020**, *110*, 20-23.

10. Yusuf, M.; Ahmad, A.; Shahid, M.; Khan, M.I.; Khan, S.A.; Manzoor, N. and Mohammad, F. Assessment of colorimetric, antibacterial and antifungal properties of woollen yarn dyed with the extract of the leaves of henna (*Lawsonia inermis*). *J. Clean. Prod.*, **2012**, 27, 42-50.
11. Yusuf, M.; Khan, S.A.; Shabbir, M. and Mohammad, F. Developing a shade range on wool by madder (*Rubia cordifolia*) root extract with gallnut (*Quercus infectoria*) as biomordant. *J. Nat. Fibers*, **2017**, 14(4), 597-607.
12. Yusuf, M.; Khan, M.A. and Mohammad, F. Investigations of the colourimetric and fastness properties of wool dyed with colorants extracted from Indian madder using reflectance spectroscopy. *Optik*, **2016**, 127(15), 6087-6093.
13. Yusuf, M. ed. *Handbook of renewable materials for coloration and finishing*. (Wiley-Scrivener: Beverly US), **2018**.
14. Yusuf, M.; Shahid, M. eds., *Emerging Technologies for Textile Coloration*, (CRC Press; Singapore), **2022**.
15. Martínez-Abad, A., Lagaron, J.M. and Ocio, M.J. Development and characterization of silver-based antimicrobial ethylene-vinyl alcohol copolymer (EVOH) films for food-packaging applications. *Journal Agric. Food Chem.*, **2012**, 60(21), pp.5350-5359.
16. Toker, R.D., Kayaman-Apohan, N.L.H.A.N. and Kahraman, M.V. UV-curable nano-silver containing polyurethane based organic-inorganic hybrid coatings. *Progress in Organic Coatings*, **2013**, 76(9), pp.1243-1250.