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Applications of Metal Nanoparticles in Healthcare and Food Safety

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Abstract. The increased world population has led to a rise in pollution, raising the risk of food contamination and foodborne illness. It is often said that illness enters by the mouth. Food spoilage has always been a great hazard to human health. Therefore, ensuring the safety of food is essential in the pursuit of good health. The advent of nanotechnology has sparked potential in the food industry. Nanotechnology has also shown its ability to reduce cases of foodborne diseases, thereby improving global food security from the root. With the introduction of nanoparticles (NPs), particularly metal NPs like gold and silver, food processing and delivery methods have been further refined. These NPs have demonstrated effective resistance against pathogens. Their antimicrobial abilities play a vital role in nano materials for food packaging. The main mechanism of metal NPs involves their interaction with bacterial cell walls, which enhances cell wall permeability and achieves cell wall damage. At the same time, toxic radicals are released from the NPs and can be dissolved to be absorbed by bacteria. These results in the leakage of cellular contents, inhibiting cell replication, and ultimately, cell death. The application of metal-based NPs significantly contributes to food safety. Therefore, in this work, the applications of various nanomaterials in food safety and healthcare are discussed in detail. This work will contribute to promoting the deep application of nanomaterials in food safety and healthcare.

Keywords: Nanomaterials; metal nanoparticles; food safety; food packaging; antibacterial activity.

1. Introduction

The increasing cases of foodborne diseases have accompanied with the progress of time and technology. An outbreak which was attributed to the Escherichia coli (E. Coli), infected 700 people over 4 states. Such incident awakened human to pursue for better food safety [1]. The world food safety day of 2021, emphasised the importance of quality food and drew greater attention to the relationship between food security and human health, particularly in preventing diseases caused by foodborne pathogens.

Nanotechnology, broadly defined as any real-life application of nanoscale technology, is a revolutionary technique of the 21st century [2]. It has widespread applications in many sectors worldwide, as this technology is not restricted in laboratory scale and can be applied in large scale manufacturing in modern industries as well. Nanostructured materials are extensively used in the food industry, including a variety of different materials such as nanotubes, nano-emulsions, nanocomposites and polymeric nanoparticles. Among these, nanoparticles (NPs) have gained significant popularity in recent years. NPs occur naturally on earth as they can form in all spheres of the earth, including atmosphere, hydrosphere, lithosphere and biosphere. The formation of NPs can occur through chemical methods, mechanical methods, and biological processes, some NPs have also been considered to form in foreign planets [3]. The commonly used NPs are metal based NPs, including silver, gold and copper. Besides, other metal oxide-based nanoparticles include copper oxide, zinc oxide and iron oxide. Metal NPs vary in size, composition, shape and structure. Their properties also largely depend on those features; however, most metal NPs hold similar properties. They have been shown to be just as effective as traditional antimicrobial agents. Their bacteria selectivity and reduction ability allow them to be involved in a range of biomedical applications [4]. Nanotechnology holds promising potential in the food industry. From food processing to packaging, nanotechnology can change the colour, nutritional functions, flavour and texture of food. The use of nanomaterials could also extend shelf life and remove pathogens from food products [5].

2. Metal Nanomaterials

In recent years, nanotechnology has gained attention across a wide range of fields, including biomedicine, mechanical, chemical and electronics engineering. Metal NPs have distinct physical and chemical properties of nanomaterials, such as their unique small size and large surface area to volume ratio. The uses of nanomaterials have expanded from traditional scientific research in drug development, medication manufacturing, and materials science into daily life tools, ranging from electronic equipment to skincare products [6]. Nanomaterials are defined as materials with nanoscale dimensions (1 to 100 nm) or materials with nanoscale structures on their surface [7]. Scientists were able to observe a NP directly, under a high spatial resolution microscope in late 20th century [8].

The classification of NPs largely depends on their properties, shapes and size. They can be grouped into the following categories including fullerenes, polymeric NPs, ceramic NPs, and metal NPs [6]. The applications of NPs, whether physical or chemical, also depend heavily on their shape and size. Metal based NPs, in particular, have been widely used in the development of new technologies, especially in biomedical sciences and engineering [9]. Their special localized surface plasmon resonance (LSPR) characteristic endows them with distinctive optoelectrical properties, making them suitable for application across many research areas [7]. They are made of pure metal, common metallic NPs include Au, Ag, Pt, Cu, Pd, Re, Zn, Ru, Co, Cd, Al, Ni, and Fe. Among these, silver and gold NPs are the most commonly used metal NPs. They are used extensively in industry and laboratories as well as various household products, including paints, sportswear, disinfectants, food storage and package equipment [10].

2.1. Silver-Based NPs

Silver NPs (AgNPs) can range in size between 1 and 100 nm. They possess strong resistance against bacteria, viruses and fungi [10]. This powerful antimicrobial property enables vast applications of AgNPs in different areas, and it is often used as an antibacterial agent. Current uses of AgNPs in household products include cosmetics, textile fabrics and refrigerator surfaces. Leveraging their antibacterial property, they are applied in clinical settings. Where they have been used for treating wounds, burns and chronic ulcers, accelerating the healing process by causing sufficient collagen deposition [11]. In recent years, there have also been attempts to integrate AgNPs into various medical devices including bone cement and surgical instruments.

Modern research has demonstrated the fact that AgNPs could penetrate bacterial cell walls and successfully disrupt bacterial DNA replication by releasing silver ions which increase permeability of cell membranes and produce reactive oxygen species [12]. This antibacterial property allows AgNPs to gain applications in the food industry, particularly in synthetic plastic polymers. The presence of AgNPs in food packaging materials can effectively prevent growth of S. aureus, E.coli, Styphimurium, and other common foodborne pathogens at low concentrations. Besides, AgNPs also offer elongation at break, which strengthens the packaging materials. It can reduce the chances of tearing or rupturing. It can also enhance the safety and quality of food products [12].

2.2. Gold-Based NPs

Colloidal gold, which is also known as gold NPs (AuNPs), typically ranges in size from 2 to 100 nm and has a neutral oxidation state. The use of colloidal gold can be traced back to Roman times when it was used for decorative stained glass. However, proper scientific evaluation of colloidal gold only began with the work of Michael Faraday in the 1850s, when he observed the differences between the properties of bulk gold and the properties of Au NPs [9]. In the 1950s, AuNPs were used for treating malignancies in humans. Today, they are used in similar ways to AgNPs, serving as antibacterial agents. By altering the functional groups of AuNPs, a highly effective nano-system against both Gram-negative and Gram-positive bacteria pathogens is acquired.

AuNPs have been used in drug delivery systems and imaging techniques in clinical studies. AuNPs are largely used in the food industry due to its therapeutic activity. It is a common use of them is in polymer material for food packaging. AuNPs-based food contamination sensor is the most promising applications of AuNPs due to their beneficial characteristics, including high selectivity, reactivity and sensitivity [13, 14]. Like AgNPs, AuNPs also offer effectual shape stability when embedded in other materials as well as the ability to produce reactive oxygen species. This allows them to interact with both gram-negative and positive bacteria. These properties decrease chances of common foodborne pathogen developments [15].

2.3. Copper-Based NPs

Copper nanoparticles (CuNPs) primarily refer to pure copper nanoparticles. However, CuNPs also include copper ions as well as CuO and Cu_2O nanoparticles, typically ranging in size from 1 to 100 nm.

Copper, being one of the most abundant elements on earth, has various characteristics including high electrical conductivity and high melting point. They are also more cost efficient than both gold and silver [16]. However, natural copper usually exists in low purity form compounds whilst applications of it often require using pure copper, copper ions or copper nanoparticles [16]. Therefore, copper needed to be extracted from its ore, in order to fully put them into biological use.

CuNPs also have an extremely large surface area to volume ratio, which allows them to be used in numerous fields, includes sensors, optics, catalyst and electronics [9]. CuNPs, being another bacteria-resistant metal, can also be used for antimicrobials applications. As CuNPs accumulate on the bacteria cell surface, they release Cu^{2+} ions which result in the reduction of transmembrane electrochemical potential of the bacteria. Consequently, the membrane integrity is affected, leading to cell death as a reslut of the leakage of essential cell components [9, 16]. Their small size effect and excellent antimicrobial properties have also gained attention in agricultural applications. CuNPs can be easily taken up by plants from soil, and their presence in soils have shown positive effects, such as promoting productions of chlorophyll. CuNPs can offer low biotoxicity and high efficiency, showing potential to improve resistance against crop diseases and increase crop yields.

Another commonly used copper-based NP is CuO NP. In terms of its structure, it is the simplest constructed member within the copper group [9]. However, strong antimicrobial property of CuO NPs is vital in inhibiting the growth of bacteria, fungi, viruses and algae. They also contribute to an important role in improving the physical structures and biological activity of biomaterials [15].

2.4. Zinc Oxide (ZnO) NPs

ZnO NP is one of the most extensively researched nanomaterials. Being the second most abundant metal oxide after iron oxide, they are inexpensive, easy to access and safe to use [17]. ZnO NPs often appear in spherical form, ranging in size between 40 and 70nm. They offer diverse advantages, including high selectivity, lower toxicity and lower microbial resistance. Those characteristics enable their applications in areas such as analytical sensing.

In addition to those physical characteristics stated above, a great number of studies concerning with ZnO NPs show they have outstanding antimicrobial effect against pathogens. They have the ability to deform fungal hyphae and inhibit growth of both Botrytis cinerea (B. cinerea) and Penicillium expansum (P. expansum) [18]. ZnO NPs exhibit active antimicrobial activity by releasing reactive oxygen species (ROS) on their surface, including hydrogen peroxide, hydroxyl radicals and peroxide radicals [14]. Those reagents are responsible for damaging pathogenic proteins by destruction of cell walls. This effect is achieved by altering the membrane permeability of pathogens and releasing toxic dissolved Zn ions that would be absorbed by pathogens [19]. Consequently, bacterial activity can be decreased.

However, ZnO NPs are harmless to humans and other animals. It makes them suitable for use in the food industry, where they are often employed as surface coatings. Saedi et al. studied ZnO NPs film through antibacterial tests. The results indicated that 3% of ZnO NPs could effectively prevent the growth of various bacteria, including B. cereus and E. coli. Further studies using SEM imaging to explore the process by which ZnO NPs attach to bacterial cell wall. It is proved that through electrostatic or direct interaction, causing leakage of cellular contents [20].

3. Conclusion

Food holds essential nutritional value, serving as the primary source of energy for any living organism. High-quality food provides more energy, thereby better sustaining the metabolism of an individual. Embracing nanotechnology in the food industry could further enhance the quality of food. In this work, a brief overview of several different metal-based NPs was presented. It focuses on their principle antimicrobial ability. Their large surface area to volume ratio property is also notable, making them invaluable antimicrobial agents, as they can interact with pathogenetic microorganisms. This review also discussed the applications of metal NPs, particularly in terms of food safety related applications. Integration of metal NPs with nanomaterial packaging acts as a barrier preventing growth of foodborne pathogens, allowing consumers to access fresh health food products.

Current obtainable information cannot provide sufficient proof of long-term impact of certain NPs on human body. Therefore, it underscores the necessity of further research to understanding the toxicity of metal NPs. The use of metal NPs must also consider their toxic impact exerted to the environment, such as water pollution. As dissolved metals enter the water system, they could harm aquatic organisms including bacteria, fungi, algae and fish, potentially disturbing the ecosystem. Despite concerns about the potential toxic effects of individual metal-based NPs, they offer promising benefits for maintaining and improving food quality. A balanced assessment of the potential metal NPs and the associated risks against it is needed. It is crucial to develop nanomaterial technology, particularly in enhancing the sustainability and safety of metal NPs. With continuous research on nanomaterials, the discovery of new methods and materials will help further optimize and refine this technology, leading to a more powerful food safety system.

References

[1] M.D. Weinroth, A.D. Belk, K.E. Belk, History, development, and current status of food safety systems worldwide, Anim Front 8 (2018) 9-15.

[2] B. Bhushan, Springer Handbook of Nanotechnology, fourth ed., Springer, Berlin, 2017.

[3] M. Sharon, History of Nanotechnology: From Prehistoric to Modern Times, first ed., John Wiley and Sons, NewYork, 2019.

[4] H. Jiang, L. Li, Z. Li, X. Chu, Metal-based nanoparticles in antibacterial applications in biomedical field: Current development and potential mechanisms, Biomedical Microdevices 26 (2024) 1-15.

[5] C. Challaram, G. Murugaboopathi, A.A. John, R. Sivakumar, S. Ganesan, S. Krithika, G.Priya, Significance of nanotechnology in food industry, Apcbee Procedia 8 (2014) 109-113.

[6] I. Khan, K. Saeed, I. Khan, Nanoparticles: properties, applications and toxicities, Arabian Journal 12 (2019) 908-931.

[7] B. Mordorski, A. Landriscina, A. Friedman, An overview of nanomaterials in dermatology, Nanoscience in Dermatology 1 (2016) 31-46.

[8] S. Chen, J. Wang, B. Xin, Y. Yang, Y. Ma, Y. Zhou, L. Yuan, Z. Huang, Q. Yuan, Direct observation of nanoparticles within cells at subcellular levels by super-resolution fluorescence imaging, Anal. Chem 91 (2019) 5747-5752.

[9] V.V. Mody, R. Siwale, A. Singh, H.R. Mody, Introduction to metallic nanoparticles, J. Pharm. Bioallied. Sci 2 (2010) 282-289.

[10] P. Talarska, M. Boruczkowski, J. Żurawski, Current knowledge of silver and gold nanoparticles in laboratory research-application, toxicity, cellular uptake, Nanomaterials 11 (2021) 2454-2467.

[11] G.E.Yılmaz, I. Göktürk, M. Ovezova, F. Yılmaz, S. Kılıç, A. Denizli, Antimicrobial nanomaterials: A review, Hygiene 3 (2023) 269-290.

[12] F. Trotta, S.D. Silva, A. Massironi, S.F. Mirpoor, S. Lignou, S.K. Ghawi, D. Charalampopoulos, Silver bionanocomposites as active food packaging: Recent advances & future trends tackling the food waste crisis, Polymers 15 (2023) 4243-4254.

[13] L. Yao, D. Bojic, M. Liu, Applications and safety of gold nanoparticles as therapeutic devices in clinical trials, J. Pharm. Anal 13 (2023) 960-967.

[14] C. Couto, A. Almeida, Metallic nanoparticles in the food sector: A mini-review, Foods 11 (2022) 402-424.

[15] H. Ahari, M. Fakhrabadipour, S. Paidari, G. Goksen, B. Xu, Role of AuNPs in active food packaging improvement: A review, Molecules 27 (2022) 8027-8049.

[16] Y. Wang, W. Zhang, Q. Yao, Copper-based biomaterials for bone and cartilage tissue engineering, Journal of Orthopaedic Translation 29 (2021) 60-71.

[17] A. M. Holban, A. M. Grumezescu, E. Andronescu, Inorganic nanoparticles designed for drug delivery and anti-infective surfaces, in: Surface Chemistry of Nanobiomaterials, Applications of Nanobiomaterials 3 (2016) 301-327.

[18] M.J. Klink, N. Laloo, A.L. Taka, V.E. Pakade, M.E. Monapathi, J.S. Modise, Synthesis, characterization and antimicrobial activity of zinc oxide nanoparticles against selected waterborne bacterial and yeast pathogens, Molecules 27 (2022) 3532-3545.

[19] A. Sirelkhatim, S. Mahmud, A. Seeni, N.H.M. Kaus, L.C. Ann, S.K.M. Bakhori, H. Hasan, D. Mohamad, Review on Zinc Oxide Nanoparticles: Antibacterial Activity and Toxicity Mechanism, Nanomicro Lett 7 (2015) 219-242.

[20] S. Smaoui, I. Chérif, H.B. Hlima, M.U. Khan, M. Rebezov, M. Thiruvengadam, T. Sarkar, M.A. Shariati, J.M. Lorenzo, Zince Oxide nanoparticles meat packaging: A systematic review of recent literature, Food Packaging and Shelf Life 36 (2023) 101045-101065.