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Nanotechnology in edible films and its future directions: A short review

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Abstract

The crucial role of food packaging in protecting and containing foodstuffs has long been recognized. However, with the rising awareness of health and environmental concerns, traditional synthetic polymers are facing increasing scrutiny. This has led to exciting advancements in the field of nanotechnology, where nanoparticles are being incorporated into packaging materials to enhance food quality. These nanoparticles offer significant advantages, including antimicrobial activity and improved UV protection, thereby extending shelf life and reducing food waste. However, the need for more sustainable and biodegradable alternatives remains paramount. Edible films, crafted from natural polymers, have emerged as a promising solution, replacing conventional plastics with an eco-friendly and renewable option. These films have the potential to revolutionize food packaging, offering improved properties that enhance storage life and ensure food safety. The development of edible films derived from food biopolymers has garnered significant research interest in recent years. This review offers a thorough analysis on edible films, exploring their functional properties and the potential of nano-fillers to further enhance their performance within food packaging systems. Highlighting the classifications of bio-based polymers and Nanofillers. Additionally, impact of Nanofillers on the several functional characteristics (like physical and mechanical) of films based on biopolymers are also discussed. Furthermore, the review highlights the futuristic prospect of of Nanotechnology in edible food packaging films.

Keywords: Edible films, Nanofillers, nanomaterials, Nanotechnology, safety issues.

1. Introduction:

Packaging materials have come into an innovative phase with the use of films that are nanocomposite, which combine biologically produced polymers with nanofillers possessing at least one dimension in the nano meter range (Attaran et al., 2017). These films leverage the biopolymer's matrix structure, infused with nanofillers, to achieve enhanced functional properties like mechanical strength, antimicrobial activity, and improved physical characteristics. These properties, often absent in biopolymers alone, are unlocked through the synergistic effect of the nanocomposite structure (Jamróz et al., 2019). The constituents of biopolymer films boast superior biodegradability and high availability. However, excessive water vapour permeability and poor mechanical characteristics are common problems with single-component films, limiting their suitability for packaging applications. This can be overcome by blending two biopolymers, creating a stronger and more impermeable film (Wu et al., 2021). Biopolymer films with nanofillers have demonstrated a remarkable preservative effect across a extensive range of food items, like dairy goods, meat and meat products, fish and shellfish, and vegetables, fruits, and mushrooms. The production of these films has been made easier by the development of nanotechnology, where nanofillers play a crucial role in enhancing their functionality (Jamróz et al., 2019). This review focuses on the latest advancements and achievements in incorporating various nanofillers, including clay, metals, metal oxides, nanocellulose, polymer nanoparticles, and more into biopolymer-based films. In addition, classifications of bio-based polymers and Nanofillers are also highlights. This review describes the impact of Nanofillers on the several functional characteristics that are with enhanced properties. It also summarizes the future prospect in this field, highlighting gaps in our knowledge and encouraging more study in this important field.

2. Biopolymers and Nanofillers

2.1. Classifications of Bio-based Polymers- Bio-polymers are categorized in three main groups:
Naturally derived bio-polymers:

a. Polysaccharides: These are the most prevalent biologically derived polymers, which can be-

- Neutral: Starch, hemicellulose, and cellulose
- Cationic: Chitosan and chitin
- Anionic: Both hyaluronic and alginic acids

b. Proteins: Examples include gelatin and whey protein
c. Others: Lipids, DNA, lignin, urushiol, and natural rubber

Directly derived polymers from microbes:

a. Polyhydroxyalkanoates (PHAs)
b. Bacterial cellulose
c. Polyε-caprolactones

Bio-based synthetic polymers:

a. Synthetic polymers that are natural or bio-based: monomers made of renewable resources, like polylactic acid (PLA).
b. Polymers that are partially bio-based: These include polyamide (PA), polyethylene (PE), and polyethylene terephthalate (PET), which are obtained from renewable resources (Baranwal et al., 2022).

2.2. Nanofillers

Nanofillers are the particles with at least one dimension in size (1-100 nm). Their incorporation into various materials, including biopolymers, can significantly enhance their properties (Jamróz et al., 2019). The four different categories of nanofillers are carbon nanostructure, inorganic, organic, and clays. Natural biopolymers like chitosan and cellulose are examples of organic nanofillers, whereas inorganic agents are metals like silver or metal oxides like ZnO. Fullerenes, carbon nanotubes, graphene, and nanofibers are the different types of carbon nanostructures. Many of the new characteristics and developments brought about by nanotechnology make the use of nanofillers as an active component in packaging materials more practical. Increased rates of breakdown, excessive hydrophobicity, poor mechanical properties, and other drawbacks limit the potential of biopolymer-based nanocomposite materials to totally replace synthetic materials. By utilising biopolymers and nanofillers to produce biodegradable packaging, biodegradable packaging sheets can be improved in terms of both performance and quality (Farshidfar et al., 2023). The relevance of several active ingredients in biopolymer films has increased dramatically in recent years due to their ability to exhibit antibacterial or antioxidant properties in addition to their role in extending the shelf life of various food products. As nanofillers with nano-biopolymer films have showed superior preservation results for dairy products, meat, poultry products, vegetables and fruits, seafood, etc., nanofillers play an active and vital part in the design of the nano-biocomposite films (Sahani and Sharma, 2021).

3. Nanofillers Impact on the Functional Characteristics of Films

3.1 Impact of Nanofillers on Polymer-Based Films' Physical Properties:

a. Reduced Hydroxyl Group Availability:

Nanofillers have a high surface area and can interact with the hydroxyl groups present in biopolymers, forming hydrogen bonds. This interaction reduces the capacity of hydroxyl groups to interact with molecules of water. Hydrophobic nanofillers, like nano-SiO_2, can further limit water absorption due to their inherent repulsion towards water molecules (Amjad et al., 2022)

b. Crystalline Structure of Nanofillers:

The crystalline structure of certain nanofillers can contribute to reduced water uptake. For example, the crystalline structure of CNC has been observed to restrict water absorption compared to the amorphous regions of the biopolymer matrix (Shojaeiarani et al., 2021)

c. Nanofiller Type and Dispersion:

The specific type of nanofiller and its dispersion within the biopolymer matrix can influence water content. Different nanofillers have varying surface area and interaction capabilities, impacting their ability to restrict water movement. Additionally, uneven dispersion of nanofillers can create pockets where water molecules can accumulate, leading to higher water content (Guchait et al., 2022)

d. Synergy between Different Nanofillers:

Combining multiple nanofillers can lead to synergistic effects on water resistance. For instance, incorporating both hydrophilic and hydrophobic nanofillers can create a layered structure that effectively restricts water penetration (Jamróz et al.,2019). By incorporating nanofillers into biopolymer films, researchers can effectively enhance their water resistance, leading to improved performance and potential applications in several fields, like food packaging, biomedical engineering, and environmental remediation.

3.2. Impact of Nanofillers on Polymer-Based Films' Mechanical Properties:

Adding nanofillers significantly affects two parameters:

a. Impact on Tensile Strength (TS): Increased TS can strengthen the biopolymer matrix through various mechanisms-

- Hydrogen and covalent bonding: Interactions between nanofillers and biopolymer functional groups (e.g., hydroxyl groups) form strong bonds, leading to a more robust network (Doh, 2020).
- Filler network formation: Nanofillers can create a network within the matrix, sharing stress and preventing crack propagation, thus enhancing film strength.
- Increased crystallinity: Some nanofillers promote increased crystallinity in the biopolymer, further enhancing its mechanical properties (Reynaud et al., 2001).

Example-Adding CNC and Ag-NPs to PLA films enhances TS due to synergistic effects between the nanofillers (Jamróz et al., 2019).

b. Impact on Elongation at Break (EAB):

- Decreased EAB: Generally, adding nanofillers decreases EAB, indicating reduced film elasticity.
- Restricted chain mobility: Nanofillers limit the movement of biopolymer chains, making the film less flexible and susceptible to breaking under high strain.
- Agglomeration: Uneven dispersion of nanofillers can create agglomerates, acting as stress concentration points and lowering EAB (Pires et al., 2021).

3.3. Antibacterial Activity of Nanofillers:

Nanofillers can impart antibacterial activity to biopolymer films through various mechanisms:

- Direct contact: Nanofillers like metal nanoparticles can damage bacterial cell walls upon direct contact (Palza, 2015).

- Release of bioactive agents: Some nanofillers can release antimicrobial compounds, inhibiting bacterial growth (Omerović et al., 2021).
- Generation of reactive oxygen species (ROS): Certain nanofillers can generate ROS, causing oxidative stress and cell membrane damage in bacteria (Liu et al., 2021).

4. Biopolymer-Based Films and Their Useful Applications with Nanofillers:

- Chitosan-gelatin films with silver nanoparticles (AgNPs) were used to protect red grapes, significantly extending their shelf life.
- The shelf life of litchi fruits was extended from 4 - 7 days by adding AgNPs to chitosan films (Kumar et al., 2018)
- Prepared minced fish paste enclosed with polypropylene films containing zinc oxide nanoparticles (ZnO NPs) showed reduced levels of E. coli and L. monocytogenes bacteria, with complete elimination observed after 10 days of storage. The antimicrobial effect was attributed to direct interaction with NPs made of ZnO or the film's ions containing Zn^{2+} being released (Gudkov et al., 2019).
- Adding ZnO NPs to chitosan/CMC films positively influenced the quality parameters for packaged Egyptian white soft cheese during storage (Golinska et.al., 2021).

These examples showcase the potential of nanofillers in developing advanced packaging materials with improved functionality and enhanced food protection.

5. Addressing Packaging Challenges with Nanofillers:

Conventional packaging materials with high water vapour permeability (WVP) and poor mechanical qualities are frequently derived from natural biopolymers. Nanotechnology offers promising solutions to improve these limitations and even introduce entirely new functionalities (Chausali et al., 2022). The primary goal of nanocomposite packaging is to increase food shelf life during distribution and storage.

6. Future Prospects of Nanomaterials in Edible Films

European Commission has established a regulatory framework encompassing nanomaterials. This framework mandates the labelling of products containing nanomaterials, including food and cosmetics, with clear information readily available for consumers (Allan et al.,2021) Additionally, online resources and databases dedicated to nanomaterials are accessible to provide further understanding and transparency. The promising properties of nanomaterials have spurred the development of numerous new materials. It is necessary to evaluate each individual's risk, though, because of the high surface-to-volume ratio, which can result in heightened reactivity and possible toxicity (Altammar, 2023). This inherent concern necessitates further research to definitively determine the viability of nanomaterials as alternatives to traditional materials across various applications.

7. Conclusion:

Edible films and coatings, a burgeoning technology, offer exciting possibilities for food preservation and enhancement. Choosing the substance, the kind of food, and the application technique are the three main determinants of the appropriate film or coating. Optimal results are achieved by carefully combining these factors based on specific needs (Díaz-Montes, Castro-Muñoz, 2021). Researchers are investigating composite edible films and coatings that contain nanomaterials as promising solutions for improved functionality. Their future application, however, hinges on crucial legislation governing the applications of nanocomposite in food products. The development of edible coatings and films with various nanoparticles probably keep for the future, which could lead to:

- Enhanced stability of the product
- Distinct colour and flavour characteristics
- Improved gas barrier properties
- Enhanced nutritional worth (Matloob et al., 2023)

For completely comprehend how these compounds behave after ingestion and paving the way for the safe and lawful use of nano-systems in commercial food products, more research is necessary.

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