УДК 664.8.038

DEVELOPMENT AND CHARACTERIZATION SMART FOOD PACKAGING MATERIAL WITH CARBON DOTS/CHITOSAN AS AN ACTIVE AGENT

Olga Freinkman [1] (Master student), **Yaroslav Ionov** [1] (PhD student)
Scientific supervisor – PhD, Leading Researcher CMBT Elena Nazarova[1]
[1]ITMO University
ofreinkman@itmo.ru

This work was supported by the Russian Science Foundation (RSF) under grant №24-76-10093, «Development of optically active indicators for smart food packaging».

Abstract
Smart food packaging addresses key challenges in the food industry by monitoring product freshness and extending shelf life through indicator and antimicrobial properties. This study developed a potential formulation for a packaging material that includes carbon dots (CDs) synthesized on nanocrystalline chitosan (ChsNCs) as active components. CDs/ChsNCs possess both indicator and antimicrobial properties. The fluorescence of the particles is quenched by spoilage metabolites released by food products into the atmosphere, allowing for the actual condition of the product inside the packaging to be observed. Regarding antimicrobial activity, both carbon dots and nanocrystalline chitosan exhibit antimicrobial activity – CDs by generating reactive oxygen species (ROS), and ChsNCs by disrupting microbial membranes. Antimicrobial efficacy was confirmed by minimum inhibitory concentration tests against E. coli, and relative cytotoxicity using the MTT assay confirmed safe particle concentrations (≥70% cell viability) that meet regulatory standards for food contact. This composite material improves consumer safety and reduces manufacturer costs by inhibiting microbial growth.

Keywords
Carbon dots, chitosan, smart food packaging, safety, material.

РАЗРАБОТКА И ХАРАКТЕРИЗАЦИЯ УМНОГО УПАКОВОЧНОГО МАТЕРИАЛА ДЛЯ ПИЩЕВЫХ ПРОДУКТОВ С УГЛЕРОДНЫМИ ТОЧКАМИ НА ХИТОЗАНЕ В КАЧЕСТВЕ АКТИВНОГО КОМПОНЕНТА

Фрейнкман О.В.[1] (магистрант), **Ионов Я.А.**[1] (аспирант)
Научный руководитель – кандидат химических наук, ведущий научный сотрудник ЦМБТ Назарова Е.А.[1]
[1]Университет ИТМО
ofreinkman@itmo.ru

Работа выполнена в рамках проекта РНФ №24-76-10093 «Разработка оптически активных индикаторов для умной упаковки пищевых продуктов».

Аннотация
Умная пищевая упаковка решает ключевые проблемы пищевой промышленности, контролируя свежесть продукта и продлевая срок его хранения за счет индикаторных и антимикробных функций. В данном исследовании разработан возможный состав для упаковочного материала, включающий в себя в качестве активных компонентов углеродные точки (CD), синтезированные на нанокристаллическом хитозане (ChsNCs). CD/ChsNCs обладают как индикаторными свойствами, так и антимикробными. Флуоресценция частиц гасится метаболитами порчи, выделяемыми пищевыми продуктами в газовую среду, что позволяет отслеживать реальное состояние продукта внутри упаковки. Что касается антимикробной активности, то как углеродные точки, так и нанокристаллический хитозан проявляют антимикробную активность — углеродные точки за счет генерации активных форм кислорода (ROS), а ChsNCs – за счет разрушения мембраны микроорганизмов. Антимикробная эффективность была установлена

тестами на минимальную ингибирующую концентрацию против *E.coli*, а относительная цитотоксичность с помощью анализа MTT подтвердила безопасные концентрации частиц (≥70% жизнеспособности клеток), соответствующие нормативным стандартам для контакта с пищевыми продуктами. Этот композитный материал повышает безопасность потребителей и снижает издержки производства за счет подавления роста микроорганизмов.

Ключевые слова
Углеродные точки, хитозан, умная упаковка, безопасность, материал.

One of the crucial challenges in the modern food industry is the development of smart food packaging. Smart packaging is a type of packaging material that can identify the actual condition of the product inside and help extend its shelf life. Therefore, creating a material that combines the properties of both indicator and antimicrobial packaging will ensure consumer safety by protecting them from contaminated food, and will also help manufacturers reduce production costs by extending the shelf life of products by inhibiting microbial growth.

Carbon dots (CDs) synthesized on a polymer carrier – nanocrystalline chitosan (ChsNCs) – could become the key functional component of smart food packaging. CDs exhibit a fluorescent response, enabling them to act as indicator molecules in a formulation: the fluorescence intensity of the nanoparticles decreases with increasing levels of spoilage metabolites in the system. Both CDs and ChsNCs possess antimicrobial properties, making it possible to impart these beneficial characteristics to the material in which they are intended to be incorporated. The antimicrobial activity of CDs is based on the formation of reactive oxygen species (ROS) under the influence of light [1]. Increased ROS concentrations lead to oxidative stress and cell death. The proposed mechanism of chitosan's antimicrobial action is that the interaction of positively charged chitosan molecules with negatively charged microbial cell membranes causes the membranes changes and cells' deaths. [2, 3]. However, ChsNCs has proven biocompatibility and biodegradability, allowing this polymer to be used as a key component in the synthesized material.

As a result of the study, a packaging material composition was developed with carbon dots on chitosan incorporated into the film as active components. To confirm the antimicrobial properties of the components included in the packaging material, a nanoparticle incubation test with *E.coli* was conducted, followed by inoculation with CFU to assess the minimum inhibitory concentration of the agents. Relative cytotoxicity tests were also conducted to ensure that the included components can safely come into contact with food products. Relative cytotoxicity was studied using the MTT assay, identifying particle concentrations at which the relative oxidative activity of cells remained at least 70%. This corresponds to the required regulatory standards for incorporating components into food packaging material and will ensure consumer safety even in the event of particle migration from the film into the product [4].

Literature

1. Li H., Huang J., Song Y.,et al. Degradable Carbon Dots with Broad-Spectrum Antibacterial Activity // ACS Appl Mater Interfaces. 2018. Vol.10, no. 32. P.26936-26946. https://doi.org/10.21203/rs.3.rs-103890/v1
2. Chen W., Jin T.Z., Gurtler J.B., et al. Inactivation of *Salmonella* on whole cantaloupe by application of an antimicrobial coating containing chitosan and allyl isothiocyanate // International Journal of Food Microbiology. 2012. Vol.155, no. 3. P. 165-170. https://doi.org/10.1016/j.ijfoodmicro.2012.02.001.
3. Nasaj M., Chehelgerdi M., Asghari B., et al. Factors influencing the antimicrobial mechanism of chitosan action and its derivatives: A review // International Journal of Biological Macromolecules. 2024. Vol.277, no. 2. P.134321. https://doi.org/10.1016/j.ijbiomac.2024.134321.

4. Порядок и методы проведения контроля миграции наночастиц из упаковочных материалов: Методические указания // М.: Федеральный центр гигиены и эпидемиологии Роспотребнадзора. 2010. 27 с.