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ANTIMICROBIAL AND ANTIVIRAL ACTIVITY OF SILVER-CONTAINING NANOCOMPOSITES FORMED BY 3D PRINTING TECHNOLOGY

Silver nanoparticles have become the focus of numerous researchers to create efficient antimicrobial and antiviral agents due to their pronounced pharmacological effects, low toxicity to the human body and the environment, and high stability in extreme conditions. To create antimicrobial drugs with silver nanoparticles, matrices from polymers of both synthetic and natural origin are used. Biopolymer polylactide (PLA) is one of the most promising materials for 3D printing (additive production) due to its physicochemical and technological properties. ***The aim*** *of the work was to study the antimicrobial and antiviral activity of silver-containing nanocomposites formed on the basis of PLA with the addition of chitosan or polyethyleneimine (PEI) by 3D printing technology.* ***Methods.*** *Peculiarities of the structural organization of silver-containing materials were investigated by the method of wide-angle radiography on an XRD-7000 diffractometer. The morphology of the samples was studied by transmission electron microscopy on a JEM-1230 instrument. Filament*

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formation proceeded through melting PLA-AgPalm-PEI or PLA-AgPalm-chitosan films in an extruder at a temperature of T=160±1°C. Samples were formed from the obtained filaments using a 3D printer. The antimicrobial activity of silver-containing nanocomposites was determined by the disk diffusion method against opportunistic pathogens S. aureus and E. coli. Cytotoxicity and antiviral activity were investigated using the MTT method and staining by gentian violet. ***Results.*** *Analysis of wide-angle X-ray diffraction patterns of products formed by 3D printing technology at 160 °C showed that PLA-Ag-PEI and PLA-Ag-chitosan materials contain metallic silver. Analysis of microphotographs of PLA-4%Ag-PEI and PLA-4%Ag-chitosan products formed by 3D printing technology showed that silver nanoparticles formed by adding chitosan as a reducing agent and stabilizer to the polymer matrix of PLA are much smaller than when using PEI. Silver-containing nanocomposite samples, such as filaments and products formed from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films subjected to heat treatment and without heat treatment, show antimicrobial activity against test cultures of S. aureus and E. coli. It was found that nanocomposites based on PEI and chitosan do not show cytotoxic effects in MDCK and HEP-2 cultures. Nanocomposites of both types show a weak antiviral effect against adenovirus serotype 2;the reduction of infectious titer was 0.5 lg$TCID_{50}$/mL. None of the studied nanocomposites showed antiviral action on the influenza virus model.* ***Conclusions****. The investigated silver-containing nanocomposites with a silver concentration of 4 % by weight, formed by 3D printing technology from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films, show antimicrobial activity against S. aureus and E. coli test cultures and antiviral activity on influenza A virus and human adenovirus and do not show a cytotoxic effect on cells. The obtained data allow us to state that the studied silver-containing nanocomposites are promising antimicrobial agents for use in various fields of medicine and the food industry.*

Keywords: silver-containing nanocomposites, polylactide, polyethyleneimine, chitosan, 3D printing, antimicrobial activity, antiviral activity.

Due to the development of microorganisms resistant to many antimicrobial agents, the need for new highly effective active substances in ecology, medicine, and the food industry is constantly growing. Research and control of viral infections, in particular a large group of respiratory diseases caused by viruses such as influenza viruses, parainfluenza viruses, respiratory syncytial viruses, adenoviruses, rhinoviruses, coronaviruses, etc., occupy an important place in modern medicine [1]. The variety of clinical manifestations of diseases, features of pathogens, and the possibility of their spread through almost all known routes of transmission, contributed to the fact that the WHO Regional Office for Europe classified viral infections as a group of diseases that significantly affect the future of infectious diseases. This is evidenced by the present when the world is facing unprecedented challenges related to the fight against the COVID-19 outbreak. COVID-19 is the latest of three pandemics caused by the coronavirus family in the last two decades (including the SARS outbreak in 2002 and the MERS outbreak in 2012). Due to the nature, characteristics, and biological and physical properties of viruses, the issue of combating them is very acute [2].

Metal nanoparticles, such as silver, copper, and zinc oxide, have become the focus of numerous researchers to create effective antimicrobial agents due to their pronounced pharmacological effects, such as antimicrobial, antiviral, anti-inflammatory, immunomodulatory, as well as high stability in extreme conditions [3–7]. Metal nanoparticles can be incorporated into polymers to create nanocomposites and used in various fields of medicine, the food industry, etc. [8, 9].

To create antimicrobial drugs with silver nanoparticles, polymer matrices based on various polymers of both synthetic and natural origin are used. In this context, the most suitable are polymers of natural origin, such as chitosan, pectin, starch, polylactide (PLA), and others. However, the effectiveness of the antimicrobial action of nanocomposite materials depends on many factors, such as their particle size, shape, concentration, type of polymer matrix, the method of introduction of metal nanoparticles into the polymer matrix, etc. [10–16].

3D printing, as one of the methods of additive production, has received much attention in the last few decades with potential use in various industries [17]. The advantages of additive production are the reduction of mass and production costs, the ability to obtain complex products with high accuracy, a significant reduction in manufacturing time, the exclusion of additional processes, and the high flexibility of structures [18, 19]. As a result, the scope of additive manufacturing is expanding rapidly, especially in the aerospace and defense industries, automotive, healthcare, and production of consumer goods [20]. Biopolymer PLA is one of the most promising materials for 3D printing due to its physicochemical and technological properties [21]. It is also an environmentally friendly material, has balanced thermomechanical properties, biocompatibility, and the ability of controlled decomposition under certain conditions.

In view of the above, the **aim** of this work was to study the antimicrobial and antiviral activity of silver-containing nanocomposites formed on the basis of PLA with the addition of chitosan or polyethyleneimine (PEI) by 3D printing technology.

Materials and methods. The objects of the study were reference strains of opportunistic pathogens *Staphylococcus aureus* ATCC 25923 and *Escherichia coli* ATCC 25922 as model gram-positive and gram-negative bacteria. The strains of bacteria were obtained from the Ukrainian Collection of Microorganisms at the Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine, Kyiv, Ukraine. Bacteria were grown on a meat-peptone agar for 24 hr at 37 °C.

Viruses and cell culture. In this study, MDCK and Hep-2 cells were used for cytotoxicity research. The influenza A virus (IAV) H1N1, strain A/FM/1/47, and human adenovirus serotype 2 (HAdV-2) were used for antiviral research. All epithelial cells were maintained in sterile plastic falcon (Bioswisstec, Switzerland) in a growth medium composed of 45% DMEM (Biowest, France), 45% RPMI 1640 (Biowest, France), and 10% fetal bovine serum (FBS, Biowest, France) heat-inactivated at 56 °C with antibiotics penicillin-streptomycin, 100 μg/mL (Biowest, France).

Research materials. The following agents were used for the production of polymeric systems based on PLA and silver nanoparticles: PLA filament (MonoFilament, Ukraine, with an average molar mass M_w = 274000 g/mol), synthetic polyelectrolyte anhydrous branched PEI (Aldrich) with $M_n = 1 \cdot 10^4$ and $M_w = 2.5 \cdot 10^4$ g/mol, natural polyelectrolyte chitosan (low molecular mass, Aldrich). Silver palmitate (AgPalm) was synthesized according to the method described in [22].

PLA-AgPalm-PEI polymer films. The required quantity of AgPalm was added to PLA solution in chloroform (with vigorous stirring by magnetic stirrer), then the temperature was increased to 60 °C, and then PEI solution in chloroform in small portions was added (molar ratio NH_2: Ag^+ = 1:1). The mixture was stirred at 60 °C within 30 min, and then it was cast on a Teflon surface. After drying at room temperature, the red-brown colored transparent film was prepared.

PLA-AgPalm-chitosan polymer films were obtained in the same way, but instead of PEI solution, a 2 wt.% aqueous solution of chitosan in acetic acid was added. After drying at room temperature, a white non-transparent film was obtained. The required quantity of AgPalm was added to PLA solution in chloroform (with vigorous stirring by magnetic stirrer), then the temperature was increased to 60 °C, and a 2 wt.% water solution of chitosan in acetic acid was added (molar ratio NH_2: Ag^+ = 1:1). The mixture was mixed at 60 °C for 30 min, and then it was cast onto the Teflon surface. After drying at room temperature, the white non-transparent film was made.

Filaments were formed by melting PLA-AgPalm-PEI or PLA-AgPalm-chitosan films in an extruder at T = 160 ± 1 °C (diameter in the origi-

nal extruder spinneret was d = 1.75 ± 0.05 mm). The film material underwent additional heat treatment to reduce Ag^+ ions to nanoparticles of metallic silver. Subsequently, the obtained filament was used to form products by 3D printing technology at the spinneret temperature of the print head T = 160 ± 1 ºC. The Ag content in the volume of films was to 4 wt% (further %). The concentration φ of silver nanoparticles in filaments and products was the same as in the original PLA films.

Research methods. Peculiarities of the structural organization of silver-containing materials were studied by the method of wide-angle radiography on an XRD-7000 diffractometer (Shimadzu, Japan), whose X-ray optical scheme was performed for the passage of the primary beam through the sample under study, using CuK_a-radiation (l = 1.54 Å) and a graphite monochromator. The studies were performed by the method of automatic step-by-step scanning in the mode U = 30 kB, I = 30 mA in the range of scattering angles ($2q$) from 3.0 to 50 degrees. The exposure time was 5 s. The temperature was T = 293 ± 2 K [23].

The size of Ag nanoparticles and their distribution in the polymer materials was examined using a JEM-1230 transmission electron microscope (JEOL, Japan) at a resolution of 0.2 nm [24].

The antimicrobial activity of silver-containing nanocomposites. The study was performed by a disk diffusion method on a solid nutrient medium Mueller-Hinton agar (MHA). Petri dishes with LB medium were inoculated with 10μl of inoculum of test microorganisms *S. aureus* and *E. coli* at a rate of 2×10^5 CFU/mL. Test samples were placed on the surface of the nutrient medium inoculated with test microorganisms. The Petri dishes were incubated for 24 h at 37 °C. An indicator of antimicrobial activity was the presence of a clear zone free of microorganisms around the nanocomposite samples.

The antiviral assay. The nanocomposites under study were placed in the wells of a 96-well plate (darker side up), and 100 μL of undiluted virus suspension was applied on top and incubated at 37 °C for 60 mins. Cells were infected with ten-fold serial dilutions of virus-containing material at 50 μL per well. A suspension of the virus was used as a control, which was kept in similar conditions without contact with composites. Adsorption was performed at 37 °C for 1.5 hr, after which 150 μL of support medium was added to the virus-containing material. Non-virus-infected cells were used as cell controls. The plate was kept in an atmosphere of 5% CO_2 at 37 ºC until the appearance of a pronounced cytopathic effect of the virus (3 days). The analysis was performed using the MTT method for influenza A virus (IAV) H1N1 and Ad-2 cells and crystal purple staining for influenza virus. All experiments were performed in triplicate. The results were analyzed spectrophotometrically on a Multiskan FC reader (Thermo Scientific, USA) at a wavelength of 538 nm. Using the obtained optical densities was determined by % of cytopathic effect (CPE) of the virus on the cells by the formula described by Kohn et al. [25]. Virus dilution was determined, which reduces the optical density of the sample compared to the cell control by 50%, which is the virus titer and is expressed in $TCID_{50}$/mL.

The cytotoxicity assay. The cytotoxicity of nanocomposites was studied using the MTT test, based on determining the functioning of the dehydrogenase activity of mitochondria. The study procedure included 24 hr of exposure of the plates in a growth medium for cell cultures at 37 ºC. The medium was then added to the monolayer of cell cultures at dilutions of 1:10, 1:100, and 1:1000. Analysis of cells was performed at 48 hr by adding a 20 μL of MTT solution (5 mg/mL, NeoFrexx, German). After 4 hr of incubation in the dark, the formazan crystal of MTT reduction was dissolved in ethanol 96%, and absorbance was measured using a microtitre plate reader Multiskan FC (Thermo Scientific, USA). The effect of cytotoxicity of the samples

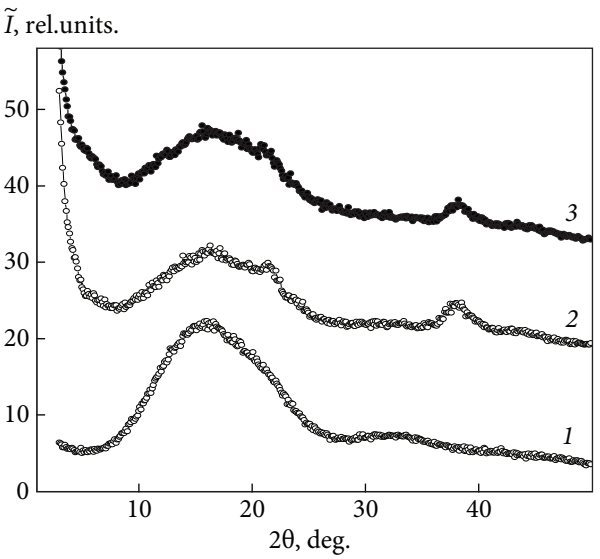


Fig. 1. Wide-angle X-ray diffraction patterns of products obtained by 3D printing technology: *1* — PLA; *2* — PLA-4%Ag-PEI; *3* — PLA-4%Ag-chitosan

was quantified as the percentage of control absorption of the reduced dye MTT at 540 nm. All experiments were repeated three times to test for sensitivity. Cell viability was assessed by the ability of live cells to reduce the yellow MTT dye to a blue formazan crystal [26].

Results. Analysis of wide-angle X-ray diffraction patterns of products formed by 3D printing technology at 160 °C showed that the materials PLA-Ag-PEI and PLA-Ag-chitosan contain metallic silver. This is indicated by the corresponding diffraction maxima at $2\theta_m$~38.2° and 44.2°, which correspond to crystallographic planes of Miller indices (111) and (200) of the fcc lattice of Ag, respectively (Fig. 1, curves 1—3).

Analysis of photomicrographs of PLA—4%Ag—PEI and PLA—4%Ag—chitosan products formed by 3D printing technology showed that silver nanoparticles formed by adding chitosan as a reducing agent and stabilizer to the polymer matrix of PLA are much smaller than that in case of using PEI (Fig. 2, 3).

In the study of the antimicrobial activity of silver-containing nanocomposites — filaments and

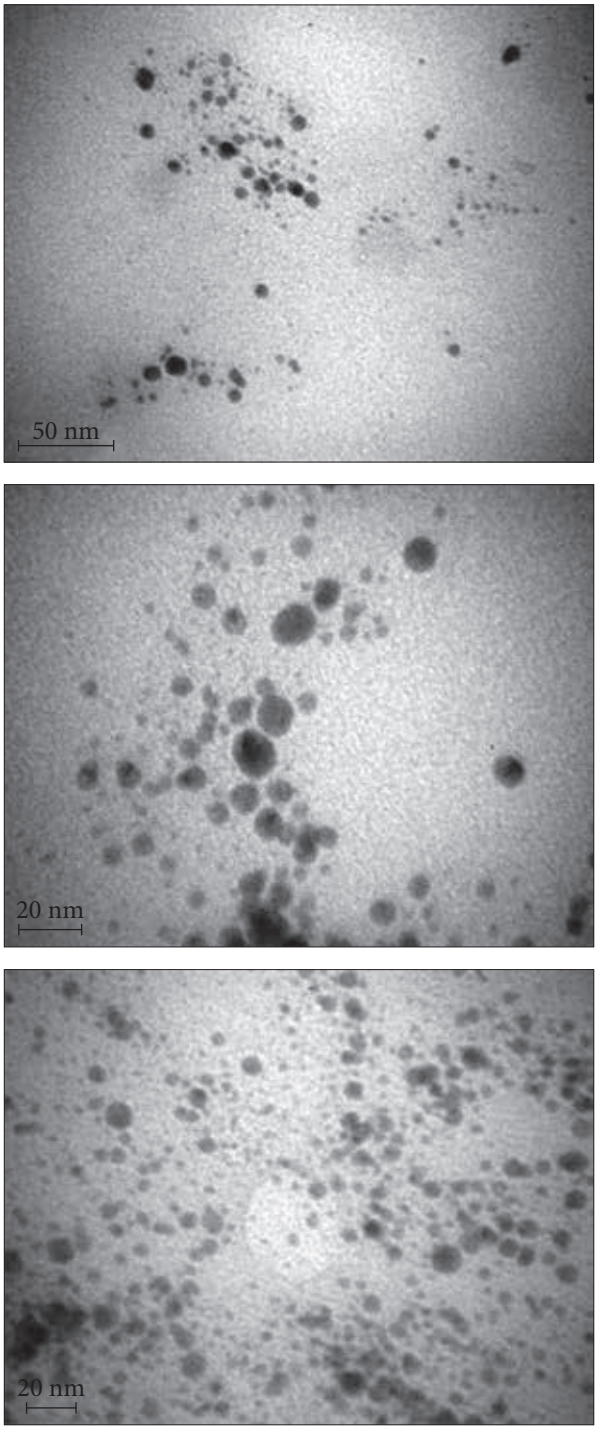


Fig. 2. Electron microscopic images of silver nanoparticles in PLA—4%Ag—chitosan products formed by 3D printing technology

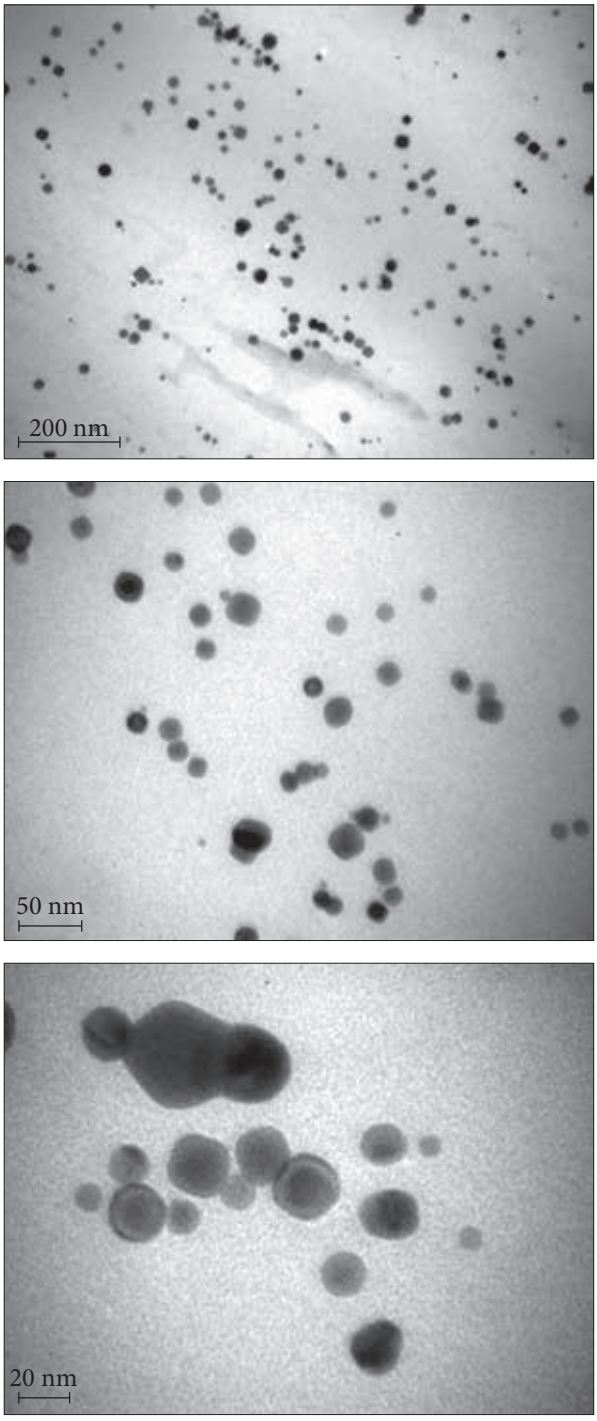
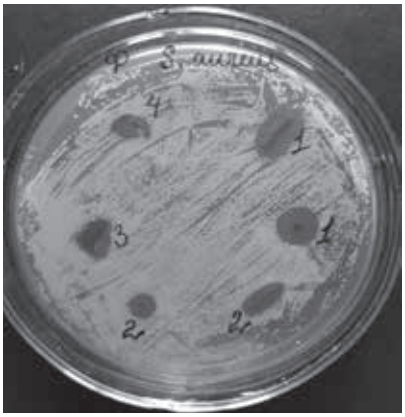


Fig. 3. Electron microscopic images of silver nanoparticles in PLA-4%Ag-PEI products formed by 3D printing technology

products PLA-4%Ag-chitosan and PLA-4%Ag-PEI formed by 3D printing technology, it was found that the samples show antimicrobial activity against test cultures of *S. aureus* and *E. coli* (Fig. 4).

In general, all test samples (filaments and products) with a concentration of silver nanoparticles of 4% were obtained from silver-ion-containing films that had not been subjected to heat treatment. But for research of antimicrobial action, filaments and products were formed from films that had passed heat treatment. That is, for the production of filaments and products based on them, we used films that had already undergone the reduction of Ag^+ ions to metal nanoparticles of Ag at 160 °C (subjected to heat treatment) and films containing silver ions, which were restored during the formation of filaments and products (without heat treatment). It was found that the filaments (samples 1, 2, 5, 6; d (diameter) = 2 mm, l (length) = 10 mm), formed from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films, subjected to heat treatment orand without heat treatment, showed antimicrobial activity against test cultures *S. aureus* and *E. coli* (Table 1). After 24 h of incubation of the samples at 37 °C on a nutrient medium, the presence of a clear zone around the test materials was observed. The diameters of the zones of growth retardation of *S. aureus* were 6.3–10.8 mm. For *E. coli*, the diameters of growth retardation zones were in the range of 8.5—10.8 mm.

Products formed from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films subjected to heat treatment (samples 5', 6'; d = 10 mm) showed antimicrobial activity only against the test culture of *S. aureus*. The diameters of the growth retardation zones were 10.6–11.2 mm. However, among the investigated products formed from PLA-4% Ag-PEI and PLA-4% Ag-chitosan films without heat treatment (samples 3, 4; d = 5 × 10 mm), only sample 3 (PLA-4% Ag- chitosan) showed little activity against



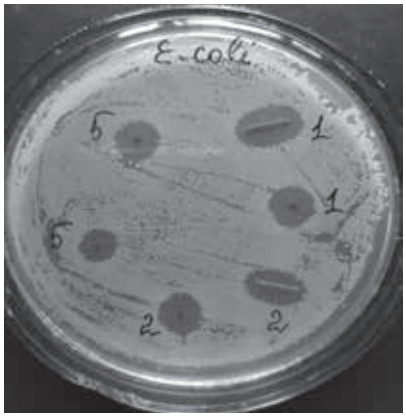


Fig. 4. Antimicrobial activity of filaments and products PLA-4%Ag-chitosan and PLA-4%Ag-PEI formed by 3D printing technology against *S. aureus* and *E. coli*: 1 — filament formed from PLA-4%Ag-PEI film that was not subjected to heat treatment, 2 — filament formed from PLA-4%Ag-chitosan film that was not subjected to heat treatment, 3 — product PLA-4%Ag-chitosan made using filament formed from a film that was not subjected to heat treatment, 4 — product PLA-4%Ag-PEI made using filament formed from a film that was not subjected to heat treatment, 5 — filament PLA-4%Ag-chitosan formed from a film that was subjected to heat treatment, 5' — product PLA-4%Ag-chitosan made using filament formed from a film that was subjected to heat treatment, 6 — filament PLA-4%Ag-PEI formed from a film that was subjected to heat treatment, 6' — product PLA-4%Ag -PEI made using filament formed from a film that was subjected to heat treatment, 7 — filament sprayed with silver

Table 1. **Antimicrobial activity of filaments and products PLA-4%Ag-chitosan and PLA-4%Ag-PEI formed by 3D printing technology against *S. aureus* and *E. coli***

Polymer system		Diameter of growth retardation zones, mm			
		S. aureus		*E. coli*	
		with thermo-chemical treatment of the film	without thermo-chemical treatment of the film	with thermo-chemical treatment of the film	without thermo-chemical treatment of the film
Control (filament)	PLA	0	0	0	0
Product	PLA-4%Ag-PEI	11.2±0.4	0	0	0
	PLA-4%Ag-chitosan	10.6±0.6	10.5±0.7	0	0
	PLA sprayed Ag	0	0	0	0
Filament	PLA-4%Ag-PEI	7.5±0.3	10.8±0.5	10.6±0.5	10.8±0.6
	PLA-4%Ag-chitosan	6.3±0.1	6.4±0.1	8.5±0.7	9.5±0.7
	PLA sprayed Ag	0	0	0	0

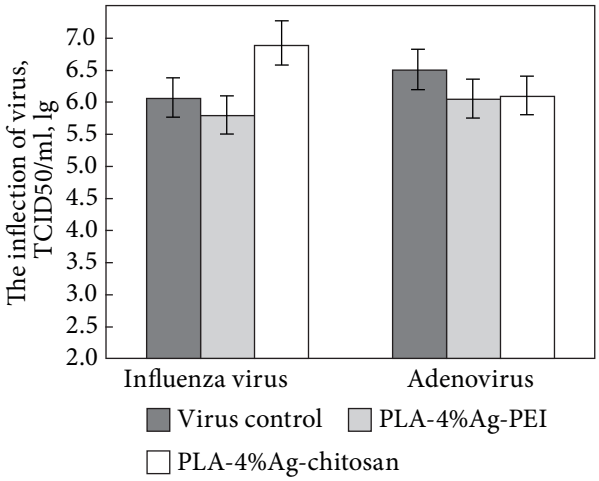
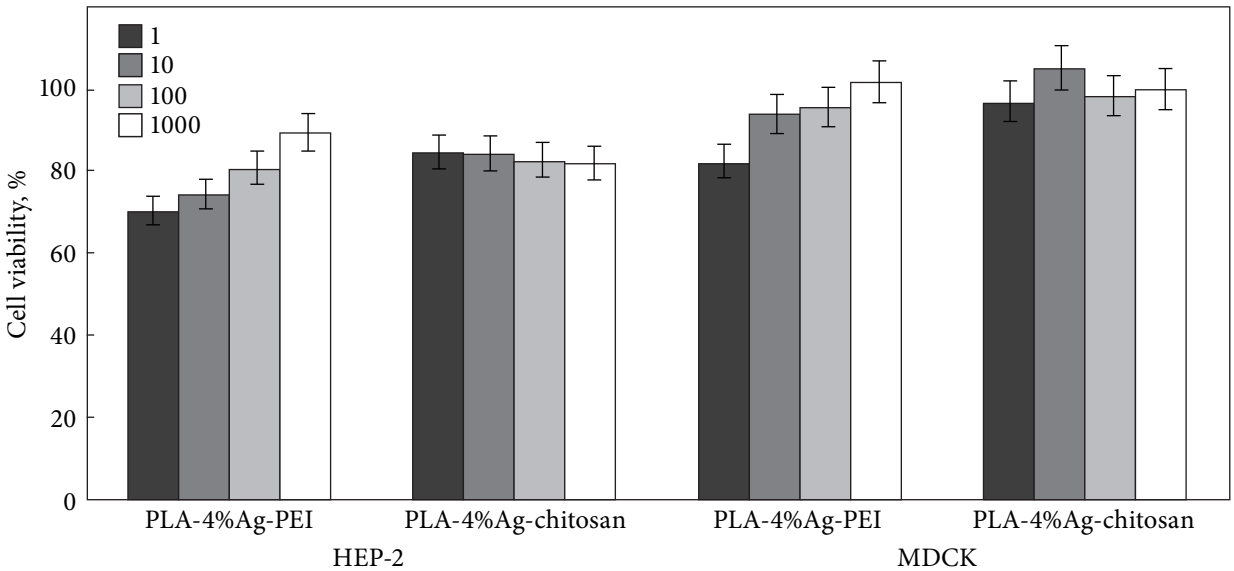


Fig. 5. Infection titer of influenza virus and adenovirus after incubation with silver-containing nanocomposite products obtained by 3D printing

Fig. 6. Influence of silver-containing nanocomposite products obtained by 3D printing on the cell viability of monolayer cell cultures



S. aureus. The diameter of the growth retardation zone was 10.5 mm, sample 4 (PLA-4% Ag-PEI) had no antimicrobial activity, and continuous growth of test culture was observed around the sample (Table 1).

For comparison, we studied filaments sprayed with silver (sample 7, d = 2 mm, l = 10 mm). The nanocomposite samples — filaments were inactive against *S. aureus* and *E. coli*. The growth of test cultures and the absence of growth retardation zones were observed on the Petri dishes (Fig. 4).

Thus, studied silver-containing nanocomposite samples — filaments formed from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films subjected to heat treatment and without heat treatment, show antimicrobial activity against test cultures of *S. aureus* and *E. coli*. Products formed by 3D printing technology from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films subjected to heat treatment were characterized by antimicrobial action, and among the similar films not subjected to heat treatment, only sample PLA-4% Ag-chitosan demonstrated antimicrobial action.

As shown in Fig. 5, the infection titer of adenovirus after incubation with nanocomposite products, based on PLA and PEI (PLA-4Ag%-PEI) or chitosan (PLA-4Ag-chitosan), was 6.05 and 6.11 $lgTCID_{50}$/mL, respectively, while a virus control was 6.51 $lgTCID_{50}$/mL. PLA-4Ag%-PEI nanocomposites inhibited the development of the CPE of the influenza virus and its titer by 0.27 $lgTCID_{50}$/mL, while PLA-4Ag-chitosan products increased the infectious titer of the virus by 0.85 $lgTCID_{50}$/mL. Thus, nanocomposite products obtained by 3D printing technology showed relative virucidal activity against influenza virus and adenovirus (Fig. 5).

Fig. 6 presents the results of cytotoxicity studies of the products PLA-4Ag%-PEI and PLA-4Ag-chitosan in epithelial cultures Hep-2 and MDCK cells. As shown, the percentage of living MDCK cells after incubation with the products on a PLA matrix with PEI or chitosan with φ = 4% silver was in the range from 82 to 100%. In Hep-2 cell culture, slightly lower cell viability was observed after incubation with all samples; the percentage was 70—89. It should be noted that the dilution of samples does not influence the cell viability of both cultures. The results indicate the absence of cytotoxic effects of nanocomposite products obtained by 3D printing technology.

Discussion. Contamination of the surface with pathogenic bacteria, viruses, and fungi is, without exaggeration, a significant problem that has been the subject of numerous scientific studies. Therefore, today there is an urgent need for new antimicrobial and antiviral materials with high bactericidal action and low toxicity to humans and the environment.

Preparations containing silver or copper nanoparticles attract the most attention. Scientists have proven that silver neutralizes more than 1,000 species of harmful bacteria, viruses, and fungi (for comparison: the spectrum of action of any chemical antibiotic is only 5–10 species). The antimicrobial and antiviral properties of silver are related to the size of its particles that come into contact with the environment. The smaller the particle and the larger the contact surface, the stronger the antimicrobial effect. The current pharmaceutical market of Ukraine is limited by expensive silver preparations only of foreign industrial production, which opens wide opportunities for the development of an effective composition of domestic antimicrobials and the latest technologies for their manufacture.

The silver-containing nanocomposite samples, i.e. filaments and products formed by 3D printing technology from films (PLA-4%Ag-PEI and PLA-4%Ag-chitosan), show antimicrobial activity against test cultures *S. aureus* and *E. coli.* The diameters of the growth retardation zones of the studied test cultures have been recorded in the range of 6.3–11.2 mm, which indicates inhibition of bacterial growth. The authors explain the antibacterial action of nanosilver by the peculiarities of the cell membrane structure [27]. Under the influence of nanoparticles, the cytoplasmic membrane of bacteria is primarily damaged, as it is one of the main targets of extreme action. The structural elements of the cell membrane are affected, and their damage leads to the regulation of the chemistry and permeability of the living cell, as well as to the destruction of its membrane, and subsequently to its death. It is possible that one of the mechanisms of antimicrobial action of silver ions is the inhibition of transmembrane transport of Na^+ and Ca^{2+} [28, 29]. Some researchers point out that silver nanoparticles inhibit the growth of bacteria by inactivating proteins containing thiol groups, forming a strong bond with the sulfur atom [30].

Viral infections are serious health challenges for humans. Recently, the majority of viral epidemics, such as the Zika virus, SARS, MERS, influenza virus, and COVID-19, have been caused by enveloped viruses. Non-enveloped viruses are more stable and demonstrate resistance to

environment stress. Thus, studying new nanocomposites with antiviral activity is extremely important. In this paper, we presented the antiviral activity and cytotoxicity of new nanocomposite products obtained by 3D printing [31—33]. Thes nanocomposites are based on PLA and two polymers, namely PEI and chitosan, with the addition of silver nanoparticles. This combination might be optimal for research [34, 35]. Silver nanoparticle is a well-known biologically active metal. The attractiveness of using silver consists in its low toxicity and biological effect at low concentrations [36]. There are a lot of reports on its antiviral, virucidal, and antimicrobial activity [37, 38]. Obtained results of cytotoxicity of nanocomposites correlates with literature; silver-containing PEI and chitosan products do not show high toxic effect at epithelial cell lines.

Conclusions. The investigated silver-containing nanocomposites with a silver concentration of 4%, formed by 3D printing technology from PLA-4%Ag-PEI and PLA-4%Ag-chitosan films, show antimicrobial activity against *S. aureus* and *E. coli* test cultures and antiviral action against influenza A virus and human adenovirus and do not show a cytotoxic effect on cells.

The obtained data allow us to state that the studied silver-containing nanocomposites are promising antimicrobial agents for use in various fields of medicine and the food industry.

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АНТИМІКРОБНА ТА ПРОТИВІРУСНА АКТИВНІСТЬ СРІБЛОВМІСНИХ НАНОКОМПОЗИТІВ, СФОРМОВАНИХ ЗА ТЕХНОЛОГІЄЮ 3Д ДРУКУ

Наночастинки срібла стали в центрі уваги численних дослідників для створення ефективних антимікробних і противірусних агентів завдяки їхнім вираженим фармакологічним ефектам, низькій токсичності для людини й довкілля та високій стабільності в екстремальних умовах. Для створення антимікробних препаратів із наночастинками срібла використовують полімерні матриці як синтетичного, так і природного походження. Біополімер полілактид (ПЛА) є одним з найбільш перспективних матеріалів для 3Д друку (адитивного виробництва), завдяки його фізико-хімічним та технологічним властивостям. **Метою** даної роботи було дослідження антимікробної та противірусної активності срібловмісних нанокомпозитів, сформованих на основі ПЛА з додаванням хітозану чи поліетиленіміну (ПЕІ) за технологією 3Д друку. **Методи.** Особливості структурної організації срібловмісних матеріалів досліджували методом ширококутової рентгенографії на дифрактометрі XRD-7000. Морфологію зразків вивчали за допомогою трансмісійної електронної мікроскопії на приладі JEM-1230. Формування філаментів відбувалося шляхом плавлення плівок ПЛА-AgPalm-ПЕІ чи ПЛА-AgPalm-хітозан в екструдері при температурі T=160±1 ºC. Із отриманих філаментів формували зразки за допомогою 3Д принтеру. Антимікробну активність срібловмісних нанокомпозитів щодо умовно

патогенних мікроорганізмів *S. aureus* and *E. coli* визначали диско-дифузійним методом. Цитотоксичність та антивірусну дію досліджували з використанням МТТ-методу та фарбування кристалічним фіолетовим генціанвіолетом. **Результати.** Аналіз ширококутових рентгенівських дифрактограм від виробів, сформованих за технологією 3Д друку при температурі 160 °С показав, що матеріали ПЛА-Ag-ПЕІ і ПЛА-Ag-хітозан містять металічне срібло. Аналіз мікрофотографій виробів ПЛА—4%Ag—ПЕІ та ПЛА—4%Ag—хітозан, сформованих за технологією 3Д друку показав, що наночастинки срібла, які сформовані при додаванні хітозану як відновника і стабілізатора до полімерної матриці ПЛА, мають значно менший розмір, ніж при використанні ПЕІ. Срібловмісні нанокомпозитні зразки — філаменти та вироби, сформовані з плівок ПЛА-4%Ag-ПЕІ та ПЛА-4%Ag-хітозан, підданих термообробці та без термообробки, проявляють антимікробну активність щодо тест-культур *S. aureus* і *E. coli.* Встановлено, що нанокомпозити на основі поліетилеіміну та хітозану не проявляють цитотоксичного впливу в культурах MDCK та HEP-2. Показано, що нанокомпозити обох типів проявляють слабку антивірусну дію щодо аденовірусу 2 серотипу: зменшення інфекційного титру становило 0,5 $lgTCID_{50}$/мл. На моделі грипу жодний з досліджуваних нанокомпозитів не проявив антивірусної дії. **Висновки.** Досліджені срібловмісні нанокомпозити з концентрацією срібла 4%, сформовані за технологією 3Д друку з плівок ПЛА-4%Ag-ПЕІ та ПЛА-4%Ag-хітозан проявляють антимікробну активність щодо тест-культур *S. aureus* і *E. coli* та противірусну дію щодо вірусу грипу типу А і аденовірусу людини та не проявляють цитотоксичного ефекту на клітини. Отримані дані дозволяють стверджувати, що досліджені срібловмісні нанокомпозити є перспективними антимікробними агентами для застосування в різних сферах медицини та харчової промисловості.

Ключові слова: *срібловмісні нанокомпозити, полілактид, поліетиленімін, хітозан, 3Д друк, антимікробна активність, противірусна активність.*