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RESEARCH ON THE IMPACT OF ACTIVE PACKAGING FOR FOOD PRODUCTION

ДОСЛІДЖЕННЯ ВПЛИВУ АКТИВНОЇ УПАКОВКИ ДЛЯ ХАРЧОВИХ ВИРОБНИЦТВ

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Abstract. *Active packaging is one of the key areas of development in modern food storage and logistics technologies, as it allows for targeted control of the gas environment, moisture, microbiological processes, and oxidation inside the packaging space. The article discusses the concept of active packaging, the classification of functional components, modern materials, and technological solutions used in the food industry. Key implementation issues are identified, including regulatory requirements, food compatibility, and restrictions on the migration of active substances. The results of studies on the impact of different types of active systems on the shelf life and safety of food products are analyzed. It is shown that the use of oxygen absorbers, moisture controllers, antimicrobial elements, and sensory indicators can significantly improve product quality and reduce losses in the supply chain.*

Key words: *active packaging; antimicrobial materials; oxygen absorbers; moisture control; indicator systems; modified gas environment; shelf life extension; food safety; packaging technologies.*

Анотація. *Активна упаковка є одним із ключових напрямів розвитку сучасних технологій зберігання та логістики харчових продуктів, оскільки вона дає змогу цілеспрямовано керувати газовим середовищем, вологою, мікробіологічними процесами та окисненням усередині пакувального простору. У статті розглянуто концепцію активної упаковки, класифікацію функціональних компонентів, сучасні матеріали та технологічні рішення, що застосовуються у харчовій промисловості. Визначено ключові проблеми впровадження, зокрема регуляторні вимоги, сумісність з харчовими продуктами та обмеження щодо міграції активних речовин. Проаналізовано результати досліджень впливу різних типів активних систем на термін зберігання та безпечність харчових продуктів. Показано, що використання поглиначів кисню, контролерів вологи, антимікробних елементів та сенсорних індикаторів здатне суттєво підвищити якість продукції та знизити втрати в*

ланцюзі постачання.

Ключові слова: *активна упаковка; антимікробні матеріали; поглиначі кисню; контроль вологості; індикаторні системи; модифіковане газове середовище; продовження терміну зберігання; харчова безпечність; пакувальні технології.*

Introduction.

The rapid development of the food industry, globalization of markets, and growing consumer demands for product quality necessitate the search for innovative packaging solutions. Traditional packaging materials mainly perform barrier and logistical functions, but modern conditions require functional systems capable of actively interacting with the product or its gas environment. Active packaging is considered a technology that improves safety, extends shelf life, and reduces food waste. The purpose of this article is to analyze modern solutions in the field of active packaging, their capabilities, advantages, limitations, and prospects for integration into the production processes of the food industry [1-4].

The modern packaging materials market is showing steady growth in the share of active systems, driven by increased demand for food products with extended shelf life and high safety standards. According to international analytical agencies, the share of active and intelligent packaging is growing by 6–9 percent annually. The main drivers of the market are the meat processing, fish, dairy, fruit and vegetable industries, as well as the ready-made meals sector.

The growth of global trade in fresh and perishable products necessitates the use of materials that can adapt to fluctuations in temperature, humidity, and gas environment during transportation. Long logistics chains involving sea and air transport require special attention. Active packaging compensates for environmental changes through the use of absorbers, regulators, and antimicrobial components.

Main text.

In the European Union, the use of active materials is regulated by a number of documents, in particular Regulation (EC) No 1935/2004 and Commission Regulation (EC) No 450/2009. These standards define the requirements for the composition of materials, permissible levels of migration of active components, and the need to confirm their safety for human health [5-8].

In the US, regulatory functions are performed by the FDA, which requires toxicological assessments of active substances, their stability, and the absence of dangerous migration during product storage. In the Asian region, local standards based on European approaches are being actively implemented.

Current research focuses on developing multifunctional systems that combine several active properties: oxygen absorption, moisture control, antimicrobial action, and indicative function. Particular attention is paid to nanomaterials that provide high efficiency even at low concentrations of active substances.

Among the most promising areas are:

✓ polymer nanocomposites with silver or copper ions;

✓ active packages based on natural sorbents (zeolites, bentonites);

✓ smart labels controlled via RFID;

✓ freshness indicators with pH-sensitive dyes;

✓ enzyme systems for gas composition control.

The work uses methods of comparative analysis, systematization, generalization, critical assessment, and expert forecasting. Various active packaging technologies were compared in terms of efficiency, cost, compatibility with products, and level of implementation in industry.

The following indicators were used to analyze efficiency:

➢ residual oxygen content in the packaging environment;

➢ changes in water activity;

➢ number of microorganisms (CFU/g);

➢ organoleptic characteristics of products;

➢ storage duration under controlled conditions;

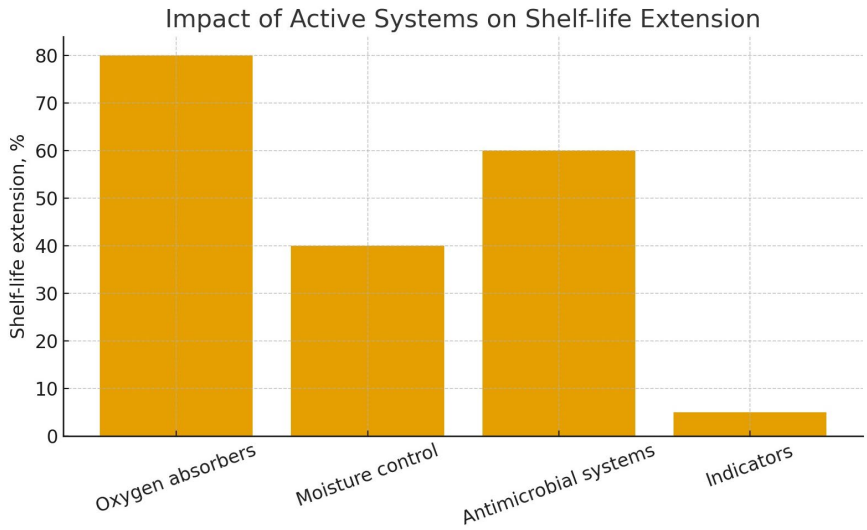
➢ indicators of migration of active substances in accordance with EFSA and FDA requirements.

Studies have shown that the use of oxygen absorbers in meat products reduces the intensity of fat oxidation by 2–3 times and extends the shelf life by 30–60 percent. In fish products, the amount of peroxide compounds decreased, which slowed down the development of foreign odors.

Packaging with absorbents showed a significant reduction in free moisture in poultry and fish products. A decrease in the growth rate of psychrophilic microorganisms was found, which extended the freshness of products by 2–4 days.

Polymers with antimicrobial properties (in particular, those containing silver nanoparticles) reduced microbial contamination by 1.5–3 logarithmic units in meat and dairy products. The use of natural antimicrobial agents (essential oils, organic acids) showed lower but stable effectiveness [9-11].

Freshness indicators clearly responded to changes in pH, which made it possible to detect spoilage of meat and fish at an early stage. Gas indicators clearly registered an increase in CO_2 concentration in products subject to fermentation or bacterial growth.



The results obtained indicate that active packaging is an effective tool for preserving food products. Oxygen absorbers proved to be most effective for fatty products, where oxidation is a critical factor in spoilage. Moisture control ensured increased microbiological stability, although its effectiveness depended largely on the characteristics of the product [12-14].

Antimicrobial materials showed high effectiveness, but their use is limited due to regulatory requirements for the migration of active components. Biopolymers with natural antimicrobial substances that do not cause unwanted migration proved to be particularly promising Sensory indicators significantly improve product safety control,

but they do not directly affect shelf life. Their role is to increase the transparency of food chains and prevent the sale of unsafe products.

In summary, active packaging reduces food waste, improves product quality, and increases safety. At the same time, it requires careful selection of technology depending on the type of product and logistics conditions [15-16].

Conclusions.

The study confirms that active packaging is one of the most promising areas of development in the modern food industry. Its use makes it possible to combine the protective, functional, and intelligent properties of packaging materials with the real needs of production, logistics, and consumers. The results obtained showed that the use of oxygen absorbers, humidity regulators, antimicrobial systems, and indicator components can significantly improve the microbiological safety, stability, and organoleptic characteristics of products.

The effectiveness of active systems depends on the type of product, the composition of the packaging environment, temperature conditions, and logistics conditions. In summary, active packaging is a key element of sustainable development in food production. It contributes to the optimization of storage times, reduction of food waste, improvement of product quality and safety, and harmonization of regulatory requirements with growing market needs.

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