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# RESEARCH OF ACTIVE COMPONENTS FOR FOOD PACKAGING BASED ON BACTERIAL CELLULOSE

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## Abstract
Bacterial cellulose (BC) is a promising biodegradable substrate for the development of active food packaging materials due to its high purity, mechanical strength and ability to retain large amounts of water. In this work, we focused on the design of BC-based systems combining pH-sensitive fluorescence and antimicrobial functionality for potential application as absorbent pads in meat packaging.
Carbon dots (CDs) were synthesized via a hydrothermal treatment of cellulose precursors in an autoclave and subsequently integrated either into BC or nanocrystalline cellulose matrices. Spectroscopic studies revealed a clear pH-dependent change in fluorescence intensity of the obtained CDs, confirming their suitability as optical pH indicators in aqueous media. In parallel, silver and zinc-based nanoparticles were synthesized and characterized to determine their hydrodynamic size distribution and colloidal stability.
The combination of pH-responsive carbon dots with metal nanoparticles embedded in a bacterial cellulose network is expected to provide a dual-function platform enabling real-time monitoring of product freshness together with antimicrobial protection. The obtained results demonstrate the feasibility of tailoring optical and colloidal properties of the synthesized nanomaterials for their further integration into BC films aimed at intelligent and active food packaging systems.

## Keywords
Bacterial cellulose, carbon dots, metal nanoparticles, smart packaging.

# ИССЛЕДОВАНИЕ АКТИВНЫХ КОМПОНЕНТОВ ДЛЯ ПИЩЕВОЙ УПАКОВКИ НА ОСНОВЕ БАКТЕРИАЛЬНОЙ ЦЕЛЛЮЛОЗЫ

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**Аннотация**
Бактериальная целлюлоза (БЦ) является перспективным биоразлагаемым субстратом для разработки активных упаковочных материалов для пищевых продуктов благодаря своей высокой чистоте, механической прочности и способности удерживать большое количество воды. В данной работе мы сосредоточились на разработке систем на основе БЦ, сочетающих чувствительную к pH флуоресценцию и антимикробные свойства, для потенциального применения в качестве абсорбирующих прокладок в упаковке мяса.

Углеродные точки (УТ) были синтезированы путем гидротермической обработки целлюлозных прекурсоров в автоклаве и впоследствии интегрированы либо в матрицы БЦ, либо в матрицы нанокристаллической целлюлозы (НКЦ). Спектроскопические исследования выявили четкое изменение интенсивности флуоресценции полученных УТ в зависимости от pH, подтверждая их пригодность в качестве оптических индикаторов pH в водных средах. Параллельно были синтезированы и охарактеризованы методом динамического рассеяния света (ДРС) наночастицы на основе серебра и цинка для определения их гидродинамического распределения по размерам и коллоидной стабильности.

Предполагается, что сочетание углеродных точек, реагирующих на pH, с металлическими наночастицами, внедренными в сеть бактериальной целлюлозы, обеспечит платформу двойного назначения, позволяющую осуществлять мониторинг свежести продукта в режиме реального времени и одновременно обеспечивать антимикробную защиту. Полученные результаты демонстрируют возможность целенаправленного изменения оптических и коллоидных свойств синтезированных наноматериалов для их дальнейшей интеграции в пленки из бактериальной целлюлозы, предназначенные для интеллектуальных и активных систем упаковки пищевых продуктов.

**Ключевые слова**
Бактериальная целлюлоза, углеродные точки, металлические наночастицы, умная упаковка

The quality and safety of fresh meat products strongly depend on storage conditions and the effectiveness of the packaging system. Standard plastic-based absorbent pads in meat trays only passively retain exudate and do not provide either information on product freshness or any additional local antimicrobial effect, while accumulated meat juice forms a favorable medium for spoilage and pathogenic microflora. Existing intelligent and active packaging solutions often involve synthetic polymers, printed indicator labels or multilayer coatings, which complicates processing, increases cost and may be associated with issues of migration and recyclability. In this context, BC is considered as a promising biodegradable substrate with a nanofibrillar structure and high water-holding capacity, capable of acting simultaneously as an absorbent and as a carrier for functional nanomaterials. The proposed approach is based on the integration of pH-responsive fluorescent carbon dots and antimicrobial metal nanoparticles into the BC network to obtain a dual-function pad for meat packaging [1,2,3].

The problem addressed in this work is the development and experimental evaluation of BC-based pads that combine optical indication of changes associated with meat spoilage and local antimicrobial activity in the exudate zone. Carbon dots are synthesized by a hydrothermal method in an autoclave from cellulose-based precursors and introduced into BC and nanocrystalline cellulose matrices. Their pH-sensitive fluorescence is characterized by spectrofluorimetry in aqueous model media with controlled pH values, allowing the dependence of emission intensity on acidity to be established and the working range relevant to meat storage to be identified. Silver and zinc-containing nanoparticles are obtained by aqueous chemical reduction/precipitation routes, and their hydrodynamic diameter and size distribution are measured by dynamic light scattering (DLS), which makes it possible to select particle sizes suitable for incorporation into polymer matrices without pronounced aggregation. The stability of fluorescence of BC-based samples in the hydrated state, as well as the preservation of colloidal stability of nanoparticles in conditions close to real packaging, is evaluated in model experiments.

The main result of the present stage of the study is the demonstration that bacterial cellulose can serve as a platform for immobilization of pH-responsive carbon dots while preserving their fluorescent properties in the hydrated state. The obtained data show that the fluorescence of the synthesized carbon dots is sensitive to pH changes (30%) in model aqueous media that simulate conditions relevant to meat products, which confirms the possibility of using them as optical indicators of changes in the medium. In addition, metal-based nanoparticles with nanometer-scale sizes have been synthesized and characterized as potential antimicrobial fillers suitable for incorporation into bacterial cellulose-based materials, providing a basis for the future creation of pads with combined indicator and antimicrobial functions.

Also, bacterial cellulose films modified with carbon dots were obtained and dried under controlled conditions, after which their resistance to leaching of the fluorescent component into aqueous media was evaluated. The washout tests demonstrated that a significant fraction of the carbon dots remains immobilized within the bacterial cellulose network upon contact with water, while retaining a detectable fluorescence signal. This indicates the possibility of using bacterial cellulose as a carrier for pH-responsive fluorescent nanomaterials without their rapid loss into the surrounding medium. Further stages of the study will be focused on the optimization of film preparation parameters, the introduction of antimicrobial metal nanoparticles into the bacterial cellulose matrix and the assessment of their antimicrobial activity in conditions relevant to meat packaging.

**Literature**


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