Development and Characterization of Edible Films from Underutilized Plant Sources for Sustainable Food Packaging Applications

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Abstract

Food packaging plays a critical role in maintaining quality, safety, and shelf life of food products. However, conventional petroleum-based plastics contribute significantly to environmental pollution and microplastic contamination. The present research proposes the development and characterization of edible films derived from underutilized crops including cowpea and red rice. The study focuses on the extraction of starch from these crops, preparation of starch nanoparticles from the same source, and fabrication of native and nano-reinforced edible films through solvent casting. Mechanical, barrier, thermal, structural, optical, biodegradation, antioxidant, and antimicrobial properties will be evaluated. The work aims to address critical research gaps related to self-reinforced starch nanoparticle systems and direct comparison between native and nano-starch films. The outcomes are expected to provide sustainable packaging alternatives while promoting utilization of indigenous crops and supporting circular bioeconomy principles.

Keywords: Edible films, Starch nanoparticles, Sustainable packaging, Biodegradable materials, Food packaging, Circular bioeconomy.

1. Introduction

The global food industry relies heavily on synthetic plastic packaging because of its low cost, durability, transparency, and excellent barrier properties. Despite these advantages, plastic packaging generates severe environmental concerns due to its non-biodegradable nature. Millions of tons of plastic waste accumulate annually in landfills, rivers, and oceans. Fragmentation of plastics results in microplastics that enter food chains and pose potential risks to human health and ecosystems.

Edible films and coatings have emerged as environmentally friendly alternatives. These materials are produced from renewable biopolymers such as starch, proteins, cellulose, gums, and lipids. They can be consumed together with food or biodegrade naturally after disposal. Among these materials, starch is particularly attractive because of its abundance, biodegradability, low cost, and film-forming ability.

Underutilized crops such as cowpea and red rice are rich sources of starch and bioactive compounds. Although these crops possess significant nutritional and technological potential, they remain largely neglected in industrial packaging applications. Development of edible films from these crops could simultaneously promote sustainability, enhance farmer income, and create value-added products.

2. Need and Rationale

The increasing concern regarding environmental sustainability has accelerated the search for biodegradable packaging materials. Current research has focused mainly on starches from corn, potato, cassava, and wheat. The packaging potential of many indigenous crops remains largely unexplored. Furthermore, conventional starch films often exhibit poor mechanical strength and high water sensitivity.

Nanotechnology provides opportunities to overcome these limitations. Starch nanoparticles can serve as reinforcing agents within film matrices, creating stronger intermolecular interactions and improving film performance. However, most available studies utilize external nanomaterials such as nanocellulose, nanoclays, or synthetic nanoparticles. Research involving starch nanoparticles derived from the same crop source remains limited.

Therefore, systematic development of native and self-reinforced nano-starch films from underutilized crops is scientifically important and industrially relevant.

3. Review of Literature

Several researchers have investigated starch-based edible films and their reinforcement with nano-scale materials to improve functional properties. Kaushik and Kaur (2016) developed thermoplastic starch nanocomposites reinforced with cellulose nanocrystals and reported significant improvements in tensile strength, thermal stability, and barrier properties. However, their work focused on external nano-reinforcement rather than self-reinforcement using starch nanoparticles.

Ma et al. (2024) developed intelligent starch–pectin composite films incorporating anthocyanins as natural pH-sensitive indicators for food freshness monitoring. Although the films exhibited enhanced functional and sensing properties, the study emphasized polymer blending and intelligent packaging applications rather than nanoparticle-mediated reinforcement.

Pelissari et al. (2017) prepared cassava starch-based films reinforced with cellulose nanofibers and demonstrated improved mechanical performance and reduced water vapor permeability. Nevertheless, the reinforcing agent was cellulose-based, and the potential of starch nanoparticles as reinforcing fillers was not explored.

Siroha et al. (2021) investigated modified pearl millet starch and reported significant alterations in physicochemical and rheological characteristics following starch modification. However, the study primarily focused on starch characterization and did not evaluate film-forming applications.

Müller et al. (2011) developed biodegradable starch-based films containing nanocellulose and observed enhanced structural integrity and barrier properties. Despite these improvements, the reinforcement mechanism relied on nanocellulose rather than starch-derived nanoparticles.

Ramos et al. (2013) produced bioactive rice starch films incorporating natural antioxidant compounds and reported improved antioxidant activity and film functionality. However, nanoparticle incorporation and comparative assessment between native and nano-starch systems were not included.

Ali et al. (2023) investigated starch nanoparticles derived from rice starch and demonstrated their potential application in biodegradable edible films. Although promising improvements in film characteristics were observed, optimization of nanoparticle concentration and systematic comparison with native starch films remained limited. Collectively, these studies highlight the growing interest in starch-based edible films while revealing a lack of comprehensive investigations on self-reinforced films prepared using starch nanoparticles derived from underutilized crops such as pearl millet.

Collectively, these studies demonstrate the feasibility of starch-based packaging but reveal significant research gaps.

4. Identified Research Gaps

1. Lack of systematic comparison between native starch films and nano-starch reinforced films from the same crop source.
2. Limited information on cowpea and horse gram starch nanoparticles.
3. Absence of optimized nanoparticle loading studies.
4. Lack of detailed structure-property relationship analysis.
5. Limited food application and shelf-life studies.
6. Minimal investigation of self-reinforced nanostructured edible films.
7. Insufficient understanding of biodegradation behavior under practical conditions.

5. Research Objectives

General Objective:
To develop and characterize edible films from underutilized crops and evaluate the effect of self-derived starch nanoparticles on packaging performance.

Specific Objectives:
- Extraction and purification of starch.
- Preparation of starch nanoparticles.
- Development of native starch films.
- Development of nano-starch reinforced films.
- Optimization of nanoparticle concentration.
- Evaluation of physicochemical properties.
- Assessment of food packaging performance.
- Investigation of biodegradability and sustainability aspects.

6. Hypothesis

H1: Starch extracted from underutilized crops can produce edible films suitable for packaging applications.

H2: Starch nanoparticles prepared from the same source significantly enhance mechanical, thermal, and barrier properties.

H3: There exists an optimum nanoparticle concentration that maximizes film performance.

H4: Nano-reinforced films exhibit superior storage performance compared with native starch films.

7. Expected Results and Discussion

Nano-starch incorporation is expected to reduce free volume within the polymer matrix, resulting in lower permeability and enhanced barrier properties. Increased crystallinity may improve tensile strength and thermal stability. SEM analysis is expected to reveal more homogeneous structures in optimized formulations.

Pearl millet and red rice starches may provide superior film-forming characteristics due to their starch composition, while cowpea and horse gram may contribute additional functional attributes. Optimized nano-starch films are anticipated to outperform native films in all major performance indicators.

8. Significance of Research

The study contributes to sustainable packaging technology, utilization of underexploited crops, reduction of plastic waste, promotion of circular bioeconomy, and generation of scientific knowledge regarding self-reinforced nanostructured films. The findings may facilitate industrial adoption of biodegradable packaging materials.

9. Expected Impact

Environmental impact includes reduction in plastic waste and improved sustainability. Economic impact includes value addition to underutilized crops and enhanced income opportunities for farmers. Scientific impact includes generation of new knowledge in edible film technology and nanostructured biopolymer systems.

10. Conclusion

This research proposes a comprehensive strategy for transforming underutilized crops into high-value packaging materials. By comparing native and nano-starch films derived from the same source and optimizing nanoparticle incorporation, the study will address major limitations in current literature. The outcomes are expected to support sustainable food packaging, promote indigenous crop utilization, and establish a foundation for future commercial applications.

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