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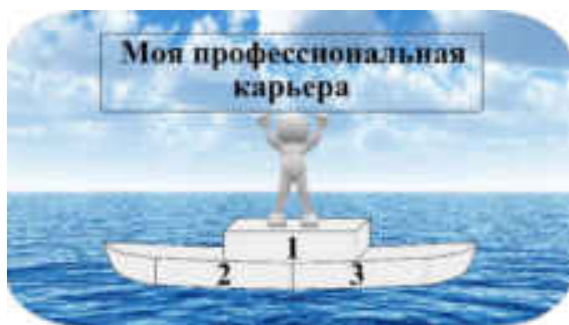


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**Международный научно-образовательный электронный журнал
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Название публикации: «DEVELOPMENT OF BIOPOLYMER FILMS INFUSED WITH ANTHOCYANINS FOR SMART PACKAGING APPLICATIONS»

Abstract

The increasing demand for sustainable and intelligent food packaging systems has stimulated the development of biopolymer-based films incorporating natural bioactive compounds. Anthocyanins, a class of pH-sensitive pigments derived from plant sources, have gained significant attention due to their colorimetric response to environmental changes. This study focuses on the development of biopolymer films infused with anthocyanins for smart packaging applications. Various biopolymer matrices, including starch, chitosan, and gelatin, were investigated for their compatibility with anthocyanin extracts. The physicochemical, mechanical, and optical properties of the films were analyzed, along with their responsiveness to pH variations. The results demonstrate that anthocyanin-incorporated films exhibit distinct color changes under varying conditions, enabling real-time monitoring of food freshness. These findings highlight the potential of such films as eco-friendly alternatives to conventional packaging systems.

1. Introduction

The global packaging industry is undergoing a transition towards sustainable and intelligent materials due to increasing environmental concerns and consumer demand for safer food products. Conventional petroleum-based plastics, while effective in preserving food, contribute significantly to environmental pollution and lack functional responsiveness.

Smart packaging technologies aim to provide real-time information about food quality by integrating sensing capabilities into packaging materials. Among various approaches, the incorporation of natural pigments such as anthocyanins into biodegradable polymer matrices has emerged as a promising strategy.

Anthocyanins are water-soluble flavonoids responsible for red, purple, and blue colors in many fruits and vegetables. Their molecular structure is highly sensitive to pH changes, leading to visible color transitions. This property can be exploited to detect food spoilage, which is often accompanied by pH shifts due to microbial activity.

This study aims to develop and characterize anthocyanin-infused biopolymer films and evaluate their applicability in intelligent food packaging systems.

2. Literature Review

Recent studies have explored the use of natural indicators in smart packaging. Biopolymers such as starch, chitosan, and gelatin have been widely investigated due to their biodegradability, film-forming ability, and compatibility with bioactive compounds.

Anthocyanins extracted from sources such as red cabbage, grape skins, and berries have demonstrated strong pH sensitivity:

- $\text{pH} < 3 \rightarrow \text{red coloration}$
- $\text{pH } 4\text{--}6 \rightarrow \text{purple}$
- $\text{pH} > 7 \rightarrow \text{blue/green}$

Research by Kuswandi et al. (2012) and others has shown that anthocyanin-based films can effectively indicate spoilage in meat and fish products.

However, challenges remain in terms of pigment stability, mechanical strength of films, and long-term performance.

3. Materials and Methods

3.1 Materials

- Biopolymers: starch, chitosan, gelatin

- Anthocyanin source: plant extracts (e.g., grape skins, red cabbage)
- Plasticizers: glycerol

3.2 Extraction of Anthocyanins

Anthocyanins were extracted using an acidified ethanol solution:

Ethanol + 1% HCl → enhanced pigment stability and extraction efficiency

The extract was filtered and stored at low temperature to prevent degradation.

3.3 Film Preparation

Film-forming solutions were prepared by dissolving biopolymers in water, followed by the addition of plasticizer and anthocyanin extract.

The solution was cast onto flat surfaces and dried under controlled conditions to form films.

3.4 Characterization

The films were evaluated for:

- **Mechanical properties** (tensile strength, elongation)
- **Optical properties** (color, transparency)
- **pH sensitivity** (color response)
- **Water vapor permeability (WVP)**
- **Thermal stability**

4. Results and Discussion

4.1 Film Formation and Appearance

All biopolymers successfully formed films with uniform distribution of anthocyanins. The films exhibited initial reddish-purple coloration.

4.2 pH Sensitivity

The films showed distinct color changes in response to pH variations:

pH Range	Color
2–3	Red
4–6	Purple
7–9	Blue
>9	Green

This confirms their suitability as pH indicators.

4.3 Mechanical Properties

Chitosan-based films exhibited higher mechanical strength, while starch-based films showed better flexibility. The addition of anthocyanins slightly reduced mechanical strength due to disruption of the polymer matrix.

4.4 Application in Food Packaging

When applied to food samples:

- fresh food → stable color
- spoiled food → noticeable color change

This demonstrates the potential for real-time monitoring of food freshness.

4.5 Limitations

- sensitivity to light and temperature
 - degradation over time
 - need for improved barrier properties
-

5. Conclusion

Anthocyanin-infused biopolymer films represent a promising approach for developing sustainable and intelligent packaging systems. Their ability to provide visual indicators of food quality, combined with biodegradability, makes them suitable for next-generation packaging technologies.

Future research should focus on enhancing pigment stability, improving mechanical properties, and scaling up production for industrial applications.

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