A study on applications and usage of metal-based nanoparticles in foods

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Abstract- Nanomaterials research is continually developing, allowing for the creation of novel materials and, more importantly, the discovery of new applications. Biomedical applications, engineering sciences, and food technologies all make extensive use of nanotechnology. The use of nanocompounds is essential for protecting, preserving, and extending the shelf life of food. The quality of food is directly impacted by alterations in lifestyle, the usage of pesticides, and biological and/or chemical pollutants. Metallic nanoparticles (MNPs) are helpful for creating goods with antibacterial properties and with the potential to lengthen food and food product shelf life. It is simple to combine biopolymers/polymers with various MNPs, that allows the merging of organic chemicals with metallic nanocompounds, which act as a transporter for a range of materials.. However, before using nanoparticles in food packaging, risk assessment is required. As quality and safety are desired in food technology, we want to address how MNPs can be employed for food preservation in this review.

Index Terms- Review, Metallic nanoparticles, Food nanotechnology, Food preservation.

I. INTRODUCTION

Depending on their size and usual structural form, nanoparticles (NPs) exhibit a variety of diverse characteristics. NPs diverge from similar materials on a macroscopic scale due to their high surface/volume ratio, opening up new possibilities for applications (Fratoddi et al., 2017). The differences in the electronic structure, the abundance of surface atoms, the rise in unsaturated bonds (dangling bonds), and the band gap variations are all caused by quantum processes (Rapa and Vinci, 2018). In order to create nanomaterials for particular purposes, controlled synthesis is used to increase the nano size of NPs (Venditti et al., 2017). This makes it possible to produce nanoscale structures with certain morphologies, controlled frameworks, and useful properties. There are many different types of nanoparticles, including magnetic, metallic, and polymeric ones. Additionally, NPs can be functionalized in numerous ways, such as hydrophilic or hydrophobic ones, which significantly influences the applications for them. NPs can however be used in a variety of applications, including biomedicine, medication delivery, sensing, optoelectronics, and food regulation (Vinci and Rapa, 2019).

Biomedical applications, engineering sciences, food, and agriculture all benefit greatly from nanotechnology. In this context, nanoparticles are essential for both the development of sensors and for the protection and preservation of food (Pandit et al., 2017). The widespread use of pesticides and other biological and chemical pollutants found in food has a direct impact on the amount of nutrients in food. Packaging materials are essential for the preservation of food products. Because they prevent food products from deteriorating due to physical, chemical, or biological reasons and maintain the overall quality during storage and handling of food products (Youssef et al., 2015). Metallic nanoparticles (MNPs) have gained a lot of attention because they can be used to create antimicrobial goods that have the potential to extend food's shelf life by preventing bacteria development. They interact with various microbial cells, exterminate them, and may prevent the development of biofilms (Rai et al., 2017). The use of MNPs in food packaging, an intelligent system for food preservation, has been demonstrated in a number of studies. Additionally, MNP-based sensors are employed to identify food pollutants, specifically microorganisms (Sarwar et al., 2018). It is commonly known that the food sector uses nanotechnology, particularly in the production and packaging of food and food-related products. Numerous studies have been conducted in this domain, and several excellent evaluations have also been published. The current review's objective is to provide a summary of the usage and applications of metallic nanoparticles in food and their adverse consequences on the environment. Additionally highlighted are antimicrobial activity, food preservation, and food contaminant identification.

II. USE OF SILVER NANOPARTICLES

As evidence of their powerful antibacterial properties, silver nanoparticles (AgNPs) can be applied in food packaging materials and processing (Siddiqi et al., 2018; Shanmuganathan et al., 2019). In this case, the efficiency of an antimicrobial packaging technique including active AgNPs on the deterioration of Fior di Latte cheese quality was evaluated by (Incoronato et al., 2011). The authors utilized agar-embedded silver montmorillonite in three distinct concentrations. It was shown that active packaging technology significantly affected on Fior di Latte cheese and extended the shelf life and quality of Fior di Latte cheese. The active packaging solution created in the study, according to the authors, might be utilized to extend Fior di Latte's shelf life. In another investigation, AgNPs and grapefruit seed extract were used to make ternary blend agar/alginate/collagen hydrogel films (Wang and Rhim, 2015). The resulting hydrogel film was extremely clear and shown effectiveness against bacteria that are found in food and are both Gram-positive (*Listeria monocytogenes*) and Gram-negative (*Escherichia coli*) (Dos Santos et al., 2020). Utilizing polylactic acid (PLA) biopolymers combined with MNPs can improve the natural constitution of PLA's physico-mechanical properties, encouraging greater flexibility and stronger mechanical constructions. The inclusion of cinnamon oil and MNPs changed the rise in barrier characteristics (Ahmed et al., 2018). In a related study by (Li et al., 2017), PLA was impregnated with AgNPs and titanium dioxide, which had no significant effect on the glass transition characteristics but increased the cold crystallisation of PLA nano-blend films, which had antibacterial efficacy against *E. coli and L. monocytogenes*. The packaging created by the intelligent nanosystem enables the regulation of oxygen restrictions, the spread of microorganisms, and the addition of sensors to assess the safety of the food. In this situation, the efficacy of low-density polyethylene/Ag (LDPE/Ag) nanocomposites in food preservation against biofilm-forming E. coli was evaluated. The outcomes demonstrated that the addition of AgNPs had no effect on the thermal or surface properties of polyethylene. Additionally, LDPE/Ag nanocomposites showed effectiveness against *E. coli* and associated biofilm (Olmos et al. 2018).

III. USE OF COPPER NANOPARTICLES

Biodegradable hydroxypropyl methylcellulose (HPMC) matrix coated by copper nanoparticles (CuNPs) was found to have an exceptional antibacterial activity. Due to the addition of CuNPs, the film demonstrated mechanical and water vapour barrier capabilities. The researchers suggested using CuNP-impregnated films to package and preserve food items like meat in order to prevent microbial development (Ebrahimiasl and Rajabpour, 2015). Additionally, research on copper-polymer nanocomposite films that have already shown antibacterial properties. These nanocomposites are effective against *Pseudomonas spp.*, *E. coli*, *S. cerevisiae*, *Streptococcus spp.*, *and S. aureus*, among other bacteria (Tamayo et al., 2016). Similarly, biodegradable poly—caprolactone, monomer from used poly(ethylene terephthalate) oil bottles, and zinc oxide-copper oxide nanoparticles were used to create scientifically manufactured metal-oxide polymer nanocomposite films. The nanocomposite metal-oxide polymer films had exceptional mechanical qualities. According to the authors, this kind of material can be used for household packaging (Varaprasad et al., 2017). Silver-copper alloy nanoparticle nanocomposite films were created by Arfat et al. (2017) using guar gum. The improved mechanical strength, as well as the effectiveness of the UV and oxygen barriers, were discovered when the scientists assessed the influence of Ag-Cu nanoparticles after loading on guar gum. Additionally, the film made in this way shown antibacterial activity against *L. monocytogenes* and *S. typhimurium*. Gram-negative bacteria were more resistant to the Ag-Cu nanoparticles than Gram-positive bacteria. There have been reports of copper-based nanocomposites having potential antibacterial action against a variety of Gram-positive and Gram-negative bacteria. Many studies have provided detailed explanations of several potential mechanisms for the mode of action of copper-based nanocomposites (Dos Santos et al., 2020).

IV. USE OF GOLD NANOPARTICLES

The major sources of food contamination are the use of dangerous chemicals during processing or the presence of chemical compounds in packaging materials, which is a significant issue that food manufacturers have noticed. One pollutant found in food that seeps through packaging into food is bisphenol A (Dos Santos et al., 2020). The most promising method takes use of gold nanoparticles (AuNPs), which have fascinating qualities including reactivity, selectivity, and specificity that make them effective and sensible against food pollutants. In order to increase the sensitivity of the detection of BPA residual in milk, AuNPs were also used to potentialize alteration of the substrate using an aggregation agent (Yang et al., 2017). Studies looked at the optical characteristics of AuNPs in thin films, enabling the production of fluorescent semiconductor material. The researchers effectively integrated AuNPs into gelatin-SiNP composite thin films. Due to its portability, flexibility, transparency, and wide range of uses, this composite film is crucial (Shi et al., 2013). The Ca^{2+} content in meat can also be determined using electrochemically sensitive sensors. With AuNPs, oxygen plasma-treated graphene was utilized. This electrochemical technique was employed to identify pork. The authors thought that this technique may be used to find Ca^{2+} in samples of meat. (Fan et al., 2020).

Different pathogenic bacteria frequently contaminate food, making prompt detection of these organisms crucial. These bacteria pose a serious threat to human health on a global scale. These microbes often consist of fungus, bacteria, viruses, and other parasites. Among these, fungus secrete numerous mycotoxins in food, which are crucial since they seriously impair human health (Richard, 2007). Mycotoxins are dangerous secondary metabolites made by a range of fungi, primarily *Aspergillus*, *Fusarium*, and *Penicillium* species. (Goyal et al., 2017). According to Mateo et al. (2018), mycotoxins cause about 25% of the food crops worldwide to become contaminated each year, causing significant economic and agricultural loss. Common food and feed products that contain these mycotoxins include cereals grains, oilseeds, spices, coffees, and nuts (Negash, 2018). The function of several AuNPs-based assays for the discovery of food-borne microorganisms was evaluated by Pissuwan et al. (2019). In a different recent study, Bhardwaj et al. (2020) included gold nanoparticles to construct a surface plasmon resonance (SPR)-based nanosensor (chip) for the detection of aflatoxin in food (AuNPs).

V. NANOTECHNOLOGY: CURRENT APPLICATIONS IN FOODS

Consumer products such as food additives, food preservation, and food packaging are just a few examples of how food nanotechnology has impacted these industries. Acceptance of this innovative technology has enhanced methods for handling and storing food that guarantee food safety. Numerous conventional substances that are utilised as food additives or packaging materials have also been found to partially exist at the nanoscale (He et al., 2019). Public concern over potential hazards has also been raised by the use of innovative food nanotechnology and the presence of nanoscale substances. In this essay, we thoroughly examine recent developments on the use of food nanotechnology (Weir et al., 2012). Nanomaterials, such as nanoencapsulation and nanoemulsion, are particularly suited for use as colour or flavour enhancers, preservatives, or carriers for food supplements, including animal feed products. When used as components or supplements in food processing, engineered nanoparticles' special features offer significant benefits (He et al.,2019). Food contact materials are designed to come into direct contact with food products during production, delivery, and storage. The food sector has been studying and developing nanotechnology as an innovative alternative for food packaging (Pereda et al., 2019). Nanomaterial-encoded edible covering has also demonstrated its potential for food preservation and storage. Fruits and vegetables that have been coated with fresh food remain edible during storage and transit. Active respiration processes may result in significant postharvest losses and decreased nutritional and aesthetic quality of goods as transit and storage times rise (He et al., 2019). Recently used nanomaterials in wide range of food products are presented in **Table 1**.

Table no 1. **Recent applications of nanomaterials in foods.**

Applications	Nanomaterials	Reference
Antibacterial activity against *staphylococcus* spp., *Listeria* spp. and *Bacillus* spp.	To create silver (AgNPs) and gold nanoparticles, chlorauric acid (HAuCl4) and silver nitrate (AgNO3) were combined with *Z. officinale* root extract (AuNPs)	Velmurugan et al., 2014
Colorimetric sensors in food safety screening	Gold nanoparticles	Chen et al., 2018
The impact of size and shape-controlled biogenic production of gold nanoparticles and their method of interactions with bacteria found in food	Gold nanoparticles	Chandran et al., 2019
Detecting trace levels of 2,4-dichlorophenoxyacetic acid (2,4-D), pymetrozine and thiamethoxam	Mesoporous silica supported orderly-spaced gold nanoparticles	Xu et al., 2020
Antimicrobial activity against *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Bacillus subtilis, Candid. albicans, Aspergillus niger, A. terreus, Penicillium expansum* and *Fusarium oxysporum*.	Cellulose Acetate/Polycaprolactone-Based Superhydrophobic Antimicrobial Film Containing Green Biosynthesized Copper Nanoparticles	El-Naggar et al., 2022
Detection of volatile sulfur compounds during fish spoilage	Colorimetric indicator based on copper nanoparticles (CuNPs)	Teymouri and Shekarchizadeh, 2022
Fabrication of	Biopolymeric films	Saravanaku

antibacterial metal-polymeric film for food packaging applications	that contain copper oxide nanoparticles, sodium alginate, and cellulose	mar et al., 2020
Antimicrobial properties against *Escherichia coli*, *Salmonella typhimurium*, *Bacillus cereus* and *Staphylococcus aureus*	Green synthesis and characterization of copper nanoparticles using *Eryngium caucasicum* Trautv aqueous extracts	Hasheminya and Dehghannya, 2020
Effective covering to enhance the barrier and antibacterial characteristics of paper for applications in food packing	Carboxymethyl cellulose/cellulose nanocrystals immobilized silver nanoparticles	He et al., 2021
Detection of aflatoxin B1 in foods and feeds	Gold nanoparticle immunochromatographic strip	Liu et al., 2013

VI. TOXICOLOGICAL CONCERNS

This review has already covered the uses of significant MNPs and other diverse nanomaterials in food. However, the presence of nanoparticles in materials, particularly those in contact with food, raises serious concerns about their toxicity and biosafety. MNPs are examples of nanomaterials that have the potential to be harmful depending on contact, exposure conditions, and exposure period. Experimental models including zebrafish, mice, and others have been used to study the toxicological effects of various nanomaterials in vitro (using a variety of cell lines) and in vivo (using living organisms) (Dos Santos et al., 2020). According to the findings that are accessible, it is evident that nanoparticles have toxicological impacts on living things as well as on natural ecosystems, a phenomenon known as ecotoxicity. There is ecological interconnectivity between these living species and the ecosystem because the flora and fauna in the ecosystem contribute to the preservation of the ecological equilibrium. However, it was shown that the ecological equilibrium may be disturbed by nanomaterials due to their toxicological effects (Sengul and Asmatulu, 2020). Therefore, it is vital to assess the toxicological impacts of nanomaterials and comprehend how they interact with the many organisms present in the environment.

Natural nanoparticles have also been interacting with many living things for millions of years in the environment. However, synthetic NPs creep into our daily life and keep growing without our knowledge. The design of manufactured NPs incorporates certain surface chemistries and features that offer them distinct toxicological and physico-chemical characteristics compared to natural ones (Turan et al., 2019). The unregulated deposition of metal-based nanoparticles in terrestrial ecosystems, particularly in agricultural systems, has seriously harmed organisms like soil bacteria and fungus. This happens as a result of the improper handling of biosolids during the wastewater treatment process and their use in agricultural fields to increase soil fertility (Ameen et al., 2021). Applications of nanotechnology have recently attracted more attention in a number of disciplines (agriculture, materials science, medicine, pharmacy, environmental protection etc.). It is inevitable that people will come into contact with nanoparticles (NPs) due to the expanding range of applications. Numerous investigations have shown that after inhalation or oral exposure, NPs accumulate in the lungs, kidneys, digestive system, heart, liver, spleen and cardiac muscle. Additionally, they disrupt the balance of glucose and lipids in mice and rats (Baranowska-Wójcik et al., 2020). Additionally, research and development are still ongoing for NP-specific toxicity assays and risk assessment approaches. Additionally, conflicting and inconsistent findings regarding the physicochemical properties as well as the fate and transit of NPs in the environment point to the need for additional study (Lekamge et al., 2020).

VII. REGULATIONS FOR HUMAN SAFETY

It is essential to analyse the environment's ability to degrade nanomaterials for human safety before using them in food packaging (Dos Santos et al., 2020). The emission of graphene-based carbon nanotubes from poly(lactic) nanocomposite films was discovered by Kotsilkov et al. (2018). The influence of contaminations and the emission of nanocompounds on polymer film are serious issues. For PLA sheets and nanoparticle migration, the measured limit for migration was calculated to be between 0.028 and 0.053 mg/cm^2 and 0.006 and 0.01 mg/cm^2, respectively. Both fall below the 0.10 mg/cm^2 total EU regulation level. According to Dimitrijevic et al. (2015), the quality of a nanomaterial determines how it affects the human body. The time required for the circulation of hydrophilic, positively charged nanoparticles increases. Although the precise mechanism is unknown, it is assumed that oxidative stress is the basis for the toxicity. The importance of nanomaterials in food science is critical from the outset till the uptake by living organisms, according to Gallocchio et al. (2015). The key principles for employing nanomaterials in food were given by the authors. Nanomaterials fall under the "Novel Food" Regulation (258/97), which applies to "foods and food ingredients with a new or intentionally modified primary molecular structure," and are subject to a risk assessment procedure before receiving market approval, when used as primary ingredients (such as in nanoemulsions). They must be entered into the EU register prior to use if they are used as food additives, according to a distinct method (Reg 1333/2008)(Gallocchio et al. 2015). It is important to highlight that Switzerland appears to be the only country with nano-specific rules built into existing legislation; in contrast, in other nations, nanoparticles are governed more subtly by mostly relying on industry input (Amenta et al., 2015).

VIII. CONSLUSION

The benefits and uses of MNPs and nanocompounds in treating contamination and preserving food are well known. Materials, mixtures, and hybridization are more appealing due of their versatility. AgNPs, AuNPs, and CuNPs are examples of MNPs that have previously shown a broad spectrum of antibacterial efficacy against pathogenic bacteria, fungi, and yeasts. They also make an appealing combination with other materials to give broad applicability due to their physical characteristics, which include high reactivity, specificity, and selectivity. Food technology requires more sensors in order to continuously monitor processes, chemicals, and nutrients. There is still much to learn about risk assessments, biosafety, and legislation pertaining to these substances.

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