UDC 678.742.4
DOI: 10.15587/2519-4852.2026.365634

HYDROGELS AND FILMS BASED ON STARCH POLYSACCHARIDES ENRICHED WITH OAK BARK EXTRACT *Quercus cortex* FOR POTENTIAL PHARMACEUTICAL APPLICATIONS

Irina Liashok, Viktoriia Plavan, Vyacheslav Shvets, Olena Kriukova, Iryna Voloshyna

The aim. *The aim of the work is to develop and study the composition and properties of hydrogels and films based on polysaccharides enriched with an aqueous extract of Quercus cortex (oak bark) for potential use in modern pharmaceutical practice.*

Materials and methods. *For polymer bases, polyvinyl alcohol of the PVA17-99 brand CAS: 9002-89-5, with a mass fraction of acetate groups of less than 2%, and potato starch (St) CAS: 9005-25-8 were used in the work. Compositions enriched with Quercus cortex (oak bark) aqueous extract were prepared by mixing solutions of 10% PVA, 10% St and in PVA/St ratios of 10/0–0/10. Hydrogels were obtained by single freezing of the compositions for 24 hours at a temperature of –15°C with subsequent thawing, and films were obtained on a platform made of organic glass using a manual frame applicator for applying coatings with a thickness of 1 mm and a working width of 100 mm with subsequent drying under normal conditions. The sorption characteristics of hydrogels and films were determined by the gravimetric method in relation to distilled water and physiological NaCl solution. Rheological studies of PVA and PVA/St compositions were carried out using a Vevor NDJ-9S rotational viscometer (PRC) according to the standard ISO 2555:2018 method.*

Results. *It was found that the compositions with PVA/St ratios of 9/1–3/7 are pseudoplastic, and when the St fraction increases to 80–90%, the system becomes dilatant, as evidenced by the value of the flow index n. The moisture content of hydrogels in PVA/St decreases from ~620 to ~560%. It was found that the density of the films is 1.1–1.35 g/cm^3, and of the hydrogels – 1.01–1.04 g/cm^3. The sorption capacity of PVA/St hydrogels is 80–670% in distilled water and 90–650% in NaCl. It was proven that the films have a strength of 100–1170 kPa, while the hydrogels – only 0–20 kPa, but compensate for this with high elasticity of 135–185% at 10–20% polysaccharides. The release of Quercus cortex (oak bark) aqueous extract is a maximum of 0.15–0.16% with a polysaccharide content of 40–50%. An aqueous extract of Quercus cortex showed antimicrobial activity against S. aureus, inhibiting its metabolism and adhesion even at low concentrations. The structural stability of PVA/St films is due to the dense macromolecular network and lower hydrophilicity of St. The possibility of regulating the properties of the materials has been established, namely, it has been proven that PVA/St films are more stable in the physiological environment and are suitable for long-term barrier coatings. PVA/St hydrogels with a water retention capacity of up to 620% can be used where fast drying is required.*

Conclusions. *It has been proven that the Quercus cortex (oak bark) aqueous extract in the composition of polymer hydrogels and films is a promising natural component for the creation of biocompatible films and hydrogels with controlled release and prolonged antimicrobial effect, which opens up wide opportunities for their practical use in pharmaceutical and biomedical technologies*

Keywords: *polyvinyl alcohol, polysaccharides, Quercus cortex (oak bark) extract, films, hydrogels, polymer compositions, sorption, rheology, antimicrobial properties*

How to cite:
Liashok, I., Plavan, V., Shvets, V., Kriukova, O., Voloshyna, I. (2026). Hydrogels and films based on starch polysaccharides enriched with oak bark extract *Quercus cortex* for potential pharmaceutical applications. ScienceRise: Pharmaceutical Science, 3 (61), 14–27. http://doi.org/10.15587/2519-4852.2026.365333

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1. Introduction

The increasing antibiotic resistance of microorganisms and the spread of diseases accompanied by the emergence of chronic wounds that are difficult to heal have prompted researchers to search for alternative therapeutic strategies. Traditional wound dressings with structural and functional limitations have proven ineffective in wound healing [1]. These dressings tend to adhere to the wound surface, causing trauma during removal [2]. The latest generation of wound dressings has unique characteristics that help create an optimal environment for wound healing. These dressings are composed of various polymers and can be divided into several groups according to their physical form, including films, foams, fibers, sponges, hydrocolloids and hydrogels [3]. Among them, hydrogels have shown promise due to their biological, chemical and physical characteristics.

Polysaccharides such as sodium alginate, chitosan, and carboxymethylcellulose have become the basis for the development of new generation biomedical materials due to

their high hydrophilicity, gas exchange capacity, and structural similarity to the human extracellular matrix [4]. Hydrogels and films based on these polymers provide an optimal moist environment, which is critical for accelerating epithelialization. However, pure polysaccharide matrices are often devoid of their own bioactivity and have limited mechanical characteristics. According to studies [5], sodium alginate and chitosan remain the most popular also due to their ability to gel under mild conditions. Natural polysaccharides have recently attracted considerable interest in terms of their potent antioxidant activity in vivo and in vitro. In particular, regarding in vitro antioxidant systems, polysaccharides have been considered in most publications as effective free radical scavengers. However, the underlying mechanisms of this antioxidant action have not been systematically illustrated, and sometimes contradictory results have appeared in different literature sources [6].

Tree bark is widely used in traditional medicine for the treatment of many diseases due to its medicinal properties, which are based on the presence of phenolic compounds that can have antioxidant, antimicrobial and anti-inflammatory effects [7]. Quercus species are known for their multicomponent phytochemical composition, which allows them to be used as sources of bioactive compounds with pharmacological activity in chronic diseases of various kinds. The bark of Quercus species, in particular, has attracted increasing attention due to its potential for a variety of medicinal uses. The extract of the *Quercus cortex* (oak bark) is a unique source of bioactive compounds, including hydrolysed tannins, catechins, and flavonoids, which exhibit potent anti-inflammatory and astringent effects [8]. The presence of phenolic compounds may correlate with the biological potential (antioxidant, antimicrobial, etc.) of the extracts of the *Quercus cortex* (oak bark) [9].

Oak bark extracts have demonstrated clear antibacterial activity against *Pseudomonas aeruginosa*, *Micrococcus flavus*, and *Escherichia coli*. The authors [9] observed strong antifungal activity against some fungi, such as *Aspergillus flavus*, *Penicillium funiculosum*, and *Penicillium ochrochloron*.

The authors [10] focus on the antimicrobial activity of extracts of *Quercus robur L.* (acorn) against *Staphylococcus aureus*, *Escherichia coli*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, *Candida albicans*, *Listeria monocytogenes*, although these studies are limited to liquid extracts without considering their stability in solid or semi-liquid dosage forms. In addition, there is a scientific debate about the influence of tannins on the mechanical properties of hydrogels: some sources [11] indicate the effect of “self-crosslinking” due to hydrogen bonds, while others [12] warn about the possible fragility of materials at high concentrations of the bioactive phase.

Pharmaceutical applications of such enriched systems allow for simultaneous wound protection and local therapy without systemic burden on the body. A critical aspect of creating pharmaceutical films is to ensure controlled release of bioactive substances. Given that uncontrolled drug release sometimes leads to high toxic concentrations first and then ineffective drug concentrations, researchers are working to develop drug delivery systems that offer the appropriate drug concentration to meet treatment needs [12]. Due to their good gelation ability at the right pH, biocompatible and hypoallergenic polysaccharide controlled release films can provide a broader medical platform for drug delivery.

Studies [13, 14] have shown that polyphenols are able to form stable complexes with polysaccharides through intermolecular interactions, in particular hydrogen bonds through numerous phenolic hydroxyl groups and aromatic rings, which contributes to the slowing down of the release of active components from the polymer matrix. The authors [15, 16] investigated the process of polyphenol release from the chitosan-polyphenol ionic complex and concluded that the rate of polyphenol diffusion depends on the pH of the medium.

Despite the significant number of studies devoted to polysaccharides and plant extracts separately, there is a lack of works in the scientific literature that comprehensively analyse hydrogels and films based on polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract in the context of their potential pharmaceutical applications. The relationship between the composition of polymer systems and their rheological characteristics, moisture retention capacity, density, sorption properties and mechanical stability remains insufficiently studied.

Special attention is required to study the kinetics of controlled release of bioactive components in physiological environments, as well as to assess the antibacterial and antiadhesive activity of such materials. It is these aspects that determine the relevance of the work and its contribution to filling the scientific gap, opening up prospects for the creation of new biocompatible materials with prolonged antimicrobial effect that can be used in pharmaceutical and biomedical technologies.

Research gap. Despite the availability of data on the properties of individual components, a comprehensive assessment of the impact of a multicomponent aqueous extract of *Quercus cortex* on the structural integrity, swelling kinetics, and biological safety of polysaccharide systems remains insufficiently elucidated. In particular, there is insufficient data on the synergistic interaction of *Quercus cortex* polyphenols with a polymer network to create stable pharmaceutical films and hydrogels with a controlled release profile.

The object of the study is the formation processes and physicochemical properties of hydrogels and films based on natural polysaccharides enriched with extract of *Quercus cortex* (oak bark), and the patterns of interaction of system components in the process of releasing bioactive substances.

The aim of the work is to develop and study the composition and properties of hydrogels and films based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract for potential use as effective agents in modern pharmaceutical practice.

2. Research planning (methodology)

To create hydrogels and films enriched with *Quercus cortex* (oak bark) aqueous extract for potential use as effective agents in modern pharmaceutical practice, the work

used synthetic, biocompatible, water-soluble PVA17-99, which provides mechanical strength and elasticity. The natural polysaccharide starch provides biodegradability, forms additional porosity and promotes controlled release of bioactive substances. Compositions based on PVA and St in ratios of 10/0–0/10 provide a balance between strength, elasticity and sorption capacity.

To develop and study the composition and properties of hydrogels and films based on polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract, the rheological properties of PVA/St solution compositions enriched with *Quercus cortex* oak bark extract were investigated depending on the ratio of polysaccharides; the dependence of the moisture content of hydrogels on the composition of the PVA/St system was determined; the density of films and hydrogels was estimated and the influence of the proportion of polysaccharides on these parameters was determined. In addition, the sorption properties of hydrogels in distilled water and physiological NaCl solution were investigated with the determination of the maximum values of sorption and desorption for different compositions.

To determine the suitability of the obtained polymer systems for pharmaceutical applications, the strength and elasticity of films and hydrogels were investigated; the kinetics of the release of *Quercus cortex* (oak bark) aqueous extract from polymer systems were analysed to ensure optimal conditions for controlled release. At the final stage of the research, the antibacterial and anti-adhesive activity of the obtained materials was evaluated.

3. Materials and Methods

3. 1. Materials

3. 1. 1. Preparation of *Quercus cortex* (oak bark) aqueous extract

Within the framework of this study, *Quercus cortex* (oak bark) TM Lyktravy was used to obtain an aqueous extract, which is the only raw material included in the State Register of Medicinal Products of Ukraine according to the composition of active substances. Registration certificate: UA/5672/01/01 Order of the Ministry of Health No. 1810 dated 04.10.2018, the validity period of the registration certificate is unlimited from 30.05.2016. The State Register of Medicinal Products of Ukraine indicates the following composition of active substances: *Quercus cortex* (oak bark) contains at least 2.5% tannins in terms of pyrogallol and dry raw materials or at least 8.0% tannins in terms of tannin and dry raw materials. Obtaining a *Quercus cortex* (oak bark) aqueous extract was carried out according to the classical instructions from the manufacturer "Lyktravy".

To do this, 100 grams of pre-crushed and dried *Quercus cortex* (oak bark) ("Lyktravy", Ukraine) are placed in an enamelled container, after which the raw material is poured with one liter of pre-boiled water at a temperature of 95°C. Extraction is carried out by heating the mixture in a water bath for 30 minutes. The key condition is to maintain a constant extraction temperature at 85°C for 30 minutes. After completion of heat treatment and subsequent cooling, the obtained aqueous extract is filtered through a pleated filter. Such filtration is a necessary stage for removing mechanical impurities and ensuring the purity of the final aqueous extract.

To assess the reliability of the research, the extract of *Quercus cortex* (oak bark) was standardized according to pharmacopoeial methods for determining the dry residue, relative density of the extract and determination of the total flavonoid content [17].

The determination of the dry residue of the extracts was carried out as follows [17]: 2.00 g or 2.0 ml of the extract was placed in a flask with a diameter of about 50 mm and a height of about 30 mm. Evaporated to dryness on a water bath and dried in a drying oven at a temperature of 100°C to 105°C for 3 h. After cooling in a desiccator over phosphorus(V) oxide P, weighing was carried out. The dry residue is 0.881 g/l.

The determination of the total flavonoid content in the *Quercus cortex* (oak bark) aqueous extract was carried out by a modified spectrophotometric method using an aluminium chloride solution [18]. For this, 1 ml of deionized water was mixed with 250 µl of the extract and 75 µl of 5% $NaNO_2$ solution. After 5 min of incubation, 75 µl of 10% $AlCl_3$ solution was added, and then 0.5 ml of 1 M NaOH solution and 0.6 ml of deionized water. The total flavonoid content was expressed in rutin equivalent (RE) and determined spectrophotometrically on an OPTIZEN POP UV spectrophotometer (Mecasys, South Korea) at a wavelength of λ = 510 nm according to a previously constructed calibration graph of the dependence of absorption on the concentration of rutin in the solution (R^2 = 0.9996).

The total flavonoid content in the *Quercus cortex* (oak bark) aqueous extract by routine was 4.86 ± 0.08 g/l.

The density of the *Quercus cortex* (oak bark) aqueous extract was also determined using a pycnometer according to the pharmacopoeial method, article 2.2.5 [17].

According to this method, the density ρ_{20}(g/cm^3) of the aqueous extract is calculated by the formula

$$\rho = \left\{\left(m_2 - m\right) \times 0.99703\right\} \Big/ \left\{m_1 - m\right\} + 0.0012,$$

where m is the mass of the empty pycnometer, in grams; m1 is the mass of the pycnometer with distilled water, in grams; m_2 is the mass of the pycnometer with the *Quercus cortex* (*oak bark*) *aqueous extract*, in grams; 0.99703 is the density of water at 20°C (in grams per cubic centimeter, taking into account the density of air); 0.0012 is the density of air at 20°C and a barometric pressure of 1011 hPa (760 mm Hg).

According to the results of measuring the density of the *Quercus cortex* (oak bark) aqueous extract using a pycnometer, it was found that ρ_{20} = 1.0008 ± 0.0002 g/cm^3.

Thus, by standardizing the extract of *Quercus cortex* (oak bark) according to pharmacopoeial methods, it was established that the extract of *Quercus cortex* (oak bark) has the following indicators: dry residue – 0.881 g/l, total flavonoid content by rutin 4.86 ± 0.08 g/l; density at 20°C 1.0008 ± 0.0002 g/cm^3.

3. 1. 2. Polymer bases for films and hydrogels

To create films and hydrogels enriched with aqueous extract of *Quercus corte* (oak bark), polyvinyl alcohol of the PVA17-99 brand (China) CAS: 9002-89-5, the mass fraction of acetate groups less than 2% and potato starch (St) (Prodenergo LLC, Kharkiv, Ukraine) CAS: 9005-25-8 were used as polymer bases in the work.

To prepare PVA and starch solutions, 90% *Quercus cortex* (oak bark) aqueous extract was used, which was obtained according to the classical instructions from "Lyktravy" and 10% PVA or starch.

When planning the study, 10% solutions of PVA and starch were used, prepared based on an *Quercus cortex* (oak bark) aqueous extrac*t*. The solutions were mixed in the ratios of PVA/starch by volume from 0/10 to 10/0 in increments of 10%, or 1 part by volume. This allowed us to fully assess the effect of the ratio of components on the studied properties of films and hydrogels.

A 10% PVA solution (40 minutes) and a 10% starch solution (10 minutes) were prepared in a water bath based on a *Quercus cortex* (oak bark) aqueous extract. The PVA and St solutions were mixed in the following volumetric ratios (Table 1) with a mechanical stirrer at a temperature of 60°C.

Table 1

Recipe of PVA/St compositions enriched with aqueous extract of oak *Quercus cortex*

Component	Volumetric parts										
PVA	10	9	8	7	6	5	4	3	2	1	0
St	0	1	2	3	4	5	6	7	8	9	10

3. 2. Method of obtaining hydrogels and films

Hydrogels based on polysaccharides, enriched with *Quercus cortex* (oak bark) aqueous extract, were obtained by the cryostructuring method, which consists in freezing the compositions at a temperature of –15°C for 24 hours with subsequent gradual thawing at room temperature. In this case, the formation of the spatial structure of PVA occurs during freezing, and St - during thawing [19, 20].

Polysaccharide-based films enriched with *Quercus cortex* (oak bark) aqueous extract were obtained on a plexiglass platform using a manual frame applicator for coating with a thickness of 1 mm and a working width of 100 mm [21]. The temperature of the compositions during mixing was 60°C, the films were dried under normal conditions for 48 hours.

3. 2. Research methods

3. 2. 1. Determination of rheological characteristics of polymer compositions

The rheological characteristics of PVA/St polymer compositions enriched with aqueous extract of *Quercus cortex* (oak bark) were determined using a Vevor NDJ-9S rotational viscometer (PRC). Measurements and calculations were performed according to the standard ISO 2555:2018 method.

3. 2. 2. Determination of moisture content of hydrogel samples

The moisture content in the initial samples of hydrogels based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract was determined on a Radwag MA-50 R moisture analyser at a drying temperature of 70°C.

3. 2. 3. Determination of sorption characteristics of hydrogels and films

The sorption properties of hydrogels based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract were evaluated by the change in the absorption of water and physiological NaCl solution (0.9%) at a temperature of 37°C using the calculation formula

$$X = \frac{m_2 - m_1}{m_1} \cdot 100\%,$$

where m_2 is the mass of the sample at a certain point in time in water or physiological NaCl solution, g; m_1 is the mass of the dry sample, g.

3. 2. 4. Determination of desorption properties of hydrogels

To consider the property of hydrogels to dry in the open air, the work conducted a study of the desorption process by the gravimetric method. For this, the change in the mass of the samples over time was recorded, leaving them in the open air at room temperature.

Moisture loss was estimated by the change in the mass of the sample over time.

$$X_B = \frac{m_2 - m_1}{m_1} \cdot 100\%,$$

where m_2 is the mass of the sample at a certain point in time of drying, g; m_1 is the mass of the dry sample, g.

3. 2. 5. Determination of the tensile strength and relative elongation of the films and hydrogels

The hydrogel and film samples had a standard width of 10 mm and a length of 85 mm. The tensile strength and elongation at break were determined on a BDO–FBO.5TH device (ZwickRoell, Germany) according to the standard test method ASTM D882-18. The destructive stress σ_p in N/m^2 is calculated by the formula:

$$\sigma_p = \frac{P_p}{b \cdot h},$$

where P_p – load at which the sample collapsed, N; b and h – the width and thickness of the working part of the sample, m.

The relative elongation at break $\boldsymbol{\varepsilon_p}$, % is calculated by the formula:

$$\varepsilon_p = \frac{\Delta l_p}{l_0} \cdot 100,$$

where Δl_p – increase in the length of the sample at rupture and at the yield point, respectively, m; l_0 – initial base of the sample, m.

3. 2. 6. Density determination

To determine the density of hydrogels and films by hydrostatic weighing, Radwag AS 220.R2 analytical balances (Poland) equipped with a density measurement module were used.

3. 2. 7. Determination of release by spectrometric method

The concentration of the aqueous extract was determined by spectrophotometric method using the optical density of the solutions. A KFK-2 spectrophotometer was used at a wavelength of 315 nm, cuvettes with a thickness of 1.065 mm. Samples measuring 1 × 1 cm were immersed in 25 ml of distilled water and 25 ml of physiological NaCl solution. They were incubated at 37°C for 24 hours.

To determine the release of the *Quercus cortex* (oak bark) aqueous extract, a calibration curve was constructed. For this purpose, solutions with an aqueous extract concentration of 0.78 to 100% were prepared and the optical density was measured at a wavelength of 315 nm in a 1.065 cm cuvette. As a result of data processing, a linear relationship was obtained

$$C = 0.5838\ D + 0.0159,\ R^2 = 0.9946,$$

where C is the concentration of the *Quercus cortex* (oak bark) aqueous extract, D is the optical density. The optical density of the samples after 24 hours of incubation was determined according to the equation of the calibration graph, which allowed determining the amount of the *Quercus cortex* (oak bark) aqueous extract released into the medium.

3. 2. 8. Obtaining seed material for test cultures

To study the antibacterial and anti-adhesive properties, test cultures of *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* PA01 were used, which were obtained from the Institute of Microbiology and Virology named after D. K. Zabolotny of the National Academy of Sciences of Ukraine for research. The strains belong to the Ukrainian collection of microorganisms.

Test cultures were grown on Nutrient broth (NB) for 24 h at a temperature of 37°C and stirring at 220 rpm, after which they were checked spectrophotometrically so that the cell concentration by optical density at a wavelength of 600 nm was within 0.2–0.6 [22].

3. 2. 9. Determination of the sensitivity of test cultures to a *Quercus cortex* (oak bark) aqueous extract using resazurin

The antimicrobial activity of the *Quercus cortex* (oak bark) aqueous extract was determined using the resazurin recovery assay [22]. The seed material of the test cultures was sown in fresh nutrient NB medium to which an aqueous solution of *Quercus cortex* (oak bark) was added at different concentrations. As a control, a cell suspension was used without the addition of the aqueous extract, and the growth of the cultures on the aqueous extract itself was checked.

The grown test cultures (*S. aureus* ATCC 25923, *E. coli* ATCC 25922, *P. aeruginosa* PA01) in nutrient broth (NB) were added (10 µl) to a 96-well plate previously containing NB medium (90 µl). They were grown for 24 h at 37°C. Then, prepared aqueous extracts of oak bark were added in triplicate to give a final concentration of 1%, 5%, 10%, 20% and 50%. The plates were closed and placed in a thermostat for growth at 37°C for 24 h. After incubation, sodium resazurinate dye (20 µM) was added to each well (100 µl) and incubated for up to 4 h in a thermostat at 37°C. Cell viability was then determined spectrophotometrically at wavelengths of 620 nm and 570 nm on a universal UV microplate reader HIPPO 96 (Biosan, Lithuania). The number of viable cells in the test samples relative to the control was then calculated as a percentage.

3. 2. 10. Determination of the effect of *Quercus cortex* (oak bark) aqueous extract on the anti-adhesive properties of test cultures

Gentian Violet dye was used to determine the effect of aqueous oak bark extract on the anti-adhesive properties of bacteria [22].

The seed material of the test cultures (*S. aureus* ATCC 25923, *E. coli* ATCC 25922, *P. aeruginosa* PA01) was added (10 µl) to a 96-well plate previously containing NB medium. Then, the prepared aqueous extract of oak bark was added so that the final concentration was 1%, 5%, 10%, 20% and 50%, and the total volume of the nutrient medium was 90 µl. The plates were closed and placed in a thermostat for cultivation at a temperature of 37°C for 24 h. 100 µl of 0.02% (v/v, diluted in deionized water) was added to the wells to fix and stain the adhered cells. After incubation for 30 min, the plates were washed with distilled water. For dye extraction, a 96% ethanol solution was used, which was added 100 µl to each well. After complete extraction of the dye (5–10 min), the optical density of the samples was measured at a wavelength of 570 nm. The percentage of adherent cells was determined according to the control samples without the addition of aqueous extract of oak bark.

4. Research results

All samples were made from a single batch of *Quercus cortex* (oak bark) aqueous extract. The results of the studies are given as the average of three parallel measurements. One sample was used for one measurement. The standard deviations did not exceed 5% for the obtained values.

4. 1. Rheological properties of PVA/St compositions enriched with *Quercus cortex* (oak bark) aqueous extract

The rheological properties of polymer compositions enriched with *Quercus cortex* (oak bark) aqueous extract determine their response to external loads and are

key to optimizing technological processes. The relationship between stress and shear rate allows us to assess the internal structure of the material, its viscosity and elasticity. It is viscosity that is the basic parameter in the development of processing technologies for PVA/St systems enriched with *Quercus cortex* (oak bark) aqueous extract. Fig. 1 shows the dependence of the viscosity of solutions on the shear rate, which demonstrates the specific behaviour of these compositions under the action of mechanical forces.

The slope coefficients of the trend lines for compositions based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract have positive values except for St, PVA/St 2/8 and 1/9.

Within the studied range of shear rates, the viscosity of solutions of compositions based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract PVA, PVA/St corresponds to a power law and is described by the Ostwald-de Waele equation: $\eta = K\gamma^{n-1}$, where K is the consistency coefficient, which depends on both the nature of the material and the type of measuring equipment, and n is the flow index. As a result of processing the experimental data by the linear regression method, the values of the constants K and n of the Ostwald-de Waele equation were obtained, which are given in Table 2.

For solutions of compositions based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract in PVA/St co-reduction from 9 / 1 to 3 / 7, the flow index $n < 1$, which indicates pseudoplasticity of the compositions. When adding a larger amount of St to the composition, the n index increases, which is probably associated with a decrease in the structuring of the system. For solutions of PVA / St 2 / 8, 1 / 9, 0 / 10, $n > 1$ is observed with an increase in the coefficient K. Such systems are dilatant, which is explained by the fact that the particles of the compositions form temporary structures that collapse under the action of shear.

Table 2

Calculated values of the constants K and n of the Ostwald-de Waele equation for compositions based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

Composition PVA	Trendline equation	R^2	n	K
PVA	$y = 0.4016x + 7.5903$	0.781	0.5984	7.5903
PVA/St (9/1)	$y = 0.2708x + 8.1269$	0.8201	0.7292	8.1269
PVA/St (8/2)	$y = 0.0758x + 8.471$	0.8864	0.9242	8.471
PVA/St (7/3)	$y = 0.2013x + 7.9866$	0.8202	0.7987	7.9866
PVA/St (6/4)	$y = 0.4016x + 7.5903$	0.7810	0.5984	7.5903
PVA/St (5/5)	$y = 0.5392x + 6.3119$	0.8536	0.4608	6.3119
PVA/St (4/6)	$y = 0.2983x + 7.2504$	0.8322	0.7017	7.2504
PVA/St (3/7)	$y = 0.4016x + 7.5903$	0.7810	0.5984	7.5903
PVA/St (2/8)	$y = –0.2041x + 9.4516$	0.9408	1.2041	9.4516
PVA/St (1/9)	$y = –0.5097x + 11.255$	0.9890	1.5097	11.255
St	$y = –0.9847x + 13.261$	0.9997	1.9847	13.261

4. 2. Determination of moisture content of hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

The work investigated the initial moisture content of hydrogels based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract, depending on the St content, Fig. 2.

With increasing starch polysaccharide content in hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract, their moisture content decreases, which can be explained by the collapse of hydrogel systems [21], in which water is displaced. This opens up opportunities for targeted regulation of the physicochemical characteristics of hydrogels in pharmaceutical and biomedical applications.

When studying the density of films and hydrogels based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract (Fig. 3), it was found that PVA/St films have a significantly higher density of 1.1–1.35 g/cm^3 than the corresponding hydrogels of 1.01–1.04 g/cm^3, which indicates a more compact and stable structure.

Hydrogels are characterized by a high-water content, which expands intermolecular distances and reduces density. For films with a content of up to 70% St, effective interaction of components is observed, while in hydrogels the density decreases at high St content due to porosity and water retention capacity. Therefore, films based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract are more structurally stable materials compared to hydrogels.

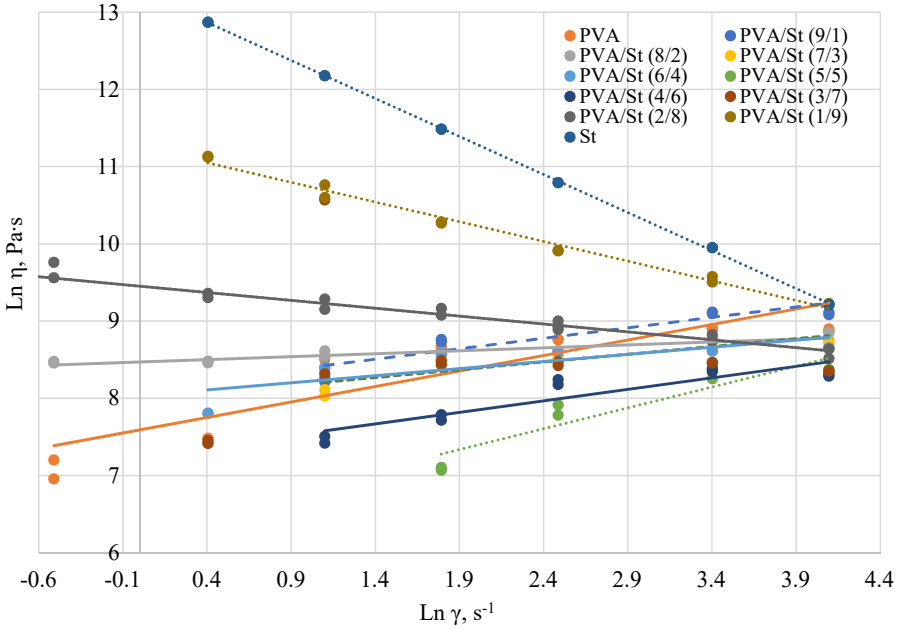

Fig. 1. Dependence of viscosity on the shear rate of solutions of PVA/St polymer compositions enriched with a *Quercus cortex* (oak bark) aqueous extract

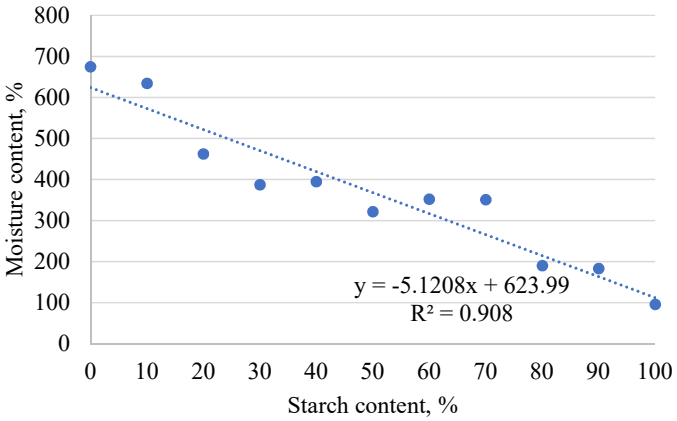

Fig. 2. Moisture content of hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract depending on the St content

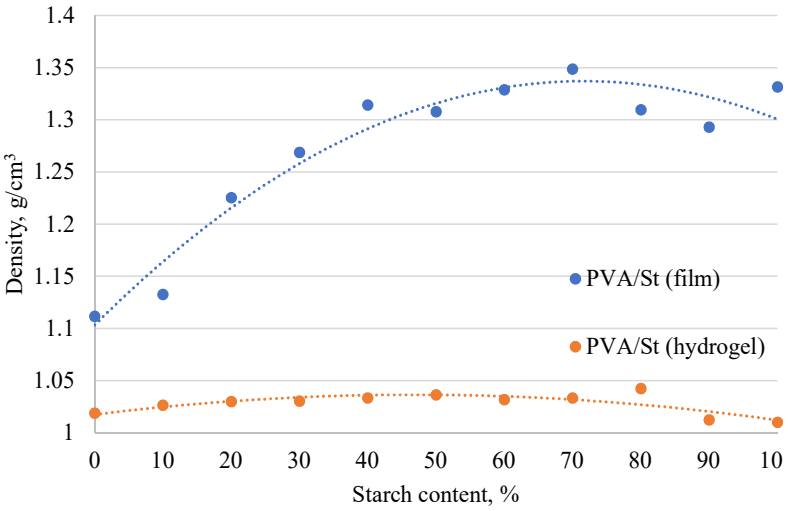

Fig. 3. Density dependence of films and hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

4. 3. Determination of the sorption capacity of hydrogels and films based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

The work involved determining the sorption capacity of hydrogels based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract in relation to distilled water (Fig. 4) and physiological NaCl solution (Fig. 5).

PVA/St hydrogels enriched with aqueous extract of *Quercus cortex* rapidly absorb water within the first 5 hours, after which they reach a state close to equilibrium. Their sorption capacity varies from 80% to 670%, depending on the ratio of components. Samples with a high PVA content show the highest swelling of 700–1050%, while increasing the St content gradually reduces water retention, reaching a minimum at 90–100% St. Pure St has the lowest equilibrium sorption of 80%, which confirms its lower hydrophilicity compared to PVA. Thus, these systems can be characterized as moderate sorbents, where the PVA content is the key factor.

In PVA/St hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract, the sorption of saline NaCl reaches equilibrium, which is characteristic of the diffusion mechanism of swelling. The inclusion of St reduces the ability of the hydrogel to swell.

The sorption capacity of films based on starch polysaccharides enriched with aqueous extract of oak bark in relation to distilled water (Fig. 6) and saline NaCl solution (Fig. 7) was investigated.

During the first 5 hours, all samples (Fig. 6) show rapid swelling in distilled water, after which the sorption gradually decreases and stabilizes, confirming the structural stability of the films based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract. Pure PVA has the highest sorption peak of about 500% and the highest equilibrium sorption value of about 350%, while pure St has the lowest, peak of about 180%, equilibrium value of about 150%. With increasing St content in the PVA/St mixture, the total sorption capacity of the film consistently decreases, which indicates that the hydrophilicity of the films directly depends on the PVA content.

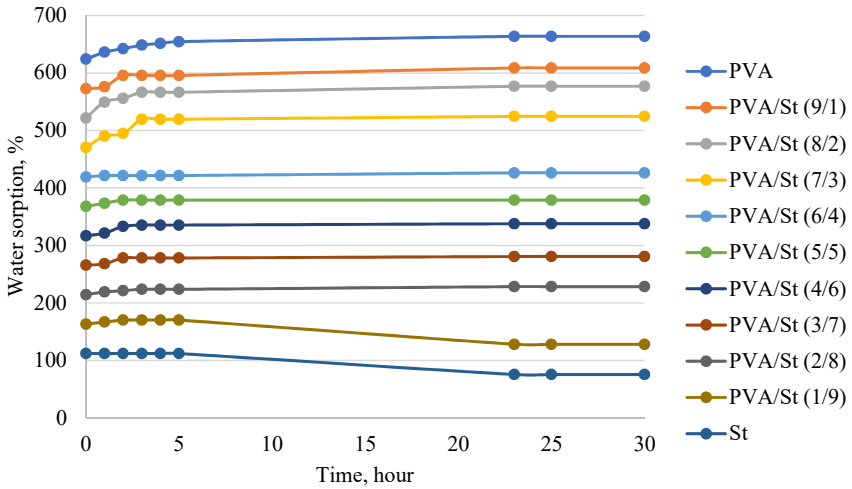

Fig. 4. Sorption of distilled water for samples of PVA/St hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

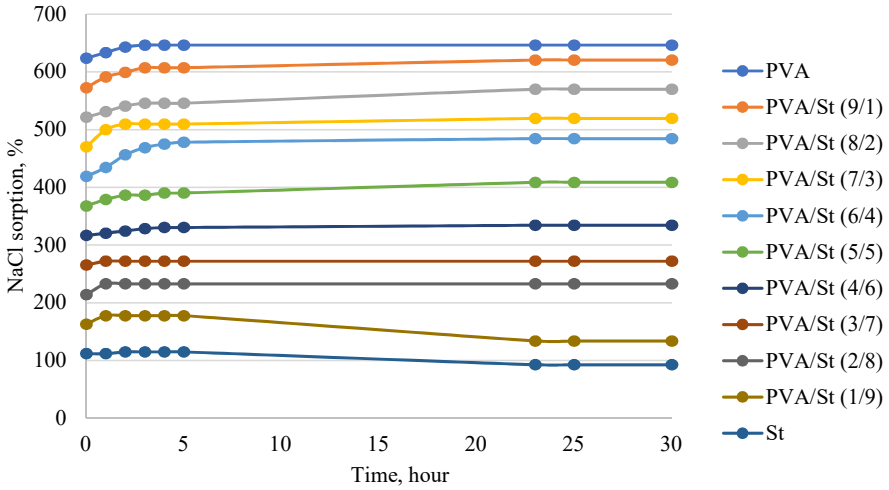

Fig. 5. Sorption of physiological NaCl solution for PVA/St hydrogel samples enriched with *Quercus cortex* (oak bark) aqueous extract

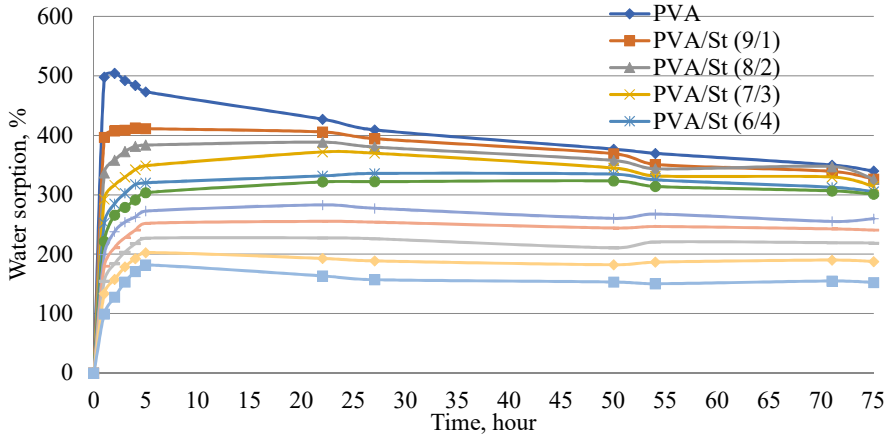

Fig. 6. Distilled water sorption for PVA/St film samples enriched with *Quercus cortex* (oak bark) aqueous extract

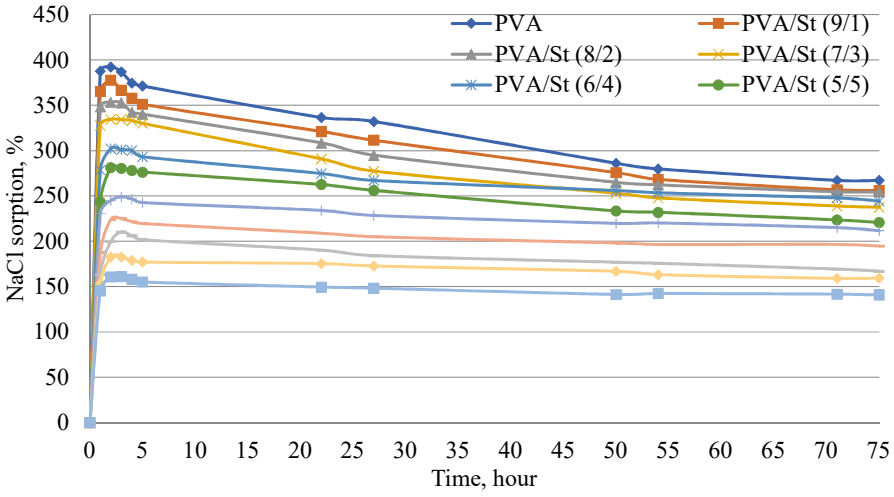

Fig. 7. Sorption of physiological NaCl solution for samples of PVA/St films enriched with *Quercus cortex* (oak bark) aqueous extract

All samples of films based on starch polysaccharides enriched with extract of *Quercus cortex* (oak bark) (Fig. 7) have a peak of sorption of physiological solution during the first 5 hours. Pure PVA enriched with *Quercus cortex* (oak bark) aqueous extract has the highest stability for 75 hours.

With an increase in the proportion of St in the PVA/St composition, the sorption gradually decreases. The lowest swelling levels of 150–165% are observed in samples with PVA/St 2/8 and 1/9. Films with PVA/St 9/1, 8/2, 7/3 have an initial sorption of 320–360%, which decreases to 240–260%. Thus, the introduction of St into the PVA matrix reduces the overall sorption capacity in physiological solution, which is associated with a change in the structure and hydrophilicity of the mixture. All films remain stable for 75 hours, without dissolving, but only gradually losing part of the absorbed liquid.

4. 5. Determination of desorption of hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

In order to assess the kinetics of moisture loss by hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract, a drying study of samples was conducted. The obtained data on the dependence of the mass fraction of water in the hydrogel on the drying time are presented in Fig. 8.

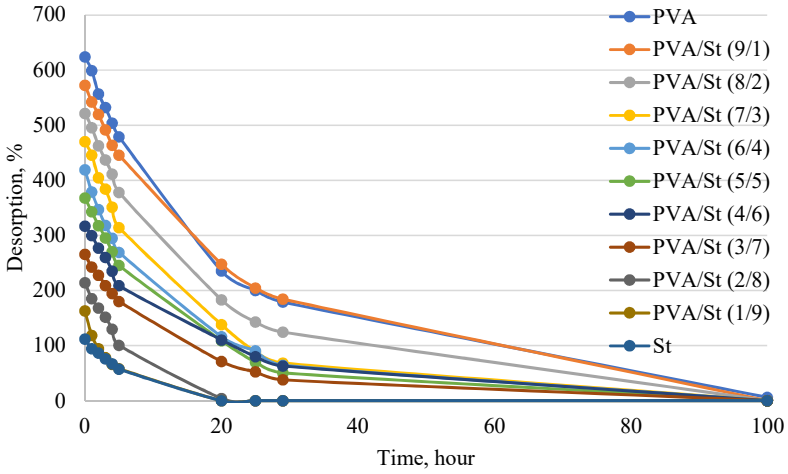

Fig. 8. Desorption of PVA/St hydrogel samples enriched with *Quercus cortex* (oak bark) aqueous extract

All samples show the highest drying rate during the first 20–30 hours, which corresponds to the evaporation of free and weakly bound water. After that, the desorption rate slows down significantly.

PVA/St hydrogels have the fastest desorption for pure St and samples with a high St content of up to 90% enriched with aqueous extract of oak *Quercus cortex*, which reaches 0% in about 20 hours. This indicates that the water absorbed by St is weakly bound and easily evaporates. Samples with a higher PVA content in the PVA/St 9/1 system retain water the longest but also absorb the most in this group. Therefore, the PVA/St ratio determines the balance between sorption and desorption, which allows predicting the behaviour of the material in contact with biological fluids.

4. 6. Determination of the physical and mechanical properties of films and hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

4. 6. 1. Determination of the destructive stress of films and hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

Fig. 9 shows the dependence of the destructive stress for films and hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract on the content of starch polysaccharides.

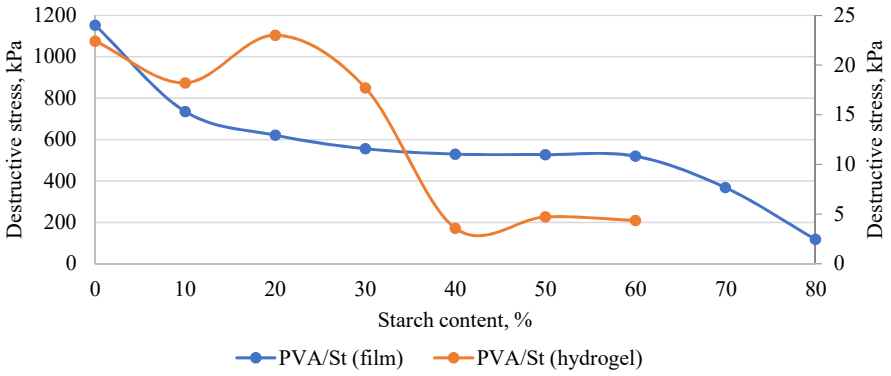

Fig. 9. Dependence of destructive stress on starch polysaccharide content f or PVA/St films and hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract

The increase in the content of starch polysaccharides for PVA/St compositions enriched with *Quercus cortex* (oak bark) aqueous extract in the films leads to a significant decrease in the destructive stress. From 1170 kPa at 100% PVA to 530 kPa at 40% St content, it remains stable up to 60% and then continues to fall to 130 kPa at 80% St content. The introduction of starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract into the compositions significantly reduces the strength of PVA/St films. And PVA/St hydrogels enriched with aqueous extract of oak bark can be recommended as soft and elastic biomedical hydrogels.

4. 6. 2. Determination of relative elongation at break of films and hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

Fig. 10 shows the dependence of the elongation at break on the content of starch polysaccharides for films and hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract.

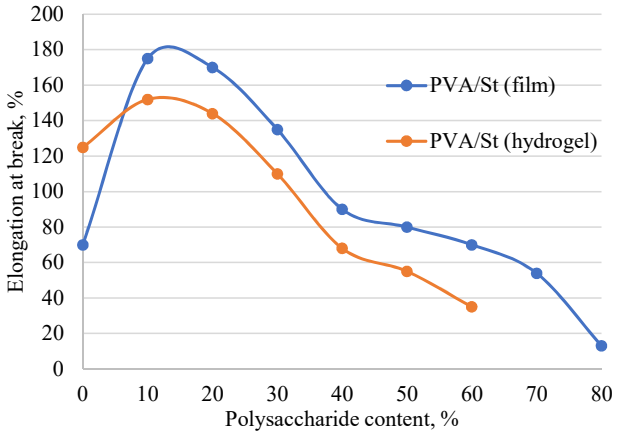

Fig. 10. Dependence of relative elongation at break on the content of starch polysaccharides for films and hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract

At a starch polysaccharide content of 10–20%, the best elasticity of 135–185% elongation of PVA/St composites enriched with a *Quercus cortex* (oak bark) aqueous extract is observed. This indicates optimal compatibility and flexibility of the polymer network. At a high 60–80% St content, the elasticity drops sharply to 10–45%, which indicates rigidity and brittleness of the structure. Therefore, low concentrations of starch polysaccharides provide the most effective combination of strength and flexibility.

Films based on starch polysaccharides enriched with a *Quercus cortex* (oak bark) aqueous extract were investigated for physicomechanical properties after 6 months without exposure to ultraviolet light. The deviation from the initial values of st was less than 3%, which indicates the stability, according to physicomechanical indicators, of films based on starch polysaccharides enriched with an *Quercus cortex* (oak bark) aqueous extract for at least 6 months.

4. 7. Research on the release of *Quercus cortex* (oak bark) aqueous extract from films and hydrogels based on starch polysaccharides enriched with *Quercus cortex* (oak bark) aqueous extract

In this work, the release of an *Quercus cortex* (oak bark) aqueous extract into distilled water and saline NaCl solution from PVA/St hydrogels was investigated using a spectroscopic method (Fig. 11).

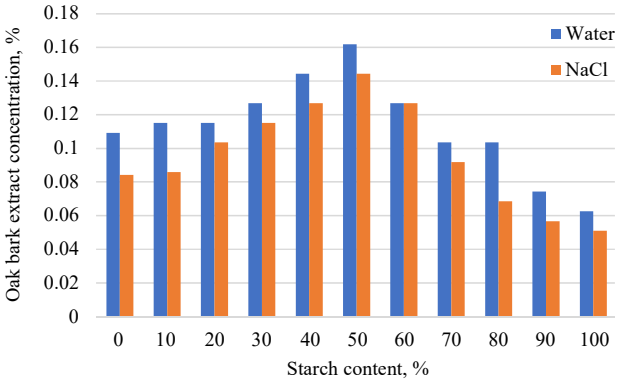

Fig. 11. Dependence of oak bark extract release after 24 hours on the starch polysaccharide content for PVA/St hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract

The release of *Quercus cortex* (oak bark) aqueous extract in PVA/St hydrogels gradually increases with an increase in the proportion of starch polysaccharides and reaches a peak of ≈0.16% in water and ≈0.15% in NaCl solution at about 50% St. A further decrease in the indicators indicates a compaction of the structure and limitation of diffusion of bioactive substances at a high St content. Thus, compositions with 50% St are promising for creating bioactive systems in modern pharmaceutical practice.

4. 8. Study of the sensitivity of *Quercus cortex* (oak bark) aqueous extract to test cultures

4. 8. 1. Opportunistic bacteria *Staphylococcus, Pseudomonas, Escherichia* in dentistry

The primary causative agents of caries and periodontitis are Streptococcus and anaerobic periodontal pathogens, but opportunistic microorganisms – *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli* – play a significant role in the development of secondary infections. Their danger lies in their ability to adhere and form biofilms on abiotic surfaces, which complicates the treatment of postoperative complications and odontogenic infections.

Thus, these pathogens pose a serious problem for dentistry due to their high resistance to antibiotics and immune response, which makes biofilm control a key task in the prevention and treatment of dental infections.

4. 8. 2. Determination of the sensitivity of test cultures to an *Quercus cortex* (oak bark) aqueous extract using resazurin

We investigated the effect of a *Quercus cortex* (oak bark) aqueous extract on test cultures *S. aureus* ATCC 25923, *E. coli* ATCC 25922, *P. aeruginosa* PA01. The data presented in Fig. 12 show the effect of a *Quercus cortex* (oak bark) aqueous extract on the metabolic activity (viability) of three reference bacterial strains *P. aeruginosa* PA01, *S. aureus* ATCC 25923 and *E. coli* ATCC 25922. The diagram shows that the test cultures under study are sensitive to a *Quercus cortex* (oak bark) aqueous extract, but the concentration added to the culture medium is important.

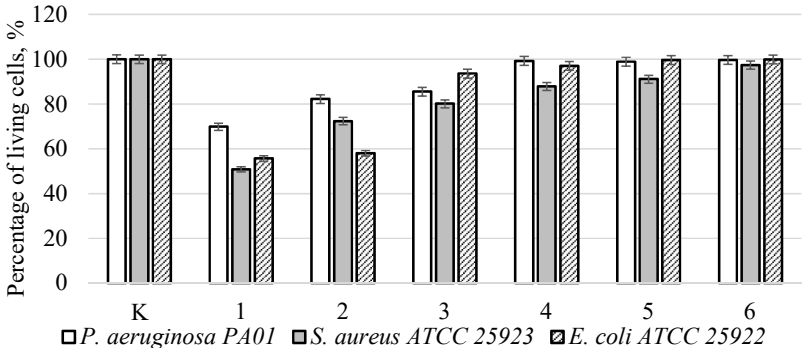

Fig. 12. Effect of *Quercus cortex* (oak bark) aqueous extract on the metabolic activity of test cultures (*S. aureus* ATCC 25923, *E. coli* ATCC 25922, *P. aeruginosa* PA01): K – control (growth of cultures on NB medium); 1 – growth of test cultures on *Quercus cortex* (oak bark) aqueous extract; 2 – 6 – differed in the amount of aqueous extract of oak bark added to NB medium: 2 – 50%; 3 – 20%; 4 – 10%; 5 – 5%; 6 – 1%

The *P. aeruginosa* PA01 strain was the most resistant to all tested concentrations of the aqueous extract, most likely because it could form biofilms and is resistant to various stress factors. However, it reduces its metabolic activity when growing on the aqueous extract by almost 30% and 18% and 14% when adding 50% and 20% of the aqueous extract of the *Quercus cortex* (oak bark) to the nutrient medium. *E. coli* ATCC 25922 were more sensitive to the concentration of the aqueous extract of the *Quercus cortex* (oak bark) of 50% and 100%, since the percentage of live cells is 42–44%.

Other tested concentrations of *Quercus cortex* (oak bark) aqueous extract have almost no effect on the survival of *E. coli* ATCC 25922 cells. The most sensitive to the concentrations of *Quercus cortex* (oak bark) aqueous extract was the strain *S. aureus* ATCC 25923. It shows a decrease in metabolic activity in all tested concentrations. Even with the addition of 5% *Quercus cortex* (oak bark) aqueous extract, a decrease in surviving cells by almost 8% was observed. It should also be noted that when growing on *Quercus cortex* (oak bark) aqueous extract, the metabolic activity of *S. aureus* ATCC 25923 was 48%. The presented results indicate that *Quercus cortex* (oak bark) aqueous extract can inhibit the development of gram-positive bacteria *S. aureus* ATCC 25923 even at concentrations of 5–50%. This is important for dentistry, since *Staphylococcus aureus* is a pathogen that can develop after surgical interventions and acute inflammatory processes.

4. 8. 2. Determination of the effect of *Quercus cortex* (oak bark) aqueous extract on the antiadhesive properties of test cultures

Bacterial adhesion is a key virulence factor and a fundamental step in the pathogenesis of most dental infectious diseases. In the oral cavity, these properties ensure microbial colonization of hard (enamel, dentin, cementum) and soft (mucosa, gingiva) tissues, as well as abiotic surfaces (dentures, implants), which directly leads to the formation of biofilms and the development of chronic inflammatory processes. The danger of the adhesive properties of microorganisms lies in the formation of a biofilm that is immersed in an exopolysaccharide matrix. Therefore, it is important to investigate how the bioactive extract of *Quercus cortex* (oak bark) will affect the adhesive properties of test cultures.

The results presented in Fig. 13 indicate that the *Quercus cortex* (oak bark) aqueous extract at a concentration of 50% can affect the adhesive properties of all tested test cultures, especially gram-negative *P. aeruginosa* PA01 and *E. coli* ATCC 25922, since their adhesive ability is 74% and 81%. The lower tested concentrations of the aqueous extract of oak bark had almost no effect on the ability of *P. aeruginosa* PA01 and *E. coli* ATCC 25922 bacteria to adhere to the surface. While the introduction of the *Quercus cortex* (oak bark) aqueous extract significantly affected the adhesive properties of *S. aureus* ATCC 25923. From Fig. 13 shows that the introduction of an *Quercus cortex* (oak bark) aqueous extract in concentrations from 1% to 20% into the culture medium of *S. aureus* ATCC 25923 caused the culture to lose its adhesive properties by almost 20%, while an *Quercus cortex* (oak bark) aqueous extract in a concentration of 50% reduced the number of cells adhering to the surface by 50%. When growing cells on the aqueous extract of oak bark itself, only 13% of the cells showed the adhesive properties of *S. aureus* ATCC 25923.

Opportunistic microorganisms of the genera *Staphylococcus, Pseudomonas* and *Escherichia* constitute an important risk factor in the development of dental infections, especially in postoperative complications and in the formation of biofilms on abiotic surfaces. Studies have shown that a *Quercus cortex* (oak bark) aqueous extract exhibits significant antimicrobial activity against test cultures *S. aureus* ATCC 25923, *E. coli* ATCC 25922 and *P. aeruginosa* PA01, with the severity of the effect depending on the concentration of the extract.

The most sensitive strain to the extract was *S. aureus* ATCC 25923, which showed a decrease in metabolic activity of up to 48–50% even at low concentrations (5–50%). *E. coli* ATCC 25922 culture showed partial growth inhibition only at high concentrations (50–100%), while *P. aeruginosa* PA01 showed the greatest resistance, retaining more than 70% of viable cells.

The extract of *Quercus cortex* (oak bark) also significantly affected the adhesive properties of bacteria. A particularly pronounced decrease in adhesion was observed in *S. aureus* ATCC 25923, for which the number of attached cells decreased to 50% when a *Quercus cortex* (oak bark) aqueous extract was added at a concentration of 50% and to 13% when cultivated on pure extract. For *P. aeruginosa* PA01 and *E. coli* ATCC 25922, the effect was less pronounced, but a slight decrease in the adhesive properties of these test cultures was still observed.

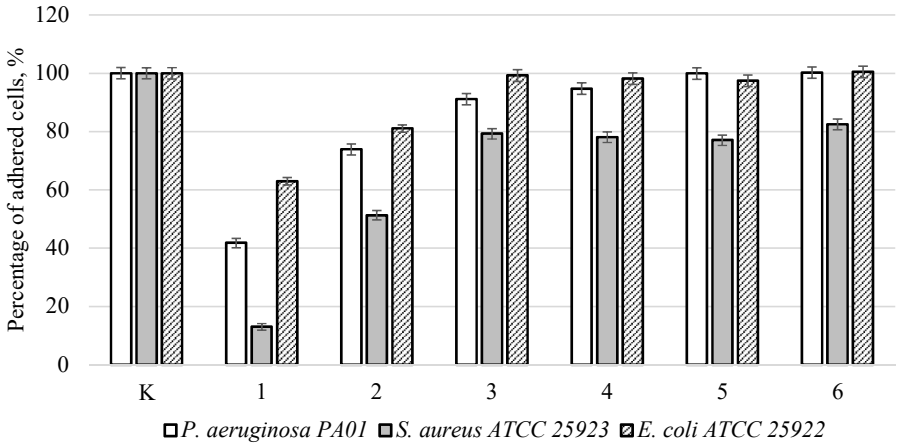

Fig. 13. Effect of oak bark extract on the metabolic activity of test cultures (*S. aureus* ATCC 25923, *E. coli* ATCC 25922, *P. aeruginosa* PA01). K – control (growth of cultures on NB medium); 1 – growth of test cultures on *Quercus cortex* (oak bark) aqueous extract; 2 – 6 – differed in the amount of aqueous oak bark extract added to NB medium: 2 – 50%; 3 – 20%; 4 – 10%; 5 – 5%; 6 – 1%

The obtained results indicate that the *Quercus cortex* (oak bark) aqueous extract has significant antibacterial and anti-adhesive properties, especially against the gram-positive strain *S. aureus* ATCC 25923. This opens up the prospects for using oak aqueous extract as a natural antimicrobial component in biocompatible materials for the prevention of infections in dentistry.

The obtained results confirm that hydrogels and films based on starch polysaccharides, enriched with *Quercus cortex* (oak bark) aqueous extract, have significant potential for pharmaceutical application. They are able not only to provide controlled release of the aqueous extract, but also to exhibit antibacterial and anti-adhesive effects against opportunistic pathogens, which is especially important in dentistry and surgery for the prevention of postoperative complications and reducing the risk of biofilm formation.

5. Discussion of research results

In the work, PVA/St compositions with a ratio of 9 / 1–3 / 7 exhibit pseudoplastic behaviour ($n < 1$), which is consistent with the data for PVA composites [23]. At the same time, for compositions with a ratio of PVA/St 2 / 8, 1 / 9, $n > 1$ is characteristic with an increase in the coefficient K, i. e. the systems are dilatant liquids. This behaviour differs from the results of other authors [24], who reported the preservation of pseudoplasticity even with a high proportion of starch. This may be due to the peculiarities of the *Quercus cortex* (oak bark) aqueous extract and the method of preparing the compositions and is explained by the fact that the particles of the compositions form temporary structures that are destroyed under the action of shear.

The decrease in the density of hydrogels at high St is consistent with the results of [25], which describe the formation of a porous structure with an increase in the starch content.

PVA/St hydrogels showed high water absorption capacity up to 1050%, while the films had half lower values up to 500%. Similar results obtained [26] confirm that the sorption capacity of binary PVA/St mixtures is determined by the ratio of components. This behaviour is explained by the fact that PVA, in comparison with St, has a larger number of hydroxyl groups capable of forming hydrogen bonds. According to the authors [27], the rate of equilibrium for PVA/St hydrogels is 10–12 hours, while in our work it was 5 hours. This can be explained by the more porous structure of our hydrogels.

PVA/St films have a significant strength of 1170 kPa at low St content but become brittle as it increases. This is consistent with the results of studies of PVA/St films, where the introduction of starch reduced the strength and increased the rigidity of the structure [28]. At the same time, according to our study, the optimal elasticity at 10–20% St is 135–185%, which differs from the results of other authors who indicated an optimum at 30–40% [24]. This may be due to the different molecular weight of PVA and the peculiarities of the interaction of the system components with the *Quercus cortex* (oak bark) aqueous extract.

According to the results of the study, the release of oak bark extract from PVA/St hydrogels reaches a peak at 50% St. This makes such compositions promising for pharmaceutical applications. Similar results were obtained in [26] with an average content of the polysaccharide Carboxymethyl cellulose (CMC) in PVA/CMC phytohydrogels.

Oak bark extract showed pronounced activity against *S. aureus* (reduction of viability up to 48%), which confirms its potential in dentistry. This is consistent with the data of Deryabin and Tolmacheva, who described antibacterial and anti-quorum sensing properties of *Quercus cortex* extract [29]. Additionally, Tanase et al. showed that oak extracts have antioxidant and antimicrobial effects against *S. aureus* and *E. coli* [30]. At the same time, the resistance of *P. aeruginosa* in our work was higher than in the results of other authors, which may be due to different strains and cultivation conditions.

Practical significance. The developed compositions based on PVA/St enriched with *Quercus cortex* (oak bark) aqueous extract combine adjustable physicomechanical properties and have pronounced biological activity. This opens prospects for their potential use as effective agents in modern pharmaceutical practice - for the creation of antibacterial coatings, biocompatible hydrogels and films with controlled properties, suitable for local application and prevention of infectious complications.

Study limitations. The use of only one type of polysaccharide, starch, as well as one type of plant extract of *Quercus cortex* (oak bark), limits the possibility of generalizing the obtained conclusions to other natural polymers or plant extracts.

Prospects for further research. In the future, it is planned to study the chemical interaction of the components of the *Quercus cortex* (oak bark) aqueous extract with the PVA/St polymer matrix and to study the prospects for the introduction of the developed films and hydrogels in dentistry.

6. Conclusions

Therefore, the work proved that the integration of the aqueous extract of *Quercus cortex* into the PVA/St polymer matrices makes it possible to combine the aqueous plant extract with a synthetic and natural polymer to create materials with regulated physicochemical properties.

It was established that PVA/St compositions with *Quercus cortex* aqueous extract can exhibit both pseudoplastic $n = 0.46–0.92$ and dilatant properties $n = 1.20–1.98$, which opens new opportunities for controlling technological processes.

The dependence of hydration properties on starch content $R^2 = 0.908$ was proven, and it was also shown that the films have a density of 1.1–1.35 g/cm^3 versus 1.01–1.04 g/cm^3 for hydrogels, which indicates their structural stability.

It was found that PVA/St hydrogels enriched with *Quercus cortex* (oak bark) aqueous extract are characterized by a significantly higher sorption capacity – up to 1050% in distilled water and 650% in saline NaCl, which is due to their porous structure and high-water content. In contrast, the films demonstrate sorption values – up to

350% in water and 260% in saline but are characterized by greater structural stability. It was proven that an increase in the proportion of St reduces the sorption indicators.

The antimicrobial effect of the aqueous extract of oak bark against *S. aureus*, *E. coli* and *P. aeruginosa* in the concentration range of 1–50% was confirmed, as well as its antiadhesive effect, which was quantified spectrophotometrically at 570–620 nm.

Thus, PVA/St compositions enriched with *Quercus cortex* (oak bark) aqueous extract allow obtaining materials that combine adjustable physicochemical parameters with pronounced biological activity. This opens prospects for the development of new biocompatible materials in pharmaceuticals and medicine, in particular for the creation of antibacterial coatings, hydrogels and films with controlled properties.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this article.

Funding

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in creating the submitted work.

Authors' contributions

Irina Liashok: Conceptualization, Data Curation, Formal analysis, Investigation, Validation, Resources, Writing – original draft, Writing – review & editing; **Viktoriia Plavan:** Conceptualization, Methodology, Supervision, Writing – review & editing; **Vyacheslav Shvets:** Conceptualization, Methodology, Formal analysis, Investigation, Validation, Writing – original draft; **Olena Kriukova:** Data Curation, Investigation, Visualization, Writing – original draft, Writing – review & editing; **Iryna Voloshyna:** Data Curation, Microbiological analysis, Visualization, Writing – original draft, Writing – review & editing.

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Received 11.05.2026
Received in revised form 18.06.2026
Accepted 23.06.2026
Published 30.06.2026

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