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ANTIMICROBIAL EFFECT OF BIOPOLYMER PACKAGING MATERIALS WITH SILVER NANOPARTICLES FOR FOOD STORAGE

Food quality and safety issues are among the most pressing and important for manufacturers, retailers, and end consumers. However, the development of pathogenic microorganisms in such products not only reduces their shelf life but also causes the development of infectious diseases in consumers. Therefore, there is currently an urgent need to find new packaging materials with antimicrobial effects that are non-toxic to humans, food, and the environment. The ***aim*** *of this article is to study the antimicrobial activity of silver-containing nanocomposites formed based on polylactide (PLA) and polycaprolactone (PCL) with silver nanoparticles by sputtering deposition.* ***Methods.*** *The structure of silver-containing nanocomposites were investigated by the method of wide-angle X-ray diffraction on an XRD-7000 diffractometer. The morphology of Ag nanoparticles on the surface of the films was studied by transmission electron microscopy method. The antimicrobial activity of silver-containing nanocomposites was determined by agar diffusion assays against opportunistic pathogens S. aureus, E. coli, P. aeruginosa, and C. albicans. The study of the impact of packaging biopolymer materials with silver nanoparticles on the total number of mesophilic aerobic and facultatively anaerobic microorganisms, bacteria of the Escherichia coli group, mold and yeasts in food products, were studied by DSTU for 30 days.* ***Results.*** *The presence of metallic silver on the PLA-PCL film surface was confirmed by wide-angle X-ray diffraction. This is indicated by the presence of two low-intensity maxima at 2θm ~ 38° and*

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44° in the diffractograms of the samples. These maxima correspond to the crystallographic planes of the face-centered cubic lattice of silver, are characterized by indices (111) and (200), respectively, and confirm the presence of metallic silver on the surface of the polylactide-polycaprolactone film. The analysis of the micrographs of the nanocomposites showed that when silver nanoparticles were sputtered on the surface of the PLA-PCL polymer matrix, a layer with a thickness of about 425 nm was formed. It was found that the prepared biopolymer packaging materials PLA and PLA-PCL with Ag nanoparticles sputtered for 3 and 5 min showed antimicrobial activity against S. aureus and E. coli and were inactive against B. subtilis and P. aeruginosa. Packaging bakery products in biopolymer films helps reduce the loss of crumb moisture during storage, slows down the loss of hydrophilic properties, and reduces fragility, which helps extend the shelf life of fresh bread. The moisture content in packaged pumpkin seeds remained stable for two months at the control level. It was found that in wheat bread (for 7 days) and pumpkin seeds (for 30 days), packaged using all types of packaging material PLA-PCL, PLA-PCL-Ag, and conventional PA/PE vacuum film throughout the experiment, no quantitative changes in MAFAnM microorganisms, yeasts, and molds were observed. Studies of the antimicrobial effect of the biopolymer packaging material PLA-PCL-Ag have demonstrated the quality and safety of the films produced, as the calculated values of the total number of microorganisms, yeast and molds, in particular, meet the standards of DSTU. ***Conclusions****. The data obtained suggest that the formed biopolymer packaging materials have antimicrobial properties and are promising for use in the food industry for food packaging, which can extend the shelf life of various product groups without alteration in quality and safety indicators.*

Keywords: *polylactide, polycaprolactone, silver-containing nanocomposites, antimicrobial activity.*

Nowadays, it is difficult to imagine any industry, especially the food industry, without using various packaging materials. Food safety is a daily concern for all food producers. According to the Food and Agriculture Organization of the United Nations (FAO), approximately one-third of the food produced each year is lost due to the development of opportunistic and pathogenic bacteria, fungi, etc. This is about 40—50% of fruits and vegetables, 35% of fish, 30% of cereals, and 20% of dairy and meat products.

Currently, most food packaging materials are made from petrochemical-based polymers due to their low cost and good performance characteristics (Wisniewska et al., 2023; Rabiee et al., 2023; Sinha et al., 2022). However, these polymers are not biodegradable, i.e., they are environmentally hazardous, which has already caused many environmental problems around the world (Sinha et al., 2023; Jouyandeh et al., 2023; Sinha and Hamdan 2023). It is noteworthy that in 2021, Ukraine adopted a law that restricts the circulation of plastic bags in Ukraine. Due to the difficulties associated with the collection and disposal of used products made of synthetic polymer materials, especially various packaging materials such as films, bags, bottles, etc., there is an urgent need for the use of biopolymers for the production of packaging materials that would decompose quickly and safely for the environment.

In recent years, there has been an increase in the development of various packaging materials using biopolymers (Abdullah et al., 2022). The inclusion of biopolymers in food packaging offers benefits such as protecting food during storage and transport, creating a favorable physical and chemical environment to ensure food quality and safety, and extending shelf life (Rossi et al., 2015).

Polylactide (PLA) has attracted particular attention for the development of polymeric packaging materials due to its natural origin and an excellent set of physical and mechanical properties (Lauer et al., 2020; Shafi et al., 2023). It is a biodegradable and biocompatible polymer with high mechanical and thermal characteristics (Khosravi et al., 2020a; 2022b). PLA with Ag nanoparticles can be considered one of the most promising polymers for the development of antimicrobial materials (Porta et al., 2020; Demchenko et al., 2022a, 2022b).

Polycaprolactone (PCL) is a biodegradable polymer that is non-toxic, biodegradable in soil, highly miscible, mechanically compatible with many polymers, has good viscosity for many matrices and a low melting point of about 60 °C (Labet M. et al, 2009).

In view of the above, the **aim** of this work is to research the antimicrobial activity of the developed biopolymer packaging materials containing silver nanoparticles for food preservation.

Materials and Methods. In the antimicrobial research, we used the following reference strains of opportunistic pathogens: *Staphylococcus aureus* ATCC 25923 as model Gram-positive bacteria, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853, as model Gram-negative bacteria, and yeast-like fungus *Candida albicans* ATCC 885-653. The bacterial strains were obtained from the Ukrainian Collection of Microorganisms at the Zabolotny Institute of Microbiology and Virology of NAS of Ukraine. The bacteria were cultured on meat-peptone agar for 24 h at 37 °C.

The samples were molded using the following materials: PLA filament (MonoFilament, Ukraine, with an average molar mass of 274000 g/mol), PCL granules (made in China with Mn = 60000-80000), silver foil with a thickness of 0.1 mm, and 99.9% trace metal base (Aldrich).

PLA-PCL films were obtained by mixing polylactide and polycaprolactone polymers in chloroform in an 80:20 mass ratio. Silver-containing nanocomposites were produced by silver sputtering deposition on the surface of the PLA-PCL film using an FC-1100 ion sputtering device (JEOL, Japan).

Research methods. Features of the structure of the samples. The structure of nanocomposites was studied by wide-angle X-ray diffraction with a XRD-7000 diffractometer (Shimadzu, Japan), the X-ray optical scheme of which was performed by passing the primary beam through the sample, using CuK_α radiation ($\lambda = 1.54$ Å) at temperature $T = 20 \pm 2$ °C (Demchenko et al., 2020).

Morphology of nanocomposites. The size of the Ag nanoparticles and their distribution in the polymer matrix was examined using a JEM-1230 transmission electron microscope (JEOL, Japan) at the resolution of 0.2 nm (Demchenko et al., 2014).

The antimicrobial activity of PLA-PCL films. The study was conducted using the disk diffusion method on a solid nutrient medium called Mueller-Hinton agar (MHA) (Case & Johnson, 1984). Petri dishes containing MHA medium were inoculated with 10μL of test microorganism inoculum at a concentration of 2×10^5 CFU/mL. The test samples were placed on the surface of the nutrient medium that had been inoculated with the test microorganisms. The Petri dishes were then incubated for 24 h at 37 °C. The presence of a clear zone free of microorganisms around the nanocomposite samples served as an indicator of antimicrobial activity.

Determination of the mass fraction of moisture in food products. The mass fraction of product moisture was determined by drying to a constant mass (Karimova et al., 2023). Pumpkin seeds were ground in a laboratory mill, and an average sample was taken. A 3—5 cm thick piece was cut from the center of the bread sample, separating the pulp at a distance of about 1 cm from the bread crust, and ground thoroughly. Two measurements of 5 g were dried at $t = 130 \pm 2$ °C (at least 20 min) and cooled in a desiccator in boxes (d = 45 mm, h = 20 mm) with lids.

The product moisture content (W, %) was calculated using the formula:

$$W = G_1 — G_2/G_1 \times 100\% \qquad (1)$$

where G_1 and G_2 — the weight of the sample before and after drying, respectively, g. The test was carried out in parallel on 2 samples.

Microbiological studies of food products. To study the microbiological characteristics of food products, we selected samples of vegetable raw materials: pumpkin seeds and wheat bread (stored at a temperature of 25 ± 1 °C). Weights of 1 g were taken from each product for the preparation of initial dilutions and subsequent sowing in nutrient media, according to the methods for determining the microorganisms necessary for assessing the safety of these products (DSTU 8051:2015; DSTU ISO 7218:2014; DSTU ISO 6887-1:2003; DSTU 7517:2014; DSTU 4583:2006; DSTU 8446:2015).

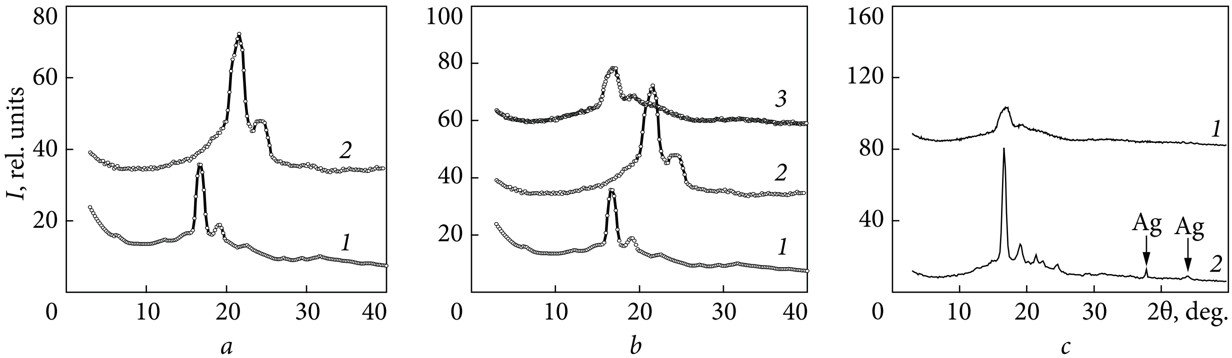

Fig. 1. Wide-angle X-ray diffractograms: *a*) *1* — PLA; *2* — PCL; *b*) *1* —PLA; *2* — PCL; *3* — PLA-PCL (80—20); *c*) *1* — PLA-PCL (80—20); *2* — PLA-PCL (80—20) — Ag

The quantity of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM) was determined according to DSTU 8446:2015. Coliform bacteria indicators were determined in accordance with GOST 30518-97. The total number of molds and yeasts was determined according to DSTU 8447:2015. Determination of spore bacteria of the genus *Bacillus* spp. in the tested samples (bread) was carried out following GOST 10444.2-94.

Statistical processing of results. In unraveling the results, we systematically computed the mean and standard deviation. We used Microsoft Excel to conduct a focused regression analysis, explicitly employing the linear regression to discern underlying trends. It is noteworthy that we conducted three repetitions for each experimental condition, contributing to the robustness and reliability of our statistical analysis.

Results. Wide-angle X-ray diffraction analysis of the initial polymer films based on polylactide (PLA) and polycaprolactone (PCL) showed that they had a semicrystalline structure (Fig. 1 *a*, curves *1* and *2*, respectively).

The analysis of the wide-angle X-ray diffractograms of the polymer blend based on PLA and PCL, taken in a mass ratio of 80 : 20, respectively, showed that this sample also has a semi-crystalline structure (Fig. 1 *b*, curve *3*). The diffractogram of the PLA-PCL blend shows diffraction maxima that characterize the crystalline structure of both the individual PLA and PCL polymers (curve *3* and curves *1*, *2*).

The presence of sputtered Ag nanoparticles on the surface of the PLA-PCL sample (mass ratio of polymers 80 : 20) was confirmed by wide-angle X-ray diffraction (Fig. 1 *c*, curves *1*, *2*).

Fig. 2 shows an image of the silver layer formed on the surface of the PLA-PCL film as a result of Ag nanoparticles sputtering.

The micrographs show that a layer of Ag nanoparticles with a thickness of ~ 425 nm is formed on the surface of the PLA-PCL film (after the sputtering time of 5 min). The analysis of the histogram of the fractional composition of nanoparticles showed that silver particles can form aggregates (Fig. 2). The shape of the nanoparticles in the PLA-PCL-Ag samples obtained by sputtering is close to spherical.

The antimicrobial activity of the formed film materials based on PLA and PCL biopolymers with Ag nanoparticles deposited on the surface of the polymer matrix for 1, 3, and 5 min was studied.

It was found that the PLA-Ag test samples (sputtered for 3 min) have antimicrobial activity against the test cultures of *S. aureus* and *E. coli*. The diameter of the zone of growth inhibition of *S. aureus* was 15.59 mm and that of *E. coli* was 16.47 mm (Table 1). The tested samples based on PLA-Ag with a spray time of 3 min did not show antimicrobial activity against the test cultures of *B. subtilis* and *P. aeruginosa*. Intensive growth of the

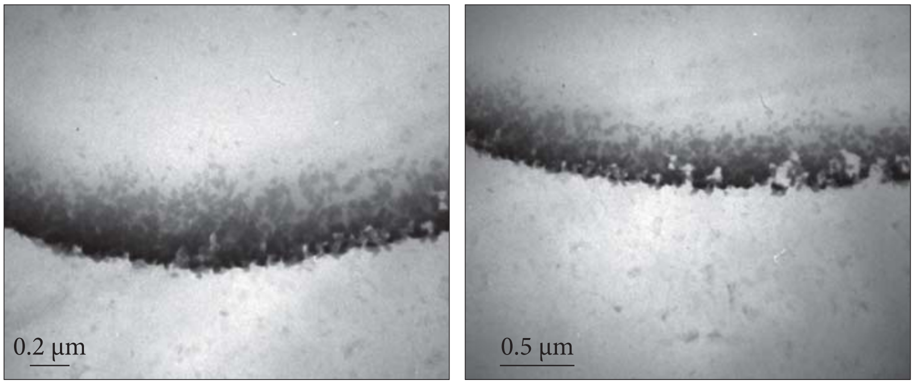

Fig. 2. Photomicrographs of transmission electron microscopy of silver-containing nanocomposites based on polylactide and polycaprolactone with silver nanoparticles formed by sputtering deposition (sputtering time of 5 min)

test cultures was observed around the test samples. The PLA-Ag samples with a silver sputtering time of 1 min did not show any antimicrobial activity.

It was shown that the formed PLA-PCL biopolymer packaging materials with Ag nanoparticles that were sputtered for 1 min do not exhibit antimicrobial activity against any of the test cultures of microorganisms (Table 1). The studied films with Ag nanoparticles sputtered for 3 and 5 min showed antimicrobial activity against the test cultures of *S. aureus* and *E. coli*. After 24 h incubation at 37 °C, a clear zone was observed around the disks of the PLA-PCL-Ag samples sputtered for 3 and 5 min, indicating inhibition of microbial growth. The diameters of the *S. aureus* growth inhibition zones were 13.80 mm for the 3 min silver sputtered sample and 14.82 mm for the 5 min silver-sputtered sample (Table 1). The antimicrobial activity against the *E. coli* test culture was observed in PLA-PCL-Ag samples with a sputtering time of 5 min. The diameter of the *E. coli* growth inhibition zone was 16.44 mm. The sample of PLA-PCL-Ag film with silver sputtering for 3 min showed a slight antimicrobial effect: the diameter of the growth inhibition zone was 11.02 mm. The tested PLA-PCL-Ag samples with an Ag sputtering time of 3 and 5 min showed no antimicrobial activity against the test cultures of *B. subtilis* and *P. aeruginosa*, and an intensive growth of the tested cultures was observed around the tested samples**.**

In the control samples (without Ag nanoparticles) of PLA, PLA-PCL, and a conventional PA/PE vacuum film, active growth of the tested microorganisms and the absence of growth inhibition zones were observed.

Thus, it was found that the biopolymeric packaging materials PLA and PLA-PCL with Ag nanoparticles, which were sputtered for 3 and 5 min, showed antimicrobial activity against *S. aureus* and *E. coli* and were inactive against *B. subtilis* and *P. aeruginosa*.

In the study of the quality and safety of wheat bread and pumpkin seeds during storage in the developed biopolymer packaging materials, the best result in terms of mechanical properties was achieved by the PLA-PCL film, and the most effective result in terms of antimicrobial activity was achieved by the PLA-PCL-Ag sample. The control was a conventional PA/PE vacuum film. Therefore, food products such as wheat bread and pumpkin seeds were packaged in these film materials, followed by vacuum packaging under aseptic conditions. The packaged wheat bread was stored at room temperature for 7 days, and pumpkin seeds — at room temperature under indirect sunlight for 60 days.

Moisture content has a significant impact on the physical and chemical stability of food products during storage and partially determines their shelf life. Packaging bakery products in the produced biopolymer films helps reduce the loss of crumb moisture during storage, slows down the loss of hydrophilic properties, and reduces brittleness, which helps extend the shelf life of fresh bread. At the same time, the physical and chemical quality indicators of the products remain at a high level (Table 2).

The moisture content in packaged pumpkin seeds remained stable at the control level for two months due to the low vapor and gas permeability of the films and other barrier properties, except for the unpackaged samples, which absorbed moisture from the air throughout the experiment (Table 3).

The vapor and water permeability of the developed biopolymer packaging materials do not allow the migration of moisture into the environment, so the natural moisture content of the test samples is maintained.

We conducted microbiological studies on wheat bread and pumpkin seeds stored in the developed antimicrobial packaging materials and in conventional packaging.

We studied the effect of the created biopolymer packaging materials PLA-PCL and PLA-PCL-Ag

Table 1. **Antimicrobial activity of biopolymer packaging materials against opportunistic pathogens**

Sputtering time, min	Polymer system	Diameter of the growth inhibition zone, mm			
		S. aureus	*B. subtilis*	*E. coli*	*P. aeruginosa*
0	PLA	0	0	0	0
	PLA-PCL	0	0	0	0
	PA/PE	0	0	0	0
1	PLA-Ag	0	0	0	0
	PLA-PCL-Ag	0	0	0	0
3	PLA-Ag	15.59±0.6	0	16.47±0.7	0
	PLA-PCL-Ag	13.80±0.5	0	11.02±0.4	0
5	PLA-PCL-Ag	14.82±0.6	0	16.44±0.7	0

Table 2. **Changes in moisture content of wheat bread**

Storage time, days	Moisture, %			
	Without packaging	PA/PE	PLA-PCL	PLA-PCL-Ag
Control (0)	41.3±0.3			
24	37.8±0.2	41.1±0.3	41.1±0.3	41.1±0.3
48	26.1±0.1	41.0±0.3	41.0±0.3	41.0±0.3

Table 3. **Changes in the moisture content in pumpkin seeds**

Storage time, h	Moisture, %			
	Without packaging	PA/PE	PLA-PCL	PLA-PCL-Ag
Control (0)	7.2±0.05			
30	7.9±0.05	7.2±0.05	7.3±0.05	7.3±0.05
60	8.3±0.05	7.2±0.05	7.3±0.05	7.3±0.05

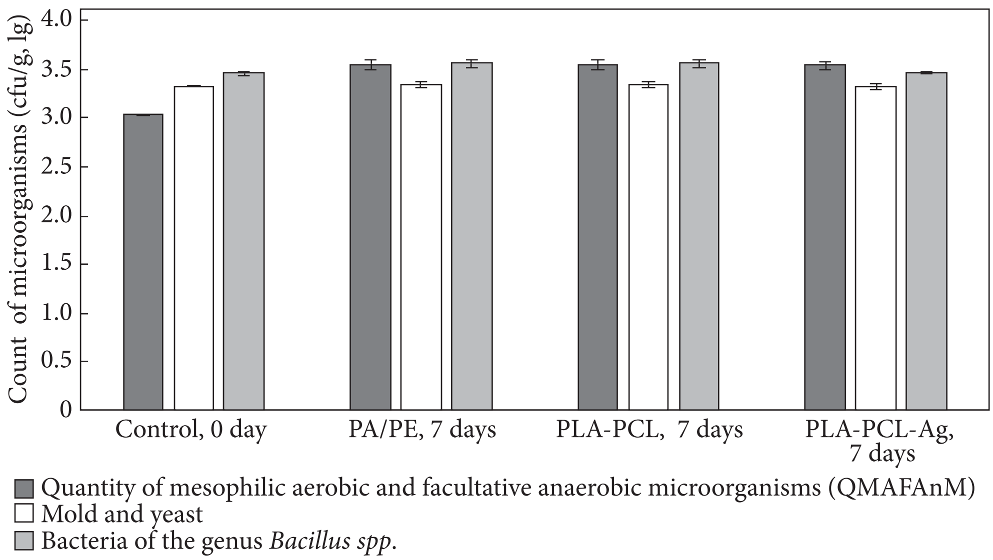

Fig. 3. The total number of microorganisms in wheat bread (M ± m, n = 3). Statistical significance p ≤0.05

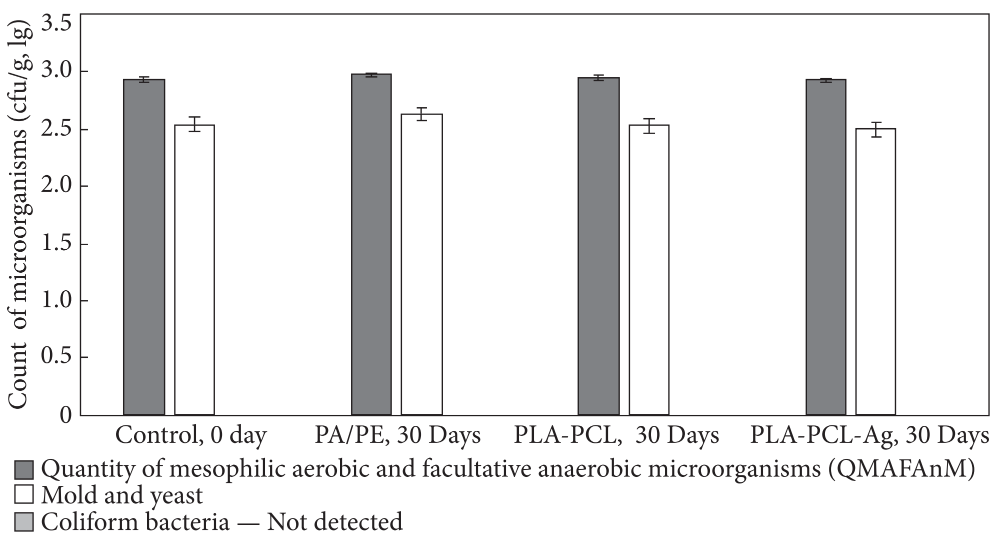

Fig. 4. The total number of microorganisms in pumpkin seeds during 30 days (M ± m, n = 3). Statistical significance p ≤0.05

on the development of extraneous microflora in samples of wheat bread and pumpkin seeds. The control sample was a conventional vacuum film from polyamide-polyethylene (PA/PE).

The first stage of our experiment was to determine the main microbiological parameters of wheat bread and pumpkin seed samples using specific methods and regulatory documents. The results of the data obtained are shown in Figs. 3 and 4. As we can see, the studies demonstrated the high quality and safety of the produced biopolymer films since the calculated indicators of the total number of microorganisms (QMAFAnM), especially yeasts and molds, meet the DSTU standards.

The analysis of the effect of the produced biopolymer packaging materials on the development of microorganisms in wheat bread during the 7-day study period did not show any significant changes in the number of the studied groups of bacteria, yeasts, and molds (Fig. 3).

The study of the quantitative changes in QMAFAnM microorganisms, yeasts, and molds in pumpkin seeds using all types of packaging material PLA-PCL, PLA-PCL-Ag, and conventional vacuum film PA/PE during the 30-day experiment, as well as in wheat bread, did not show any significant changes (Fig. 4).

We did not detect any bacteria of the *Escherichia coli* group (coliform bacteria) in pumpkin seeds, regardless of the packaging material used (Table 4).

Thus, it was found that in wheat bread (for 7 days) and pumpkin seeds (after 30 days), with the use of all types of packaging material PLA-PCL, PLA-PCL-Ag, and conventional PA/PE vacuum film throughout the experiment, no quantitative changes were observed in MAFAM microorganisms, yeasts, and molds. The study of the antimicrobial effect of the biopolymer packaging material PLA-PCL-Ag demonstrated the quality and safety of the films since the calculated indicators of the total number of microorganisms (QMAFAnM), in particular yeasts and molds, met the DSTU standards.

Discussion. The development of pathogenic microorganisms in food products not only reduces their shelf life but also leads to the development of infectious diseases in consumers. The improvement of the microbiological quality and the extension of the shelf life of food products is an important factor in the provision of high-quality and safe food to the population. Microbiological spoilage is one of the main factors limiting the shelf life of food products. Important parameters to ensure a long shelf life are the hygiene of the production process, the storage temperature, and the packaging method (Quintavalla et al., 2002; Martin et al., 2020; Appendini et al., 2002). A clear knowledge of the microbiological quality of food is one of the most important tasks in food safety assessment. The available information on the prevalence of pathogens in food is quite limited, and it is difficult to fully compare and generalize the data.

Based on the characteristics of each type of raw material, it is necessary to develop films for the packaging of food and raw materials as one of the possible ways to combat the development of harmful microbiota to maintain safety and prolong the shelf life of food products.

In this work, we have investigated silver-containing biopolymeric materials PLA-PCL, obtained by mixing polylactide and polycaprolactone polymers dissolved in chloroform in a mass ratio of 80:20, on the surface of which silver nanoparticles were sputtered. It was found that the biopolymer materials prepared with silver nanoparticles, sputtered for 3 and 5 min, showed antimicrobial activity against *S. aureus* and *E. coli* and were inactive against *B. subtilis* and *P. aeruginosa*.

Moisture content has a significant influence on the physicochemical stability of food products during storage and partially determines their shelf life. In the study of quality and safety indicators of wheat bread and pumpkin seeds during storage in the developed biopolymer packaging materials, the best result in terms of mechanical properties was shown by the film based on PLA-PCL, and the most effective result in terms of an-

Table 4. **The total number of microorganisms in pumpkin seeds after 30 days (M±m, n=3)**

Microbial groups, (CFU/g, log10)	0 Day	PA/PE	PLA-PCL	PLA-PL-Ag
Quantity of mesophilic aerobic and facultative anaerobic microorganisms (QMAFAnM)	2.93±0.02	2.8 ±0.03	2.94±0.02	2.92±0.02
Mold and yeast	2.53±0.06	2.62±0.02	2.52±0.05	2.49±0.05
Coliform bacteria	Not detected	Not detected	Not detected	Not detected

timicrobial activity was shown by the PLA-PCL-Ag sample. The packaging of bakery products in the developed biopolymer films contributes to a lower loss of crumb moisture during storage, slows down the loss of hydrophilic properties, and reduces the fragility, which helps prolong the shelf life of the bread's freshness. At the same time, the physical and chemical quality indicators of the products remain at a high level.

The spoilage of food products, especially bakery products, is a very common occurrence. One of the most common biological contaminants is the growth of microscopic fungi, which are highly toxic to humans and animals. It should be noted that among the various types of packaged food, microbial spoilage of bread causes huge economic losses to the bakery industry (Valerio et al., 2008). Molds and yeasts are the most common causes of bread spoilage (Pepe et al., 2003). In addition, contamination with microscopic fungi is a fairly common bacterial spoilage of bread products. For example, B. *subtilis* actively grows in mesophilic and humid conditions (Bardaa et al., 2016), as bacterial endospores do not die during bread baking (Beuchat et al., 2013). Therefore, the detection of yeasts and molds, as well as QMAFAnM, is regulated by GOST.

We have studied the effect of the created biopolymer packaging materials in the form of PLA-PCL and PLA-PCL-Ag films on the development of extraneous microflora in samples of wheat bread and pumpkin seeds. The antimicrobial studies demonstrated the quality and safety of the biopolymer films produced, as the calculated indicators for both the total number of microorganisms (QMAFAnM) and for yeasts and molds were in line with the DSTU standards. In wheat bread (after 7 days) and pumpkin seeds (after 30 days), when PLA-PCL and PLA-PCL-Ag packaging materials or vacuum packaging films were used throughout the experiment, no quantitative changes in QMAFAnM, yeasts, and molds were observed.

According to the literature, silver nanoparticles are one of the most powerful antimicrobial agents, inhibiting the growth of about 650 different types of microorganisms (viruses, molds, fungi, and yeasts) (Nechifor et al., 2021; Kukushkina et al., 2021). The combination of polylactide-polycaprolactone biopolymers with silver nanoparticles allows one to obtain materials with effective antimicrobial activity. Literature data show that the combined use of packaging material with Ag nanoparticles has an antibacterial effect against gram-positive (*S. aureus, B. cereus*) and gram-negative (*E. coli*) microorganisms. However, the former has a higher antimicrobial resistance due to the structure of the cell wall (Vasile et al., 2020). The use of such films is promising for the packaging of special dietary bakery products. Such products contain raw materials that are unconventional for bakery production, which improves the nutritional value of the products and contributes to their health benefits, which in turn increases their cost. At the same time, the use of raw materials that are only valuable in terms of functional properties can lead to a faster loss of freshness and faster microbiological deterioration of the products compared to mass consumer products. Increasing the shelf life of these types of products by using the packaging materials investigated is therefore a promising direction.

Conclusions. It was found that the biopolymeric materials prepared with silver nanoparticles sputtered for 3 and 5 min exhibited antimicrobial activity against *S. aureus* and *E. coli* and were inactive against *B. subtilis* and *P. aeruginosa*. Packaging bakery products in biopolymer films helps reduce the loss of crumb moisture during storage, slows down the loss of hydrophilic properties, and reduces fragility, which helps extend the shelf life of fresh bread. The moisture content of pumpkin seeds in the packaging remained stable for two months at the control level. It was found that in wheat bread (for 7 days) and pumpkin seeds (for 30 days), using all types of packaging material PLA-PCL, PLA-PCL-Ag, and conventional PA/PE vacuum film throughout the experiment, no quantitative changes in MAFAnM, yeasts, and molds were observed. Studies of the antimicrobial effect of the biopolymer packaging material PLA-PCL-Ag have demonstrated the quality and safety of the films produced, as the calculated values of the total number of microorganisms, yeasts and molds meet the DSTU standards. The data obtained suggest that the formed biopolymer packaging materials have antimicrobial properties and are promising for use in the food industry for food packaging, which can extend the shelf life of various product groups without alteration in quality and safety indicators.

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Conflict of interest. The authors declare that there are no conflicts of interest.

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АНТИМІКРОБНА ДІЯ ПАКУВАЛЬНИХ БІОПОЛІМЕРНИХ МАТЕРІАЛІВ З НАНОЧАСТИНКАМИ СРІБЛА ДЛЯ ЗБЕРІГАННЯ ХАРЧОВИХ ПРОДУКТІВ

Питання якості та безпечності харчових продуктів є одними з найбільш актуальних та важливих для працівників торговельних мереж та кінцевих споживачів. Однак розвиток патогенних мікроорганізмів у таких продуктах не лише зменшує їхній термін придатності, але й викликає розвиток інфекційних захворювань у споживачів. Тому наразі існує нагальна потреба в розробці нових пакувальних матеріалів з антимікробною дією, які є не токсичними для людини, харчових продуктів та довкілля. **Метою** роботи було дослідити антимікробну активність срібловмісних нанокомпозитів, сформованих на основі полілактиду (ПЛА) та полікапролактону (ПКЛ) з наночастинками срібла методом напилення. **Методи.** Структуру срібловмісних нанокомпозитів досліджували методом ширококутного рентгенівського розсіювання на дифрактометрі XRD-7000. Морфологію наночастинок Ag на поверхні плівок вивчали методом трансмісійної електронної мікроскопії. Антимікробну активність срібловмісних нанокомпозитів щодо умовно-патогенних мікроорганізмів *S. aureus, E. coli, P. aeruginosa* та *C. albicans* визначали диско-дифузійним методом. Дослідження впливу пакувальних біополімерних матеріалів з наночастинками срібла на загальну кількість мезофільних аеробних і факультативно анаеробних мікроорганізмів, бактерій групи кишкової палички, плісеневих грибів та дріжджів у харчових продуктах проводили згідно з ДСТУ впродовж 30 діб. **Результати.** Методом ширококутової рентгенографії було підтверджено наявність металічного срібла на поверхні плівки ПЛА-ПКЛ наявністю на дифрактограмах зразків двох малоінтенсивних максимумів при $2\theta_m \sim 38°$ і 44°, що відповідають кристалографічним площинам гранецентрованої кубічної ґратки срібла, характеризуються індексами відповідно (111) і (200). Аналіз мікрофотографій нанокомпозитів показав, що при напиленні наночастинок срібла на поверхню полімерної матриці ПЛА-ПКЛ утворюється шар товщиною ~425 нм. Встановлено, що розроблені біополімерні пакувальні матеріали ПЛА та ПЛА-ПКЛ з наночастинками Ag, напилених протягом 3 та 5 хв, демонстрували антимікробний ефект щодо *S. aureus* та *E. coli* і були неактивними щодо *B. subtilis* та *P. aeruginosa*. Пакування в ці плівки хлібобулочних виробів сприяє меншій втраті вологи м'якушки в процесі зберігання, сповільненню втрати гідрофільних властивостей та зменшенню крихкості, що подовжує термін зберігання свіжості хліба. Стабільність вологості насіння гарбуза в такій упаковці зберігалася протягом двох місяців на рівні контролю. Встановлено, що у хлібі пшеничному (протягом 7 діб), та в гарбузовому насінні (протягом 30 діб), при використанні всіх типів пакувального матеріалу ПЛА-ПКЛ, ПЛА-ПКЛ-Ag та звичайної вакуумної плівки ПА/ПЕ впродовж всього експерименту, кількісних змін мікроорганізмів МАФАМ, дріжджів і плісеневих грибів не спостерігалось. Дослідження антимікробної дії біополімерного пакувального матеріалу ПЛА-ПКЛ-Ag продемонстрували якість та безпечність створених плівок, адже розраховані показники як загальної кількості мікроорганізмів, так і окремо дріжджів та плісеневих грибів відповідають нормам ДСТУ. **Висновки.** Отримані дані дозволяють стверджувати, що розроблені біополімерні пакувальні матеріали характеризуються антимікробними властивостями та є перспективними для застосування в харчовій промисловості для пакування харчових продуктів, що дозволить збільшувати термін зберігання різних груп продуктів без зміни показників якості та безпечності.

Ключові слова: *полілактид, полікапролактон, срібловмісні нанокомпозити, антимікробна активність.*