AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 05 Issue: 10 October 2024 Article No: 34

Applications of Nanotechnology in Food Processing and Packaging

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SUMMARY

Nanotechnology is an advanced tool that can greatly benefit the food, pharmaceutical, and agricultural sectors. Nanomaterials offer the ability to produce healthier, safer, and higher-quality functional foods, especially those that are perishable or semi-perishable. These materials improve food quality and extend shelf life compared to traditional methods while also reducing contamination risks. This overview explores the current and potential uses of nanotechnology in food production, focusing on processing, packaging, safety, and storage. By modifying particle size, cluster formation, and surface properties, nanotechnology enhances food bioavailability, taste, texture, and consistency. A Nano sensor in smart packaging help monitor food quality during storage, and the impact of nanomaterials on biological systems is also analysed. Additionally, the use of nanomaterials for food protection and the delivery of nutraceuticals is highlighted.

INTRODUCTION

Nanotechnology, which involves manipulating nanomaterials, plays a vital role in enhancing food quality, crop improvement, and human health within the food and agriculture sectors (Duncan, 2011). Engineered nanoparticles have gained prominence in various fields, including medicine, agro-food, and wastewater treatment, due to their unique physical, chemical, and biological properties, such as increased surface-area-to-volume ratio, altered solubility, and toxicity compared to larger particles (Parisi et al., 2015; El-Temsah and Bioforsk, 2006). Nanoparticles like silver, gold, zinc oxide, titanium dioxide, and carbon are widely produced for their antimicrobial properties, being used in items such as air filters, food containers, deodorants, and more (El-Temsah and Bioforsk, 2006; Kumari et al., 2012). Nanosized copper oxides (nCuO) are also heavily utilized in commercial biocide products due to their potent antibiotic effects (Nair et al., 2010).

Nanomaterials, ranging from 1 to 100 nm in size, are insoluble or bio-persistent particles used across industries, including medicine, electronics, agriculture, and food (Duncan, 2011). Food waste is a significant issue, with over 1.3 billion metric tons lost annually due to inadequate post-harvest practices, poor storage, and transportation (Tricco et al., 2019). To address the global food crisis driven by population growth and environmental concerns, it is crucial to reduce food waste and boost food production. The main causes of food waste are microbial contamination and degradation, which reduce food quality, threaten food security, and increase the risk of foodborne illnesses (Sperber and Doyle, 2009). Nanotechnology offers solutions through nanosensors that detect pathogens and contaminants, enhancing food safety. Additionally, nanotechnology-based packaging extends shelf life by incorporating antimicrobial properties, improving over conventional plastic packaging (Sekhon, 2010). Nanotechnology is also used for detecting food toxins, enhancing flavor, and color formation. Smart systems utilizing nanotechnology allow for better monitoring and control of food products. Nano-based delivery systems can enhance the nutraceutical value of food.

Beyond food applications, nanomaterials promote plant growth, such as TiO2 improving plant growth, gold nanoparticles increasing seed yield, and cellulose nanocrystals boosting seed germination through better water absorption (Bajpai et al., 2018). Biologically synthesized metallic nanoparticles possess antibacterial properties that protect plants from disease and reduce environmental pollution. Carbon nanotubes, for example, can damage or kill E. coli cells by physically puncturing them (Kang et al., 2007). Nano-biosensors are used in food production to detect contaminants, including cancer-causing microorganisms. This analysis explores nanotechnology's applications in food processing, preservation, storage, and safety, focusing on extending shelf life and enhancing food quality. It also reviews the potential of nanotechnology in nutraceuticals, pathogen detection, and its impact on human and animal health.

Nanotechnology in Food Processing: "Nanofood" refers to food produced using nanotechnology for processing, production, safety, and packaging. Nanotechnology enhances post-harvest food processing by improving bioavailability, taste, texture, and consistency, as well as masking unpleasant flavors or odors. It also modifies particle size, distribution, and surface charge (Powers et al., 2006). Edible nano-coatings, approximately 5 nm thick, can be applied to various foods such as meat, fruits, vegetables, cheese, baked goods, and confectionery to serve as moisture and gas barriers while enhancing flavor, color, and shelf life. Some baked products even feature antibacterial nano-coatings (Azeredo et al., 2009; Naoto et al., 2009).

Nanofilters are used in food processing, such as removing lactose from milk for lactose-intolerant individuals, or extracting color from beetroot juice while preserving flavor. Nanoscale filters can also eliminate bacteria from milk and water without boiling, and similar nanomaterials are employed in filtering beer and milk using nanosieves (Sekhon, 2010; Naoto et al., 2009).

Nanotechnology for Food Packaging

The packaging industry plays a major role in the global economy, with around 55–65% of $130 billion in the U.S. spent on food and beverage packaging (Brody et al., 2008). In recent years, the use of active and intelligent packaging for muscle-based foods, like meat, has grown significantly to prevent spoilage, reduce contamination, retain moisture, enhance tenderness, and preserve color (Kerry et al., 2006). Nanosensors in packaging detect toxins, pesticides, and contamination, alerting consumers to spoilage through changes in flavor and color (He et al., 2019). Many nanoparticles used in food packaging exhibit antimicrobial properties, acting as carriers for antimicrobial agents, and are designed to release these agents in a controlled manner, providing protection against microbial spoilage (Sorrentino et al., 2007).

Nanoparticles are also used to introduce bioactive substances like enzymes, antioxidants, and anti-browning agents to extend shelf life even after packages are opened (Cha and Chinnan, 2004). Commonly used inorganic nanoparticles include silver, zinc oxide, titanium oxide, and others, which serve as antimicrobials and sometimes as food additives (He et al., 2019). Nanoparticles, such as SiO2, clay, and carbon nanotubes, are incorporated into polymer matrices to improve plastic properties, making them lighter, more heat-resistant, and less permeable to gases (Duncan, 2011). Polymer nanocomposites, containing 2-8% nanoscale materials like carbon nanoparticles or nanoclays, are highly reactive due to their increased surface area (Brody, 2006).

Silver zeolite exhibits antibacterial activity by producing reactive oxygen species (ROS) and is used for food preservation and medical sterilization. Silver-based nanocomposites offer longer-lasting antibacterial effects than silver zeolite (Inoue et al., 2002; Matsumura et al., 2003). Additionally, carbon nanotubes help absorb unpleasant odors and remove CO2, while nanoclays like bentonite improve the gas barrier properties of packaging, preventing oxygen and moisture from spoiling food (Egger et al., 2009). Incorporating active nanoparticles into polymer matrices enhances packaging by adding antioxidant, antibacterial, and scavenging properties, ultimately extending the shelf life of food products (Sorrentino et al., 2007).

Organically modified nanoclays in polymer matrices enhance mechanical strength and act as barriers to gases, volatiles, and moisture (Chaudhry et al., 2008). Notably, the addition of nanofillers to biodegradable PLA polymers accelerates their degradation compared to PLA without nanofillers. Polymer-clay nanocomposites significantly improve the mechanical, thermal, and barrier properties of packaging materials (Ray et al., 2006). Nanotechnology in packaging helps prevent oxidation, control moisture migration, regulate respiration rates, and inhibit microbial growth, while also maintaining flavor and aroma (Brody et al., 2008).

Chitosan-based nanocomposites, particularly those containing silver, have demonstrated antimicrobial properties (Rhim et al., 2013). Silicate nanoparticles serve as effective barriers to gases and moisture in food packaging, reducing spoilage (Neethirajan and Jayas, 2015). Additionally, water-based nanocomposites form thin coatings that block oxygen in packaging, and nanoemulsions can clean packaging equipment and remove pesticide residues from fruits and vegetables. Nanoemulsified bioactive ingredients can be added to beverages without affecting their appearance (Rhim et al., 2013).

CONCLUSION

Nanotechnology plays a pivotal role in improving food production through advanced processing, packaging, and storage, enhancing food quality, flavor, and texture. Nanomaterials and nanosensors provide real-time information about food conditions and nutritional content, while improving safety by detecting pathogens. Nano-based delivery systems also boost the bioavailability of hydrophobic food bioactives, which typically have low stability. Despite these benefits, the adoption of nanofoods presents challenges for both governments and industries, particularly in gaining consumer trust. Proper regulation and labeling are essential to ensure safe use and consumer acceptance, as nanotechnology holds great potential to enhance food quality and human health.

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