TECHNOLOGIES AND ENGINEERING

Journal homepage: https://technologies-engineering.com.ua/en
Vol. 26, No. 2, 2025

Received: 18.11.2024
Revised: 14.03.2025
Accepted: 30.04.2025

UDC 664.286

DOI: 10.30857/2786-5371.2025.2.4

Antimicrobial and sorption properties of polymer films based on modified starch with xeroform for veterinary purposes

Daria Kuchynska

Postgraduate Student
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
https://orcid.org/0009-0007-5928-6639

Olena Ishchenko*

Doctor of Technical Sciences, Professor
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-9510-6005

Roman Kachan

PhD in Technical Sciences, Associate Professor
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
https://orcid.org/0000-0001-7974-2784

Olha Sumska

PhD in Technical Sciences, Associate Professor
Kherson State Agrarian and Economic University
25031, 5/2 University Ave., Kropyvnytskyi, Ukraine
https://orcid.org/0000-0003-1606-6103

Olena Roik

PhD in Pharmacy, Associate Professor
Kyiv National University of Technologies and Design
01011, 2 Mala Shyianovska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-5988-6577

Abstract. The development of effective and safe wound healing materials is becoming exceedingly important in veterinary medicine, particularly concerning the treatment of infected wounds and the prevention of secondary infections. A promising strategy involves the fabrication of polymeric films possessing combined functionalities. The aim of this study was to evaluate the antimicrobial and sorption properties of polymer films based on a blend of modified starch and polyvinyl alcohol, containing 10 wt.% xeroform, for their potential application as veterinary dressing materials. The antimicrobial activity of the films was determined using the agar diffusion method against *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans*, and *Aspergillus niger*; sorption characteristics were evaluated based on water uptake kinetics and methylene blue dye adsorption, measured by photoelectric colorimetry. The investigated films demonstrated pronounced antibacterial and fungicidal activity against all tested strains of modern wound pathogens, confirming the efficacy of xeroform within the polymer matrix, exhibiting complete inhibition against *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans*, and *Aspergillus niger*. Additionally, the compositions exhibited high liquid absorption capacity, essential for exudate removal from the wound surface, with water uptake ranging from approximately 180% to over 230% at equilibrium and methylene blue adsorption exceeding 50% within 60 minutes. The kinetics of water uptake and methylene blue dye adsorption were

Suggested Citation:
Kuchynska, D., Ishchenko, O., Kachan, R., Sumska, O., & Roik, O. (2025). Antimicrobial and sorption properties of polymer films based on modified starch with xeroform for veterinary purposes. *Technologies and Engineering,* 26(2), 48-57. doi: 10.30857/2786-5371.2025.2.4.

*Corresponding author

significantly dependent on the starch modification conditions and the modified starch / polyvinyl alcohol blend ratio in the composition. The obtained results indicate the potential of the developed modified starch / polyvinyl alcohol / xeroform films as active wound healing coverings with integrated bioactive components (antiseptics) for veterinary use, possessing antiseptic and high sorption properties that contribute to therapeutic efficacy. The possibility of varying the starch modification conditions and composition allows for targeted regulation of the material's functional characteristics to adapt them to specific clinical needs and animal species

Keywords: polysaccharides; polyvinyl alcohol; bismuth tribromophenate; therapeutic wound dressings; antiseptic; photoelectric colorimetry; veterinary medicine

Introduction

Infectious complications significantly impede the process of wound healing, often leading to prolonged recovery and severe health consequences. The development of effective antimicrobial wound dressings is therefore a crucial area of ongoing research in biomedical materials. Many existing wound coverings do not provide sufficient protection against infection or require frequent changes, increasing patient discomfort and the risk of secondary infections.

Contemporary research efforts are directed towards creating innovative wound dressings that can release antimicrobial agents in a sustained manner to improve therapeutic efficacy and reduce dressing frequency. Authors F.M. Aldakheel *et al*. (2023) demonstrated the novelty of using polymer hydrogels containing silver nanoparticles, which exhibited prolonged antibacterial activity and accelerated wound closure in animal studies. However, the broad applicability and potential toxicity of nanoparticles require further investigation. Similarly, G.M. Lanno *et al.* (2020) explored electrospun nanofiber scaffolds loaded with antibiotics, reporting enhanced drug delivery and a significant reduction in bacterial burden in infected wounds. While promising, the scalability and long-term stability of such nanofiber systems in a clinical setting remain challenges.

A well-established antiseptic with pronounced antibacterial and antifungal properties is xeroform (bismuth tribromophenolate). A crucial aspect for ensuring the clinical effectiveness of wound healing films incorporating xeroform is the successful preservation of its inherent antimicrobial properties within the polymer matrix. J.N. Grauberger *et al.* (2024) investigated polymer matrices for controlled drug release, highlighting the tunability of material properties to achieve desired release kinetics, a concept directly relevant to optimising xeroform delivery. Furthermore, A.A.K. Nizam *et al*. (2025) suggested that bismuth salts, components of xeroform, can inhibit bacterial β-lactamases, offering a potential strategy to combat antibiotic resistance, a growing concern in wound management. The integration of xeroform into a flexible film matrix could offer a more convenient application compared to its traditional powder form.

The use of polysaccharides, particularly starch, is gaining prominence as a base for wound healing materials due to its inherent biocompatibility, biodegradability, affordability, and low toxicity. V. Vivcharenko *et al*. (2021) explored modifications of wound dressings with bioactive agents, highlighting how the enrichment of biomaterials with compounds like curcumin, essential oils, and vitamins can enhance their pro-healing properties and accelerate skin regeneration. Similarly, S. Shulga & O. Shulga (2024) explored the modification of potato starch with benzoic acid chlorine hydride, reporting alterations in the starch's physicochemical properties that could be relevant for material science applications, although their direct application in wound dressings requires further study. B.N. Biyimba *et al.* (2025) further demonstrated that modification of starch allows for tailoring its physicochemical and functional properties, which is essential for developing effective wound dressings with specific characteristics. However, native starch has limitations such as inadequate mechanical properties and rapid degradation, necessitating chemical modifications to enhance its suitability for prolonged-action wound dressings, as noted by M. Kaur *et al.* (2012).

Effective management of wound exudate is a fundamental requirement for successful wound healing. D. Alessio *et al.* (2023) highlighted that excessive exudate can hinder tissue repair by diluting essential growth factors and accumulating detrimental proteases within the wound bed. Furthermore, a moist, protein-rich environment created by unmanaged exudate provides an ideal breeding ground for pathogenic microorganisms, increasing the risk of biofilm formation and subsequent infection. Consequently, the development of wound dressings with high absorption capacity is crucial for maintaining a balanced moisture level conducive to tissue regeneration and for removing these harmful components. Evaluating the sorption properties of polymeric materials, such as starch-based films, through assessments of water uptake and the adsorption of model substances like methylene blue, therefore provides important insights into their potential for managing wound fluids and creating a favourable healing environment, which is a key factor in preventing complications and promoting effective tissue repair.

The aim of the present study was to evaluate the *in vitro* antimicrobial and sorption properties of novel polymer films composed of modified starch (MS) and polyvinyl alcohol (PVA) incorporating xeroform, against key pathogens commonly associated with wound infections.

Materials and Methods

Modification of potato starch and film preparation

Potato starch (CAS 9005-25-8) was modified using citric acid (CAS 77-92-9). The modification was performed

with two different concentrations of citric acid solution (0.5 mol/L and 1 mol/L). For each concentration, the reaction was conducted at a constant temperature of 40°C, varying the reaction time across three durations: 1.5, 2.0, and 2.5 hours. This approach aligns with previous studies demonstrating citric acid's effectiveness in altering starch properties (Rema *et al.*, 2018). The selection of different reaction times aimed to investigate the influence of modification duration on the final characteristics of the resulting films (Morán *et al.*, 2013).

The fabrication of films involved the initial preparation of 10% (w/v) solutions of modified starch (MS) and polyvinyl alcohol (PVA 17-99). The selection of this concentration was guided by prior studies indicating optimal film-forming characteristics for both polymers (Lani & Nagadi, 2014). Following the preparation of individual solutions, they were blended in proportions necessary to yield three distinct MS:PVA mass ratios in the resulting films: 25:75, 50:50, and 75:25. Film formation from these blended solutions was achieved via the solution casting method, a standard and versatile technique widely utilised for producing polymer films.

In response to inquiries regarding the criteria for selecting specific film formulations for detailed investigation, it should be noted that the samples presented in this work (with the indicated MS/PVA ratios and starch modification conditions) were chosen based on the results of extensive preliminary studies (Ishchenko *et al.*, 2023). These initial investigations encompassed a significantly wider range of variations in polymer blend ratios and starch modification parameters (including different acid types, concentrations, and reaction times) than those presented here. During these preliminary stages, numerous film formulations were fabricated and evaluated for critically important initial properties such as their ability to form homogeneous, non-brittle films, preliminary mechanical strength and flexibility, primary stability in aqueous media, and initial functional indicators like preliminary water uptake or basic antimicrobial screening.

The compositions included in this study were selected as the most promising candidates based on the results of this comprehensive preliminary screening, demonstrating the best combination of necessary physico-mechanical characteristics for potential application as wound dressings and encouraging initial functional performance. Thus, the selection of these specific samples for detailed evaluation of sorption and antimicrobial properties in the current work is justified and targeted, focusing on providing in-depth characterisation of the materials with the highest potential for further development as functional veterinary dressings, informed by the outcomes of preliminary material optimisation efforts.

In vitro antimicrobial activity evaluation

To confirm that xeroform retained its antimicrobial activity within the polymeric film matrix and to evaluate the *in vitro* antibacterial and antifungal properties of the composite films, a series of tests were conducted. The agar diffusion method was employed to assess the diffusion capability and efficacy of the incorporated active substance. This qualitative technique is a rapid tool for the initial assessment of microbial sensitivity to antimicrobial compounds or test substances. The methodological basis of this method relies on the ability of compounds to diffuse into the agar medium, leading to the inhibition of test strain growth. The rate of diffusion is determined by the physicochemical properties of the substance, solvent characteristics, nutrient medium composition, and pH value. The principle involves placing the active substance onto an agar medium previously inoculated with a test culture, followed by evaluating the zones of inhibited microbial growth that form due to the diffusion of the compound into the agar (Barillo *et al.,* 2017). The resulting zones of inhibition allow for establishing and characterising the antimicrobial activity of the tested samples, as their formation is a direct consequence of the diffusion of biologically active substances into the solidified nutrient medium.

The following test cultures were utilised in the experimental work: *Escherichia coli, Staphylococcus aureus, Candida albicans,* and *Aspergillus niger*. Microorganism cultivation and sensitivity determination were performed under optimal conditions using Sabouraud agar for fungi and Meat-peptone agar (MPA) for bacteria. Fifteen millilitres of the appropriate nutrient medium, previously inoculated with the respective test culture, were poured into standardised Petri dishes placed on a horizontal surface. To dry the surface of the medium after inoculum addition, plates with semi-open lids were left in a laminar flow hood for no more than 15 minutes (Wang *et al.*, 2018). Microorganism cultivation and incubation were carried out in a TC80m-2 thermostat. *Candida albicans, Escherichia coli,* and *Staphylococcus aureus* were incubated at 37 °C, while 32 °C was optimal for *Aspergillus niger*. Suspension concentrations for *Candida albicans, Escherichia coli*, and *Staphylococcus aureus* were determined using a Densi-La-Meter-2 nephelometer (Erba Lachema s.r.o., Czech Republic); a Goryaev chamber (hemocytometer) was used for *Aspergillus niger*. The final inoculum concentration for all test cultures was adjusted to $0.5x10^5$–$2.5x10^5$ CFU/mL. After the nutrient medium solidified, pieces of the developed polymer films were placed onto its surface. Primary results were evaluated after 24 hours, and final results after 72 hours of incubation. Criteria for experiment validity included a uniform microbial lawn of consistent density across the entire Petri dish surface and the formation of uniformly circular inhibition zones. Results were recorded under reflected light against a dark matte background. When measuring the diameter of inhibition zones, the zone of complete suppression of visible growth was considered, and measurements were taken using a caliper with an accuracy of 1.0 mm.

Evaluation of sorption properties

Sorption properties are of paramount importance for wound dressing materials, as they directly influence their

capacity to manage wound exudate – a key factor in promoting a moist healing environment while preventing maceration of the surrounding skin. Effective absorption of excess fluid is essential for optimal wound healing. Furthermore, the ability of a material to adsorb various substances from the wound bed, such as toxins, inflammatory mediators, proteases, or even bacterial components, can contribute to wound cleansing, reduction of bacterial load, and modulation of the inflammatory response, thereby accelerating the healing process.

To assess these critical functional characteristics, the water uptake kinetics and methylene blue adsorption properties of the developed films were evaluated. Water uptake measurements provide insights into the material's capacity to absorb aqueous fluids, simulating exudate management, and inform about its swelling behaviour, which can impact the material's mechanical integrity, conformability to the wound surface, and potential for sustained release of incorporated substances. Methylene blue adsorption was investigated as a model to understand the material's potential for binding and removing cationic species or other soluble contaminants from the wound environment.

Colorimetric determination of methylene blue concentration and water uptake measurement

The concentration of Methylene Blue (MB) dye was quantified using a KFK-2 photoelectric colorimeter. Optical density (absorbance) measurements were performed at a wavelength of 670 nm, employing cuvettes with a 10 mm path length. Distilled water served as the reference blank for all measurements. A calibration curve was constructed by plotting the measured optical density values against the known mass concentrations of prepared MB standard solutions. This established calibration curve was subsequently used to determine the concentration of MB in experimental samples.

The sorption efficiency of the materials was evaluated by the degree of absorption of the MS dye, which was calculated by the formula (1):

$$\eta = \frac{C_i - C_f}{C_i} \cdot 100\%, \quad (1)$$

where C_i – initial concentration of the test substance; C_f – final concentration of the test substance after a certain period of time.

The water uptake kinetics were determined gravimetrically. Pre-weighed dry film samples (m) of defined dimensions were immersed in distilled water at ambient temperature. At predetermined time intervals, samples were carefully removed from the water, surface water was gently removed by blotting with filter paper, and the swollen samples were immediately weighed (m_1). The percentage of water uptake (W) at each time point (t) was calculated using the following equation:

$$W = (m - m_1)/m_1, \quad (2)$$

where m – mass of the sample at a certain moment of time in water, g; m_1 – mass of the dry sample, g.

Measurements were continued until equilibrium swelling was achieved, indicated by a negligible change in weight over subsequent time points.

Results and Discussion

Evaluation of antimicrobial properties

The antimicrobial properties of the developed MS/PVA films incorporating 10 wt.% xeroform were evaluated using the agar diffusion method against representative bacterial and fungal pathogens commonly implicated in wound infections. Evaluation of antibacterial activity against *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive) bacteria revealed potent and consistent results across all six tested film formulations. Each composition demonstrated maximum bactericidal and bacteriostatic effects against both tested bacterial strains. This high level of uniform antibacterial efficacy indicates that the incorporated xeroform is effectively active within the polymer matrix and capable of inhibiting the growth and viability of key bacterial pathogens.

Similarly, the films exhibited strong fungicidal properties. Evaluation against *Candida albicans* (yeast-like fungus) and *Aspergillus niger* (mold fungus) showed a 100% antifungal effect for all six tested formulations. This was evidenced by the complete absence of fungal growth on the film samples and extending across the agar surface area influenced by diffusion of the active agent, indicating pronounced inhibition throughout the test environment. In stark contrast, control dishes without film samples exhibited continuous and robust fungal growth under the same conditions. Collectively, these findings demonstrated the broad-spectrum antimicrobial efficacy of the developed films, confirming their potential to inhibit both bacterial and fungal pathogens relevant to wound infections.

Evaluation of sorption properties

To evaluate the films' potential for adsorbing soluble substances from the wound environment, the adsorption kinetics of Methylene Blue (MB), a model cationic dye, were investigated. To accurately determine the concentration of Methylene Blue (MB) in the experimental samples during the adsorption studies, a calibration curve was constructed. This is a fundamental step in colorimetry, establishing a reliable relationship between the measured optical density (absorbance) and the known concentration of the analyte. A series of standard MB solutions with varying concentrations were prepared by serial dilution (Table 1), and their optical densities were measured at the predetermined wavelength of 670 nm.

The resulting data points were plotted to generate the calibration graph (Fig. 1), which exhibited a strong linear correlation between optical density and MB concentration. The equation of this linear relationship, along with the coefficient of determination (R_2), derived from the calibration curve, was then used to calculate the residual MB concentration in the supernatant solutions obtained during the adsorption experiments.

***Table 1**. Method of serial dilutions*

№ sample	Volume of 0.0073% solution of methylene blue, ml	Methylene blue concentration, %	Optical density (D) at λ = 670 nm
1	1	0.292	0.012
2	2	0.584	0.019
3	3	0.872	0.034
4	4	1.168	0.041
5	5	1.46	0.048
6	6	1.752	0.060

***Source:** developed by the authors of this study based on the findings of experimental research*

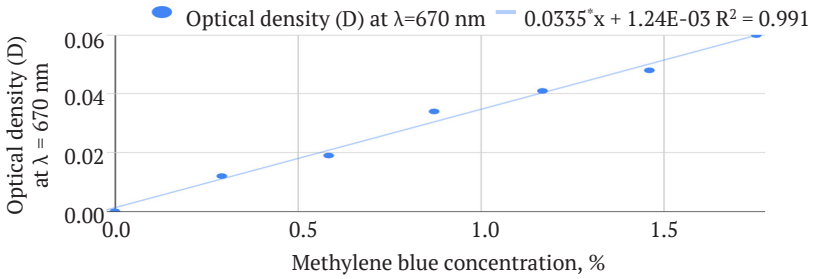

***Figure 1**. Calibration graph for determining residual concentration*
***Source:** developed by the authors of this study based on the findings of experimental research*

The experiments were conducted by immersing film samples in MB solution and monitoring the decrease in MB concentration over time using photoelectric colorimetry (Permana *et al.*, 2023). The adsorption capacity was expressed as the percentage of MB absorbed by the film samples relative to the initial amount in solution. The obtained results, presented in Table 2 and visually represented in Figure 2, demonstrated a significant capacity of all tested film compositions to adsorb Methylene Blue. MB absorption increased with exposure time for all samples, reaching substantial levels within the 60-minute observation period. Notably, the maximum adsorption percentage observed among the tested formulations at 60 minutes exceeded 50%, confirming the high sorption potential of the developed composite films.

***Table 2**. Measurement of MB absorption by samples (%) depending on exposure time t (min)*

Film composition	Type of starch modification	Exposure time (min)			
		15	30	45	60
MS/PVA (25/75) + xeroform 10 w.%	Citric acid, 1 mol, 1.5 h	34.55	40.91	42.73	43.64
MS/PVA (75/25) + xeroform 10 w.%	Citric acid, 1 mol, 2.5 h	39.09	45.45	49.09	50.00
MS/PVA (75/25) + xeroform 10 w.%	Citric acid, 0.5 mol, 1.5 h	40.91	42.73	45.45	49.09
MS/PVA (50/50) + xeroform 10 w.%	Lactic acid, 1 mol, 2 h	27.27	33.64	35.45	40.00
MS/PVA (75/25) + xeroform 10 w.%	Lactic acid, 1 mol, 2.5 h	30.91	36.36	41.82	41.82
MS/PVA (25/75) + xeroform 10 w.%	Lactic acid, 0.5 mol, 2 h	41.82	48.18	50.91	50.91

***Source:** developed by the authors of this study based on the findings of experimental research*

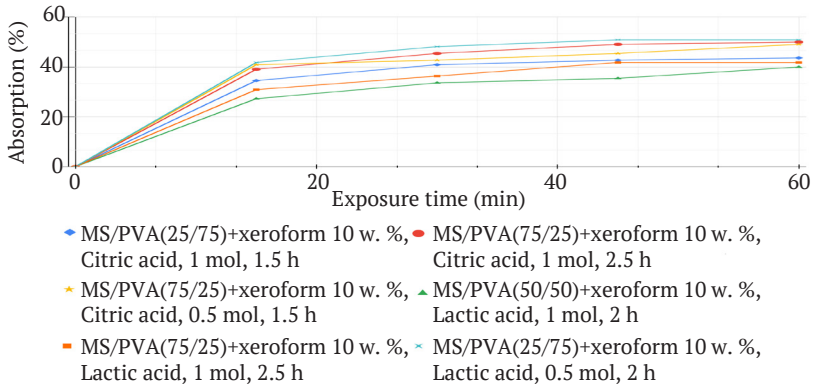

***Figure 2**. Methylene blue absorption kinetics of films based on MS/PVA with xeroform*
***Source:** developed by the authors of this study based on the findings of experimental research*

The kinetics and overall capacity of MB adsorption were found to be influenced by both the ratio of modified starch (MS) to polyvinyl alcohol (PVA) in the film composition and the specific conditions of starch modification (type and concentration of organic acid, reaction time). For instance, films with an MS/PVA ratio of 25:75 modified with lactic acid (0.5 mol/L, 2 h) exhibited the highest adsorption percentage, reaching 50.91% after 60 minutes. While variations in kinetics were observed across different formulations, all samples consistently showed robust adsorption capabilities.

These high Methylene Blue adsorption values are indicative of the films' promising potential to absorb and remove not only wound exudate but also other detrimental soluble components present in the wound bed, such as toxins or inflammatory mediators, which are often cationic or polar. The demonstrated high sorption capacity, particularly for MB as a model contaminant, reinforces the functional utility of these materials for active wound management and highlights the synergistic role of the polymeric matrix in complementing the antiseptic action of xeroform by contributing to wound cleansing. The ability to tailor the sorption performance through variations in polymer ratio and starch modification conditions allows for optimising the material's properties for specific clinical applications and the management of different types and volumes of wound exudate.

Water uptake kinetics: Influence of polymer composition and modification on swelling dynamics

Effective management of wound exudate is a fundamental requirement for modern wound dressings. High liquid absorption capacity is essential to remove excess fluid from the wound bed, prevent maceration of periwound skin, and provide a moist environment conducive to healing. To evaluate the potential of the developed films for this critical function, their water uptake kinetics were investigated using a gravimetric method (Kas'yanenko *et al.*, 2018). The results of the water uptake kinetics studies are presented in Figure 3.

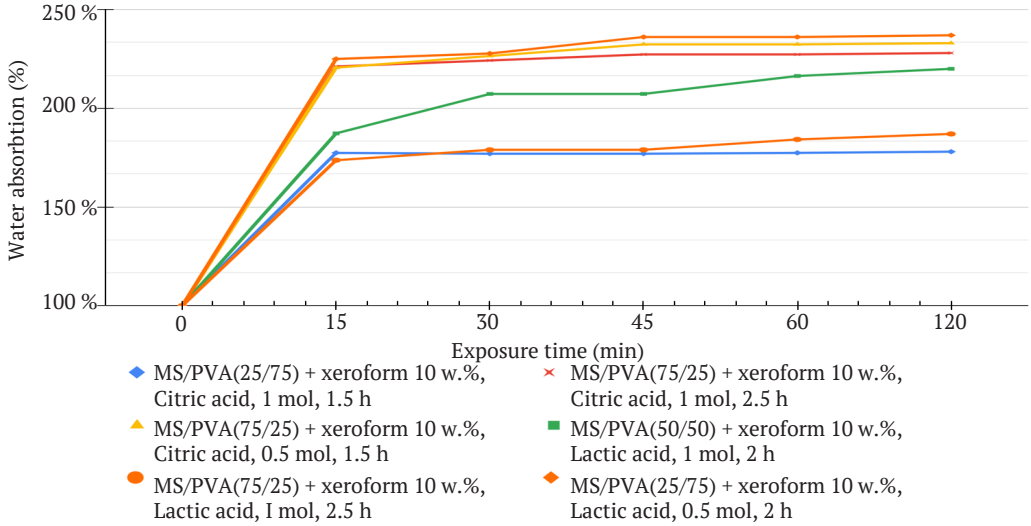

***Figure 3**. Kinetics of water absorption of films based on MS/PVA with xeroform*
***Source:** developed by the authors of this study based on the findings of experimental research*

The data revealed a rapid initial absorption of water by all film samples within the first 15 minutes of immersion, followed by a slowing rate of uptake as they approached equilibrium swelling within the 120-minute timeframe. Notably, all developed film compositions demonstrated very high-water uptake capacities, with swelling percentages ranging from approximately 180% to over 230% at near-equilibrium conditions. These values significantly underscore the materials' potential for effective exudate management.

The kinetics and maximum water uptake capacity were found to be highly dependent on the specific formulation, influenced by both the MS/PVA ratio and the type and conditions of starch modification. Films with a higher proportion of modified starch (MS/PVA 75:25), particularly those modified with citric acid (0.5 mol/L, 1.5 h and 1 mol/L, 1.5 h), exhibited the highest water uptake, reaching peak swelling percentages exceeding 220%. Conversely, formulations with a higher PVA content or modified with lactic acid generally showed lower, albeit still substantial, water absorption capacities.

The observed high water uptake capacity is a crucial attribute for wound dressing materials, indicating their ability to efficiently absorb large volumes of wound exudate. This rapid initial uptake and high equilibrium swelling are desirable characteristics for maintaining a dry wound surface while preserving a moist healing environment underneath the dressing. Furthermore, the variations in swelling kinetics and capacity depending on the composition allow for tailoring the material's performance to suit different types of wounds with varying levels of exudation. These findings affirm the potential of the developed MS/PVA/xeroform films as effective materials for exudate management in veterinary wound care.

Thus, the developed film matrix not only provides convenient and controlled delivery of xeroform to the wound, but also allows for the full realisation of its antimicrobial potential, creating a reliable barrier against infectious complications and promoting effective regeneration of damaged tissues. The use of a composite material with xeroform opens up prospects for its alternative application, making its use more convenient, effective and aimed at achieving optimal wound healing effect with minimising the risk of secondary infection.

The evaluation of the developed MS/PVA/xeroform films revealed functional properties that compare favourably with other materials documented in the literature. The observed water uptake capacity, which ranged from approximately 180% to over 230% across different formulations, demonstrated a significant ability to absorb wound exudate. This swelling capacity was notably higher than typically reported for unmodified or acid-modified starch films alone, as indicated by the findings of M. Kaur *et al*. (2012) and A.I. Martins *et al.* (2018). Furthermore, the water uptake of the current films was comparable to or exceeded the values observed for numerous experimental polymer-based wound dressings, including other starch/PVA composites specifically designed for wound care, as reported by A. Delavari & I. Stiharu (2022) and A. Delavari *et al.* (2022). This high absorbency is crucial for effective fluid management in exuding wounds, potentially preventing maceration and promoting a favourable healing environment.

In addition to their fluid handling capabilities, the films exhibited a substantial adsorption capacity for Methylene Blue, exceeding 50% within 60 minutes. This suggested a potential for removing soluble contaminants from the wound bed, which can impede the healing process. While benchmark adsorbents might demonstrate higher capacities, the adsorption performance of the developed MS/PVA/xeroform films was substantial and comparable to values reported for some other polymeric wound dressing materials evaluated using MB as a model contaminant (Delavari & Stiharu, 2022). This dual functionality, combining exudate absorption and contaminant removal, presents a significant advantage for wound management.

The incorporation of xeroform (Bismuth tribromophenolate) into the polymer matrix provided a potent antimicrobial component. D. Alessio-Bilowus *et al.* (2025) recognised xeroform as an antiseptic and anti-inflammatory agent widely employed for the prevention and treatment of wound infections. K.L. Johnson *et al*. (2023) highlighted its monocomponent nature and its antiseptic, astringent, and drying properties. The broad-spectrum antimicrobial activity of xeroform has been established against a wide range of bacteria such as *Escherichia coli, Pseudomonas aeruginosa, Bacillus subtilis, Staphylococcus aureus, Staphylococcus epidermidis, Staphylococcus haemolyticus, Streptococcus viridans, Enterococcus faecalis*, and *Salmonella typhimurium*, as well as certain fungi such as *Candida albicans*, as D. Chattopadhyay *et al.* (2016) previously reported. S. Bose *et al.* (2023) suggest that the protective albuminate film formed by this process on the damaged surface may alleviate pain by covering nerve endings and inhibit pathogenic microflora by disrupting their metabolic processes.

In the present study, the developed films demonstrated complete (100%) antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*, and complete fungicidal action against *Candida albicans* and *Aspergillus niger* across all tested formulations. This high level of broad-spectrum efficacy is a critical advantage for preventing and treating wound infections, particularly in the context of polymicrobial contamination, which is common in both human and veterinary wounds. When compared to the antimicrobial spectrum and activity reported for Xeroform gauze, which typically exhibited inhibition zones of specific diameters against these pathogens (Barillo *et al*., 2017), the observed complete inhibition within the tested area suggested a potent and effective delivery of the antimicrobial agent integrated into the polymer matrix, achieving comprehensive microbial suppression. Comparable antimicrobial effects against *Escherichia coli* and *Staphylococcus aureus* were also reported for certain micromycete strains by I. Rubezhniak (2020), confirming the relevance of broad-spectrum agents across diverse biological systems.

The synergistic action of the polymer matrix's inherent sorption function and the incorporated xeroform's antiseptic action in the developed MS/PVA composite films offers a dual therapeutic benefit. This combination of efficient wound disinfection coupled with the simultaneous absorption and removal of potentially harmful exudate and soluble contaminants is particularly advantageous and relevant in veterinary practice. As noted earlier, constraints on the frequency and timeliness of dressing changes are common in veterinary settings. In such scenarios, the material's ability to maintain an optimal healing environment for an extended duration by concurrently controlling infection and managing exudate becomes paramount, placing increased performance demands on the dressing material. The antiseptic and astringent effects of xeroform are primarily attributed to its ability to form stable complexes with proteins found in microbial cells and tissue exudate, leading to their coagulation, as suggested by A.I. Martins *et al.* (2018).

While the modified starch and PVA base of the films contributed to the desirable sorption properties, M. Kaur *et al.* (2012) previously noted that native starch exhibits certain limitations, including insufficient mechanical strength and susceptibility to rapid degradation and retrogradation, which restrict its direct application in film form for wound care. The modification of starch and its combination with PVA in the current study likely addressed some of these limitations, resulting in a more robust and functional material.

Collectively, the results of this study demonstrated that the developed MS/PVA/xeroform films possessed a compelling combination of high-water uptake and significant contaminant adsorption for effective exudate and wound management, coupled with complete, broad-spectrum antimicrobial efficacy against key wound pathogens. This multifunctionality positions them as highly promising candidates

for active wound dressing applications, particularly in veterinary medicine where the need for effective, long-lasting wound care solutions is significant. The observed water uptake kinetics, characterised by rapid initial absorption followed by high equilibrium swelling, further supported the potential of these films for managing wound exudate effectively. The dependence of both water uptake and methylene blue adsorption kinetics on the specific starch modification conditions and the MS/PVA blend ratio indicated the potential for tailoring the material's sorption properties to meet specific clinical requirements.

Conclusions

This study successfully investigated the potential of novel polymeric films fabricated from a blend of modified starch (MS) and polyvinyl alcohol (PVA), incorporating 10 wt.% xeroform, as active wound dressing materials for veterinary applications. The developed films demonstrated significant antimicrobial efficacy, exhibiting pronounced antibacterial activity against both Gram-negative (*Escherichia coli*) and Gram-positive (*Staphylococcus aureus*) bacteria, as well as complete fungicidal action against the yeast-like fungus (*Candida albicans*) and the mold fungus (*Aspergillus niger*). These results unequivocally confirm the effective integration and broad-spectrum antiseptic activity of xeroform within the polymer matrix, which is critical for inhibiting microbial proliferation and preventing secondary infections in wounds.

Furthermore, the composite films exhibited very high liquid absorption capacity, a vital characteristic for effectively managing wound exudate and promoting a suitable microenvironment for healing. Water uptake kinetics revealed a rapid initial absorption followed by high equilibrium swelling, with values ranging from approximately 180% to over 230% depending on the specific formulation. Concurrently, the films showed substantial methylene blue adsorption capacity, exceeding 50% within 60 minutes of exposure, indicative of their potential to adsorb soluble contaminants from the wound bed. The kinetics of both water uptake and methylene blue adsorption were shown to be dependent on the specific starch modification conditions and the MS/PVA blend ratio, indicating the potential for tailoring the material's sorption properties.

In summary, the combination of demonstrated antimicrobial activity and these high sorption capacities positions the developed MS/PVA/xeroform films as highly promising candidates for innovative wound coverings in veterinary medicine. Their ability to simultaneously combat infection and effectively manage exudate addresses key challenges in wound care. The findings suggest that variable processing parameters and composition can be leveraged to tune the functional characteristics of the dressings for optimal performance across diverse clinical scenarios and animal species.

Future research will focus on a comprehensive evaluation of the developed films' performance properties, including detailed characterisation of the kinetics and mechanism of xeroform release to ensure a sustained therapeutic effect, expanded *in vitro* evaluation of antimicrobial activity against a broader spectrum of clinical isolates and resistance profiles, rigorous *in vivo* assessment of their wound healing efficacy and biocompatibility, and further optimisation of their physico-mechanical properties to facilitate practical and effective clinical implementation.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

References

[1] Aldakheel, F.M., Mohsen, D., El Sayed, M.M., Fagir, M.H., & El Dein, D.K. (2023). Green synthesized silver nanoparticles loaded in polysaccharide hydrogel applied to chronic wound healing in mice models. *Gels*, 9(8), article number 646. doi: 10.3390/gels9080646.

[2] Alessio, D., Kumar, N., Nolan, R., Klein, J., Ridelman, E., & Shanti, C. (2023). 772 bismuth tribromophenate gauze is superior to silver sulfadiazine cream for mixed-depth scald burns in children. *Journal of Burn Care & Research*, 44(2), S172-S173. doi: 10.1093/jbcr/irad045.247.

[3] Alessio-Bilowus, D., Klein, J.D., Ridelman, E., & Shanti, C.M. (2025). Xeroform gauze versus silver sulfadiazine for mixed-depth pediatric scald injuries: A retrospective study. *JPRAS Open*, 43, 133-139. doi: 10.1016/j.jpra.2024.11.006.

[4] Barillo, D.J., Barillo, A.R., Korn, S., Lam, K., & Attar, P.S. (2017). The antimicrobial spectrum of Xeroform®. *Burns*, 43(6), 1189-1194. doi: 10.1016/j.burns.2016.10.023.

[5] Biyimba, B.N., Ekaette, I., & Cobbinah-Sam, E. (2025). Starch functionality in cosmetics and personal care products. *Carbohydrate Polymers*, 364, article number 123597. doi: 10.1016/j.carbpol.2025.123597.

[6] Bose, S., Singh, D.V., Adhya, T. K., & Acharya, N. (2023). *Escherichia coli*, but not *Staphylococcus aureus*, functions as a chelating agent that exhibits antifungal activity against the pathogenic yeast *Candida albicans*. *Journal of Fungi*, 9(3), article number 286. doi: 10.3390/jof9030286.

[7] Chattopadhyay, D., Sen, R., & Ghosh, A. (2016). An inexpensive bismuth-petrolatum dressing for treatment of burns. *Plastic and Reconstructive Surgery Global Open*, 4(6), article number e737. doi: 10.1097/GOX.0000000000000741.

[8] Delavari, A., & Stiharu, I. (2022). Preparation and characterization of eco-friendly transparent antibacterial starch/polyvinyl alcohol materials for use as wound-dressing. *Micromachines*, 13(6), article number 960. doi: 10.3390/mi13060960.
[9] Delavari, A., Abbasi, S., Rajabzadeh, G., Ghasemi, S., & Hashemi, S.A. (2022). Optimizing biodegradable starch-based composite films formulation for wound-dressing applications. *Micromachines*, 13(12), article number 2146. doi: 10.3390/mi13122146.
[10] Grauberger, J.N., Joshi, N., Joo, A., Phelan, A.L., & Lalikos, J.F. (2024). Xeroform stick-down dressing: A novel treatment for pediatric partial-thickness burns. *Plastic and Reconstructive Surgery*, 92(4S), S123-S128. doi: 10.1097/SAP.0000000000003795.
[11] Ishchenko, O., Kuchynska, D., Plavan, V., & Ostrauskaitė, J. (2024). Wound dressings films based on the citric acid modified starch. In *The 10th international conference on advanced materials and systems (ICAMS 2024)* (pp. 101-106). Poland: Sciendo. doi: 10.2478/9788367405805-014.
[12] Johnson, K.L., Papac, N., & Hirshburg, J.M. (2023). Xeroform gauze bolster: A cost-effective alternative to synthetic skin grafts. *Cureus*, 15(9), article number e45307. doi: 10.7759/cureus.45307.
[13] Kas'yanenko, I., Neskorozhena, H., & Kramarenko, V. (2018). Influence of filling on water uptake of films based on water-borne coating materials. *Chemistry & Chemical Technology*, 12(4), 466-472. doi: 10.23939/chcht12.04.466.
[14] Kaur, M., Oberoi, D.P.S., Sogi, D.S., & Gill, B.S. (2012). Physicochemical, morphological and pasting properties of acid treated starches from different botanical sources. *Journal of Food Science and Technology*, 48, 460-465. doi: 10.1007/s13197-010-0126-x.
[15] Lani, N.S., & Ngadi, N. (2014). Preparation and characterization of polyvinyl alcohol/starch blend film composite. *Applied Mechanics and Materials*, 554, 86-90. doi: 10.4028/www.scientific.net/AMM.554.86.
[16] Lanno, G.-M., Ramos, C., Preem, L., Putrinš, M., Laidmäe, I., Tenson, T., & Kogermann, K. (2020). Antibacterial porous electrospun fibers as skin scaffolds for wound healing applications. *ACS Omega*, 5(46), 30011-30022. doi: 10.1021/acsomega.0c04402.
[17] Martins, A.I., Silva, A., & Pinto, P. (2018). Impact of acid hydrolysis and esterification process in rice and potato starch properties. *International Journal of Biological Macromolecules*, 120(Pt A), 959-965. doi: 10.1016/j.ijbiomac.2018.08.170.
[18] Morán, J.I., Vázquez, A., & Cyras, V.P. (2013). Bio-nanocomposites based on derivatized potato starch and cellulose, preparation and characterization. *Journal of Materials Science*, 48, 7196-7203. doi: 10.1007/s10853-013-7536-x.
[19] Nizam, A.A.K., Masri, S., Fadilah, N.I.M., Maarof, M., & Fauzi, M.B. (2025). Current insight of peptide-based hydrogels for chronic wound healing applications: A concise review. *Pharmaceuticals*, 18(1), article number 58. doi: 10.3390/ph18010058.
[20] Permana, M.D., Sakti, L.K., Luthfiah, A., Firdaus, M.L., Takei, T., Eddy, D.R., & Rahayu, I. (2023). A simple methods for determination of methylene blue using smartphone-based as digital image colorimetry. *Trends in Sciences*, 20(4), article number 5149. doi: 10.48048/tis.2023.5149.
[21] Rema, R., Alummoottil, N.J., & Janardanan, S. (2018). Effect of chemical modification with citric acid on the physicochemical properties and resistant starch formation in different starches. *Carbohydrate Polymers*, 202, 29-38. doi: 10.1016/j.carbpol.2018.08.128.
[22] Rubezhniak, I. (2020). Antibacterial activities of cultural filtrates of some strains of micromycete. *Biological Systems: Theory and Innovation*, 11(2), 42-49. doi: 10.31548/biologiya2020.01.042.
[23] Shulga, S., & Shulga, O. (2024). Potato starch modification with benzoic acid chlorine hydride. *Ukrainian Chemistry Journal*, 89(12), 110-119. doi: 10.33609/2708-129X.89.12.2023.110-119.
[24] Vivcharenko, V., & Przekora, A. (2021). Modifications of wound dressings with bioactive agents to achieve improved pro-healing properties. *Applied Sciences*, 11(9), article number 4114. doi: 10.3390/app11094114.
[25] Wang, R., Lai, T.P., Gao, P., Zhuang, H., Ho, P.L., Woo, P.C.-Y., Ma, G., Kao, R.Y.-T., Li, H., & Sun, H. (2018). Bismuth antimicrobial drugs serve as broad-spectrum metallo-β-lactamase inhibitors. *Nature Communications*, 9, article number 439. doi: 10.1038/s41467-018-02828-6.

Антимікробні та сорбційні властивості полімерних плівок на основі модифікованого крохмалю з ксероформом для ветеринарного призначення

Дар'я Кучинська

Аспірант
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
https://orcid.org/0009-0007-5928-6639

Олена Іщенко

Доктор технічних наук, професор
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
https://orcid.org/0000-0002-9510-6005

Роман Качан

Кандидат технічних наук, доцент
Київський національний університет технологій та дизайну
01011, вул. Мала Шияновська, 2, м. Київ, Україна
https://orcid.org/0000-0001-7974-2784

Ольга Сумська

Кандидат технічних наук, доцент
Херсонський державний аграрно-економічний університет
25031, просп. Університетський, 5/2, м. Кропивницький, Україна
https://orcid.org/0000-0003-1606-6103

Олена Роїк

Кандидат фармацевтичних наук, доцент
Київський національний університет технологій та дизайну,
01011, вул. Мала Шияновська, 2, м. Київ, Україна
https://orcid.org/0000-0002-5988-6577

Анотація. Розробка ефективних та безпечних ранозагоювальних матеріалів набуває надзвичайної важливості у ветеринарній медицині, особливо щодо лікування інфікованих ран та запобігання вторинним інфекціям. Перспективна стратегія передбачає виготовлення полімерних плівок, що мають комбіновані функціональні можливості. Метою цього дослідження було оцінити антимікробні та сорбційні властивості полімерних плівок на основі суміші модифікованого крохмалю та полівінілового спирту, що містять 10 мас. % ксероформу, для їхнього потенційного застосування як ветеринарних перев'язувальних матеріалів. Антимікробну активність плівок визначали методом дифузії в агаровому середовищі проти *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans* та *Aspergillus niger*; сорбційні характеристики оцінювали на основі кінетики водопоглинання та адсорбції барвника метиленового синього, виміряних фотоелектроколориметрично. Досліджені плівки продемонстрували виражену антибактеріальну та фунгіцидну активність проти всіх протестованих штамів сучасних ранових патогенів, підтверджуючи ефективність ксероформу в межах полімерної матриці, зокрема, повне пригнічення росту *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans* та *Aspergillus niger*. Крім того, композиції виявили високу рідинопоглинаючу здатність, необхідну для видалення ексудату з поверхні рани, з водопоглинанням у рівноважному стані від приблизно 180 % до понад 230 % та адсорбцією метиленового синього, що перевищувала 50 % протягом 60 хвилин. Кінетика водопоглинання та адсорбції барвника метиленового синього значною мірою залежала від умов модифікації крохмалю та співвідношення модифікованого крохмалю і полівінілового спирту в композиції. Отримані результати свідчать про потенціал розроблених плівок на основі модифікованого крохмалю, полівінілового спирту та ксероформу як активних ранозагоювальних покриттів з інтегрованими біоактивними компонентами (антисептиками) для ветеринарного застосування, що мають антисептичні та високі сорбційні властивості, які сприяють терапевтичній ефективності. Можливість варіювання умов модифікації крохмалю та складу дозволяє цілеспрямовано регулювати функціональні характеристики матеріалу для адаптації їх до специфічних клінічних потреб та видів тварин

Ключові слова: полісахариди; полівініловий спирт; вісмуту трибромофенолят; лікувальні ранові пов'язки; антисептик; фотоелектроколориметрія; ветеринарна медицина