Development of active biodegradable packaging material from fiber-reinforced starch-protein blends for application in food products

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Chapter 8

Summary, Conclusion and Future Scope

The development of active biodegradable packaging materials from fiber-reinforced starch-protein blends presents a promising advancement in sustainable food packaging. This thesis explores various aspects of material modification and performance enhancement to improve the functional properties of these bio-composite films. Key findings highlight the effectiveness of intensive blending in altering the hydrophilic nature of protein-starch blends, the role of combination of ultrasound and cellulase treatment in reducing water vapor permeability, and the superior performance of banana fiber-reinforced films over bamboo shoot fiber alternatives. Additionally, the incorporation of cinnamon essential oil (CNO) significantly enhanced the films' antioxidant and antimicrobial properties, effectively extending the shelf life of food products. The study concludes that these composite films hold great potential for active packaging applications, with prospects focusing on scaling up production, optimizing treatment conditions, and incorporating intelligent packaging systems to enhance functionality and long-term performance.

The following points of conclusions obtained from the thesis are summarized below:

Chapter 1: Chapter 1 provides a comprehensive introduction to the significance of biodegradable food packaging and the growing need for sustainable alternatives to conventional plastics. It highlights the environmental concerns associated with petroleum-based packaging materials and emphasizes the role of active and intelligent packaging technologies in improving food safety, quality, and shelf life. The chapter explores the potential of biopolymers, such as starch and protein, reinforced with natural fibers, in developing eco-friendly packaging solutions. Additionally, it discusses the challenges associated with biopolymer-based materials, including their mechanical and barrier limitations, and the strategies used to enhance their properties through modifications and the incorporation of active agents like essential oils. The study particularly focuses on developing an innovative biodegradable packaging system for fresh grapes, aiming to address issues of food preservation, sustainability, and consumer safety. This research is structured around key objectives, including biopolymer film formulation, fiber

reinforcement, and the integration of natural active compounds, laying the foundation for subsequent experimental investigations.

In Chapter 2, an extensive review of biopolymer-based packaging materials has been presented, with a particular focus on starch and protein-based systems. The literature revealed that biopolymers offer promising sustainable alternatives to conventional packaging materials due to their biodegradability, renewability, and eco-friendly nature. The chapter explored various aspects including starch modification techniques, protein-based materials, composite film development, natural fiber reinforcement, and active packaging systems incorporating essential oils and natural extracts. The review highlighted both the advantages and challenges of these materials - while they offer excellent biodegradability and environmental benefits, they often require modification or reinforcement to match the mechanical and barrier properties of traditional packaging. Significant attention was given to active packaging systems that can extend food shelf life through antimicrobial and antioxidant properties. The literature also emphasized the importance of safety considerations and toxicity aspects in developing these packaging materials. Overall, the review demonstrated that while biopolymer-based packaging materials show great potential for sustainable packaging solutions, continued research is needed to optimize their properties and ensure their commercial viability.

Chapter 3: Intensive blending can transform the hydrophilic nature of the protein-starch blend into a more hydrophobic one, improving WVP and solubility. The findings of this chapter emphasize the significant role of modified starch and casein in enhancing the mechanical, thermal, and barrier properties of PS-based films. The superior performance of HMTF and UTF 30 films in terms of strength, stability, and biodegradability highlights their potential for sustainable packaging applications. While these films offer effective protection against environmental factors, their sensitivity to moisture necessitates further optimization to ensure consistency across diverse applications. The promising results lay the foundation for further research in subsequent chapters.

Chapter 4: This chapter concluded that a combination of ultrasound and cellulase enzyme USET treatment emerged as the most effective modification technique, achieving WVP reductions of up to 34% compared to native fibers. Matrix-fiber compatibility played a crucial role, with banana fiber compositions responding better to modifications than bamboo-shoot fibers.

Chapter 5: This chapter concludes that Banana fiber-reinforced films demonstrated superior performance compared to bamboo shoot fiber (BSF)-reinforced PS-casein films, particularly after ultrasound and enzyme modifications.

Chapter 6: Composite films, especially those with 1% cinnamon EO, have significant potential for active food packaging due to their antioxidant and antimicrobial qualities, along with physical property enhancements. The study successfully developed active bio-composite films by incorporating cinnamon and clove essential oils into a potato starch-casein-banana fiber matrix, with 1% cinnamon essential oil (CNO) emerging as the optimal concentration for enhanced antioxidant, antimicrobial, and mechanical properties. The films demonstrated improved characteristics including optical clarity, structural integrity, barrier properties, and biodegradability, making them promising alternatives to conventional plastic packaging. The developed films show particular potential for food packaging applications, though further research is needed to evaluate their scalability, cost-effectiveness, and long-term stability in real-world conditions.

Chapter 7: Incorporating cinnamon essential oil (CNO) was particularly effective in slowing grape respiration and demonstrating superior antioxidant and antimicrobial properties, extending shelf life by up to 10 days. This chapter highlights the development and application of an active biodegradable film incorporating 1% CNO in a potato starch-casein-banana pseudostem fiber composite for food packaging, particularly grape preservation. The results demonstrate the film's superior antimicrobial properties, maintaining lower microbial growth compared to conventional polypropylene and fiber-reinforced films. Additionally, the active film effectively preserved key quality parameters such as total soluble solids, titratable acidity, pH, firmness, and physiological weight loss over the storage period. These findings underscore the potential of bio-based active packaging in enhancing shelf life and quality retention, contributing to sustainable food preservation solutions.

Future Scopes:

1. Scaling Up Production for the Developed Active Biodegradable Packaging Film focusing on increasing production, improved cost-effectiveness, and ensuring long-term performance in case of real-world food packaging applications.
2. Optimization of Treatment Conditions (ultrasound and cellulase) that will enhance the treatment conditions and explore the performance variability of natural fibers across different types and compositions for improved bio-composite films and fiber-matrix adhesion for enhancement of mechanical properties.
3. Enhancing Functionality by incorporating hydrophobic coatings, advanced polymer blends, and surface treatments to prevent moisture penetration. Also, the incorporation of intelligent packaging systems such as time-temperature indicators, freshness sensors, and RFID tracking can be explored to enhance real-time monitoring and product safety.