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Physicochemical and Biomedical Properties of Gelatin-Based Composite Films

G. G. Abdikarim,[1,4,*] Sh. N. Zhumagaliyeva,[1,*] Zh. A. Abylov,[1] Joachim Koetz,[2] M. I. Choudhary,[3] M. Zh. Turmukhanova[1] and N. P. Altynbay[1]

Abstract

Natural polymer-based biomaterials are getting more and more attention because they are very biocompatible, biodegradable, and useful for treating wounds. As a natural biopolymer, gelatin is a flexible base for adding bioactive compounds that help tissues heal and grow back. The goal of this study was to make and describe gelatin-based films that contain *Tamarix hispida* (TH-10) extract and 1-amyl-2-methyl-4-benzoxy decahydroquinoline hydrochloride (DHQ) for use as multifunctional wound dressings. Composite films were fabricated via solvent casting using 12 wt.% gelatin as the polymeric matrix. The films were analyzed using FT-IR spectroscopy, scanning electron microscopy (SEM), and mechanical testing. Drug-release behavior, swelling capacity, and moisture permeability were evaluated to determine the films' biomedical performance. FT-IR confirmed hydrogen-bond interactions between gelatin, TH-10, and DHQ, forming a stable composite structure. SEM micrographs revealed a uniform and defect-free morphology. Mechanical properties showed a tensile strength of 4,62 ± 0,12 MPa and an elongation at break of 34,76 ± 4,35%. Drug-release studies demonstrated high desorption efficiencies—59 wt.% for TH-10 and 50 wt.% for DHQ—indicating controlled release characteristics. Incorporation of TH-10 and DHQ enhanced the antioxidant, anti-inflammatory, and anesthetic effects of gelatin-based films. These composite films exhibit promising potential as multifunctional wound dressings for biomedical applications.

Keywords: Gelatin-based film; *Tamarix hispida*; Wound dressing; Drug release; Mechanical properties.
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1. Introduction

Gelatin-based biomaterials have emerged as versatile platforms for wound healing due to their biocompatibility, biodegradability, and physicochemical similarity to collagen.[1,2] As a natural polymer, gelatin forms flexible, transparent, and water-permeable matrices capable of incorporating a wide range of bioactive agents. However, despite their favorable mechanical and hydrophilic properties, unmodified gelatin films generally exhibit insufficient antimicrobial, anti-inflammatory, antioxidant, and analgesic activities, which limits their effectiveness in biomedical applications.[3–5]

Beyond food and biomedical packaging, gelatin-based biopolymer films are increasingly considered for agro-environmental applications, where material design must account for drought/salinity stresses and changing water availability. Climate-driven shifts in water resources and irrigation practices directly affect the performance requirements of biodegradable protective materials and coatings used in field conditions (*e.g.,* humidity, salinity, and temperature fluctuations), as discussed in recent regional hydrology assessments. These constraints motivate development of mechanically robust, barrier-tunable gelatin composite films for real operating environments.[6–9]

Gelatin is extensively utilized in the biomedical field, particularly for wound healing.[10] This biomaterial is produced through the cryopolymerization of gelatin and dopamine, resulting in a biodegradable interpenetrating polymer network used in dry cryogenic hemostats. Given the complications associated with diabetes mellitus, which often lead to severe skin injuries, current treatments for diabetic

[1]*Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan*
[2]*University Potsdam, Potsdam, Brandenburg, 14469, Germany*
[3]*H.E.J. Research Institute of Chemistry, International Center for Chemical and Biological Sciences, University of Karachi, Karachi, Sindh, 75270, Pakistan*
[4]*Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkistan, 161200, Kazakhstan*
[*]*Email:* gulzat.abdikarim@mail.ru (G. G. Abdikarim), shynarnur1@gmail.com (Sh. N. Zhumagaliyeva)

skin wounds remain inadequate, with drug delivery effectiveness limited by penetration depth.[11,12] Additionally, scientific studies highlight the use of gelatin-based biomaterials in managing burn wounds. Burns are clinically challenging to treat because the wounds are prone to bacterial infections and produce large amounts of pus and serum. To address this, a biodegradable cryogel composed of gelatin and silver nanoparticles has been proposed, which aids burn wound healing by absorbing significant amounts of water and exhibiting strong antibacterial properties.[13] In addition, several studies have demonstrated that gelatin-based films enriched with growth factors, plant extracts, or other therapeutic agents have a positive impact on wound healing under both *in vivo* and *in vitro* conditions.[14] authors has found that gelatin films that incorporate epidermal growth factor (EGF) accelerate the process of re-epithelialization in skin wound models. Films made from squid gelatin enriched with the plant extract *Lawsonia* inermis showed antioxidant activity, increasing the wound closure rate. In a recent study, gelatin films incorporating silver nanoparticles and biologically active substances that contribute to wound healing, demonstrating that their physicochemical and antimicrobial properties are effective in treating skin lesions

Because gelatin has a molecular structure and function closely resembling those of collagen, it is frequently utilized in the creation of biomaterials, collagen substitutes, and in cellular and tissue engineering.[15] The presence of functional groups such as -NH_2 and -COOH in its composition also makes it ideal for producing phytofilms and capsules based on gelatin.[16] However, the limited antimicrobial and anti-inflammatory properties of gelatin-based films restrict their range of applications.[17]

To address these limitations, recent research has focused on hybrid gelatin systems containing both natural and synthetic bioactive compounds. Natural plant extracts are particularly attractive because of their complex mixture of polyphenols, flavonoids, terpenoids, and other secondary metabolites with documented antioxidant, antimicrobial, and wound-healing properties.[4,14,18–20]

The polyphenolic compounds present in the plant exhibit significant antimicrobial, antioxidant, and anti-inflammatory biological activities.[21] This study focuses on the plant *Tamarix hispida*, which is classified within the genus *Tamarixia* and is recognized as a prevalent source of plant materials rich in biologically active substances. Research has identified the presence of various biologically active compounds, including terpenoids, polyphenols, and steroid complexes, in *Tamarix hispida*.[22] Furthermore, it has been demonstrated that extracts from this plant, along with its individual constituents, possess antimicrobial, antifungal, cytotoxic, and antioxidant properties, in addition to serving as hemostatic agents and exhibiting antidiabetic activity.[23] In parallel, synthetic compounds such as anesthetics/analgesics can be co-immobilized to enhance functionality of wound dressings. Decahydroquinoline derivatives (*e.g.,* DHQ) represent a promising class of locally acting anesthetic/analgesic agents with favorable physicochemical properties, but their incorporation into gelatin matrices and interaction with natural extracts remains underexplored. Based on these considerations, the present study focuses on the fabrication of gelatin-based composite films containing Tamarix hispida extract (TH-10) and 1-amyl-2-methyl-4-benzoxy decahydroquinoline hydrochloride (DHQ) as active functional components for multifunctional wound dressings. The scientific rationale of this design lies in integrating (i) gelatin's biocompatible and film-forming polymer network, (ii) plant-extract driven antioxidant and anti-inflammatory activity to modulate wound microenvironment, and (iii) anesthetic/therapeutic drug incorporation for local biomedical function. The composite system is expected to exhibit favorable morphological uniformity, mechanical robustness, swelling control, and sustained drug release, thereby providing a promising strategy for next-generation wound dressing development.

2. Materials and methods

2.1 Materials

Gelatin powder (Ph. Eur., NF) pure, (128-192 Bloom batch) from Appli Chem, Germany, was used without additional cleaning. Glycerin (Pharmpur, Ph.Eur, BP, USP) from Scharlab, S.L. Spain, with a purity > 99 wt% was used without additional cleaning. Potassium sorbate (Sigma Aldrich, USA) with a purity > 99 wt% was used without additional cleaning. TH-10 – Dry brown extract isolated from 10 wt.% aqueous-alcoholic solution of *Tamarix hispida* plant. DHQ (1-amyl-2-methyl-4-benzoxydecahydroquinoline hydrochloride) was used as an active compound in the composite films. The compound was provided as a white crystalline powder and used without further purification.

2.2 Preparation of dry extract TH-10

A dry extract of *Tamarix hispida* was prepared using the maceration method. Briefly, the dried plant material was immersed in a 10 wt.% aqueous ethanol solution at a solid-to-liquid ratio of 1:4 (w/v), followed by filtration. The filtrate was concentrated and dried to obtain TH-10 as a brown, water-absorbent dry extract. Upon exposure to open air, the extract tends to absorb moisture and forms granules. The extract is insoluble in benzene and chloroform, slightly soluble in 70 wt.% and 96 wt.% ethanol–water mixtures, and readily soluble in water as well as in 10 wt.% and 50 wt.% aqueous ethanol solutions.[23]

2.3 Preparation of a gelatin-based film (GF)

Gelatin-based films were prepared by the solvent casting method, as previously reported[23] (Fig. 1). Briefly, gelatin was dispersed in distilled water to obtain a 12 wt.% solution and allowed to swell for 30 min. The mixture was then stirred for 10 min at 35 - 40 °C using a mechanical mixer until complete dissolution. After cooling to room temperature, the gelatin

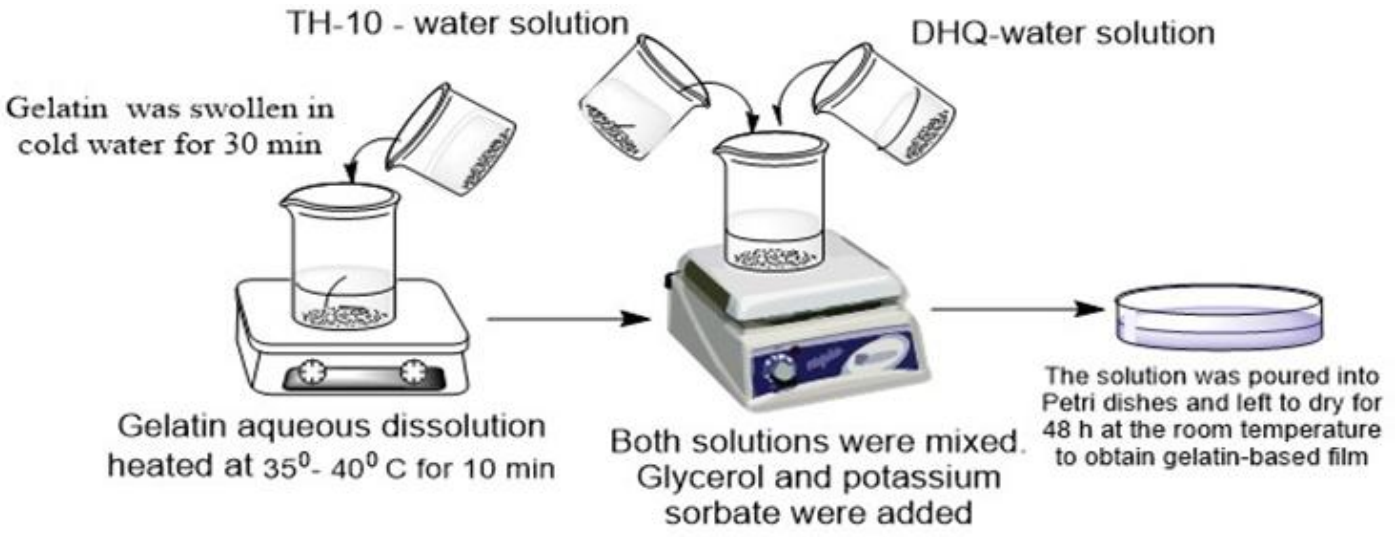


Fig. 1: Preparation of a gelatin-based film (GF).

solution was supplemented with TH-10 (1 wt.%), glycerol (5 wt.%), potassium sorbate (0.02 wt.%), and DHQ (0.1 wt.%). The total mass of the film-forming solution was fixed at 10 g. The resulting mixture was poured into Petri dishes and dried in a vacuum dryer at 30 °C until constant weight was achieved.

2.4 Physicochemical characterization

2.4.1 Swelling capacity

The swelling capacity of the films was evaluated using the equilibrium swelling method. Film specimens (0.1 g) were cut into strips of 1 × 5 cm and dried at room temperature until constant weight was obtained. The dried samples (m_0) were then immersed in distilled water at room temperature until equilibrium swelling was reached. After removal, excess surface water was gently wiped off and the swollen samples were weighed (m). The swelling degree (α) was calculated according to Eq. (1):

$$\alpha = \frac{m - m_0}{m_0} \quad (1)$$

where m is the mass of the swollen sample, m_0 is the mass of the dry sample, and α is the swelling degree. All measurements were performed at least in triplicate, and the results were reported as mean values.

2.5 Moisture content of gelatin films

The moisture content of the film samples was determined using a gravimetric method. The initial weight of each film sample (W_1) was recorded, after which the samples were dried in an room temperature until constant weight. The dried weight was recorded as W_2. The moisture content (MC) was calculated according to Eq. (2):

$$MC = \frac{W_1 - W_2}{W_1} \times 100 \quad (2)$$

where MC is the moisture content (%), W_1 is the initial mass of the film (g), and W_2 is the final constant mass after drying (g). All measurements were performed at least in triplicate.

2.6 Microstructure determination

Microstructural analysis of the films was studied using a Scanning Electron Microscope (SEM) on a Hitachi S-4800 HR-SEM (Japan). Prior to SEM observation, the films were stabilized in a desiccator containing P_2O_5 to remove moisture from the film. The samples were fixed on copper plates, coated with gold to make them electrically and observed directly at an accelerating voltage of 10 kV.

2.7 Fourier Transform Infrared (FT-IR) spectroscopy studies

Fourier-transform infrared (FT-IR) spectroscopy was used to evaluate the chemical structure of the films and the interactions between gelatin and the incorporated active compounds (TH-10 and DHQ). FT-IR spectra were recorded using an FT-IR spectrometer (FTIR-8900S, Shimadzu, Japan) employing the KBr pellet method. All spectra were obtained by averaging 10 scans in the range of 4000–500 cm^{-1} with a spectral resolution of 2 cm^{-1}. The film thickness used for FT-IR measurements was approximately 0,512 mm.

2.8 Mechanical properties of the film

The mechanical properties of the gelatin-based films were evaluated according to ASTM D882. Tensile tests were performed using a texture analyzer (TA.XTPlus, Stable Micro Systems, Surrey, UK) equipped with a 7.5 kg load cell. Prior to testing, the film samples were equilibrated in a closed desiccator at 45–50% relative humidity (RH) for 48 h. The conditioned films were cut into rectangular strips (50 mm × 10 mm), with an average thickness of approximately 1.0 mm.

The initial grip separation (gauge length) was set to 50 mm, and the samples were stretched at a crosshead speed of 10 mm/min until failure. Tensile strength (TS), elongation at break (EB), and Young's modulus (YM) were obtained from the stress-strain curves. TS was defined as the maximum stress

sustained by the film, while EB was calculated as the percentage elongation at rupture.[24]

The thickness of each film was measured using a digital micrometer (Yu-Su 150, China). Thickness was recorded at five different positions for each sample, and the average value was used for calculations.

2.9 Quantitative determination and release behavior of TH-10 from gelatin-based films

The development of polymeric drug delivery systems is an effective approach for improving the therapeutic performance of low-molecular-weight and natural bioactive compounds by enabling sustained release and reducing fluctuations in drug concentration. In this work, gelatin-based films were designed as carrier matrices to provide controlled release of the plant extract TH-10 as well as the synthetic compound DHQ.

2.9.1 UV–Vis quantification of TH-10

The quantitative determination of TH-10 was performed using UV–Vis spectroscopy. UV–Vis spectra of TH-10 aqueous solutions at different concentrations were recorded using an Agilent Cary 60 spectrophotometer (USA) within the range of 200–800 nm. The maximum absorbance wavelength used for quantification was selected based on the most intense characteristic absorption band in the TH-10 spectrum. Calibration curves were constructed by plotting absorbance versus TH-10 concentration using quartz cuvettes with a 1 cm path length. The selected analytical wavelength for TH-10 determination was $\lambda = 265$ nm.

In addition, absorbance changes in the UV region corresponding to aromatic functional groups (*e.g.,* benzene-ring related transitions) were observed around $\lambda = 234$ nm, confirming the presence of phenolic and aromatic compounds in the Tamarix extract.

2.9.2 Release kinetics of TH-10 and DHQ from gelatin films

To evaluate the capability of the gelatin films to provide a prolonged therapeutic effect, the release behavior of TH-10 and DHQ from the polymer matrix was studied spectrophotometrically using the Agilent Cary 60 instrument. Gelatin composite films containing 12 wt.% gelatin and loaded with TH-10 and DHQ were prepared by the solvent casting method. The release process was monitored by measuring the UV–Vis absorbance of the release medium at characteristic wavelengths of TH-10 and DHQ.

The obtained quantitative data allow assessment of the interaction between the active compounds and the gelatin matrix and provide insight into the controlled-release potential of the developed film system.

2.10 Statistical analysis

All measurements were performed in triplicate, and the averaged values were expressed as mean ± standard deviation. To assess the significance of differences between mean values, a one-way analysis of variance (ANOVA) was conducted using a statistical software package, followed by Duncan's multiple range test at a significance level of 5%.

3. Results and discussion

3.1 Quantitative determination of the TH-10 release from a polymeric dosage form

The release profiles of TH-10 and DHQ from the gelatin-based composite film (G-TH-DHQ) show a rapid initial stage followed by a plateau, which is characteristic of burst sustained release from hydrated polymer networks. Such behavior is commonly observed in gelatin-based carriers, where the early "burst" is associated with dissolution/desorption of molecules located near the film surface or weakly associated with the polymer, followed by a slower stage governed by diffusion through the swollen network and gradual relaxation/degradation effects.[14,25,26]

In distilled water (Fig. 2), both actives were released intensively within the first 30 min and approached equilibrium by ~180 min, reaching ~59% for TH-10 and ~50% for DHQ. This high cumulative release suggests that a large fraction of the loaded compounds remains physically entrapped or reversibly bound (*e.g.,* via hydrogen bonding) rather than irreversibly immobilized within the gelatin matrix. Similar gelatin film/hydrogel systems have been reported to provide efficient release and to be suitable for wound-relevant applications when the network structure permits sufficient hydration and diffusion.[27,28]

Release in physiological solution (Fig. 3) was consistently higher (~51% TH-10 and ~46% DHQ), indicating that the ionic environment promotes desorption and diffusion. This trend is consistent with the known influence of ionic strength (NaCl) on gelatin structure and intermolecular interactions: salts can screen electrostatic attractions, modify hydrogen-bonding patterns, and alter network organization, thereby affecting swelling, chain mobility, and transport of small molecules. Mechanistically, the higher saline release can be attributed to (i) charge screening of gelatin ionizable groups ($-COO^-/-NH_3^+$), which weakens polymer solute associations, and (ii) competitive ion–polymer interactions that reduce the effective binding of TH-10/DHQ to gelatin, facilitating their displacement into the surrounding medium. The aqueous and physiological release data confirm that G-TH-DHQ films can provide rapid availability of the actives followed by a controlled approach to equilibrium an advantageous profile for wound dressings, where early dosing may help suppress oxidative/inflammatory burden while sustained delivery supports continued local therapeutic action.[29–31]

3.2 pH-dependent swelling and release behavior of gelatin composite films

The swelling and release performance of gelatin-based polymeric carriers is strongly influenced by the pH of the surrounding medium because gelatin contains ionizable functional groups. Changes in pH modify the degree of protonation/deprotonation of these groups, altering polymer-

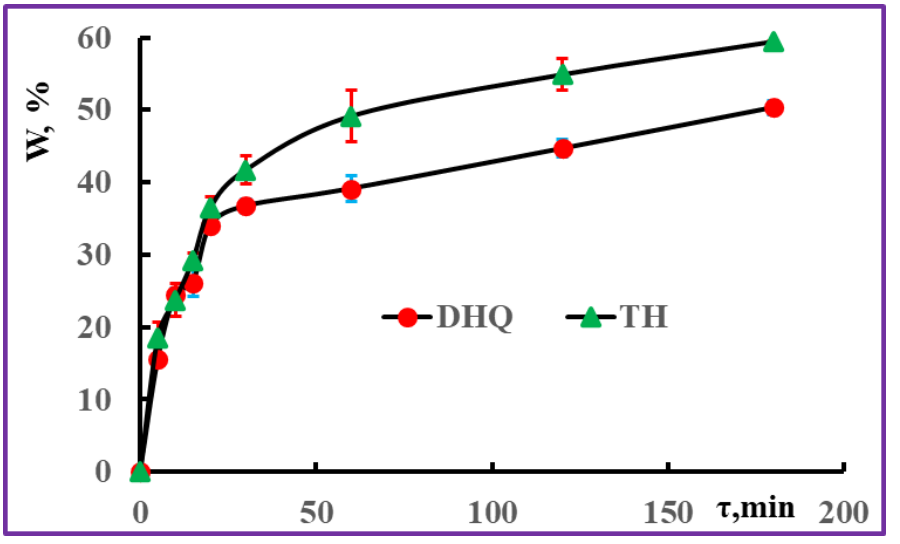


Fig. 2: Kinetics of DHQ and TH-10 release from gelatin into aqueous solution G-TH- DHQ based composite film samples

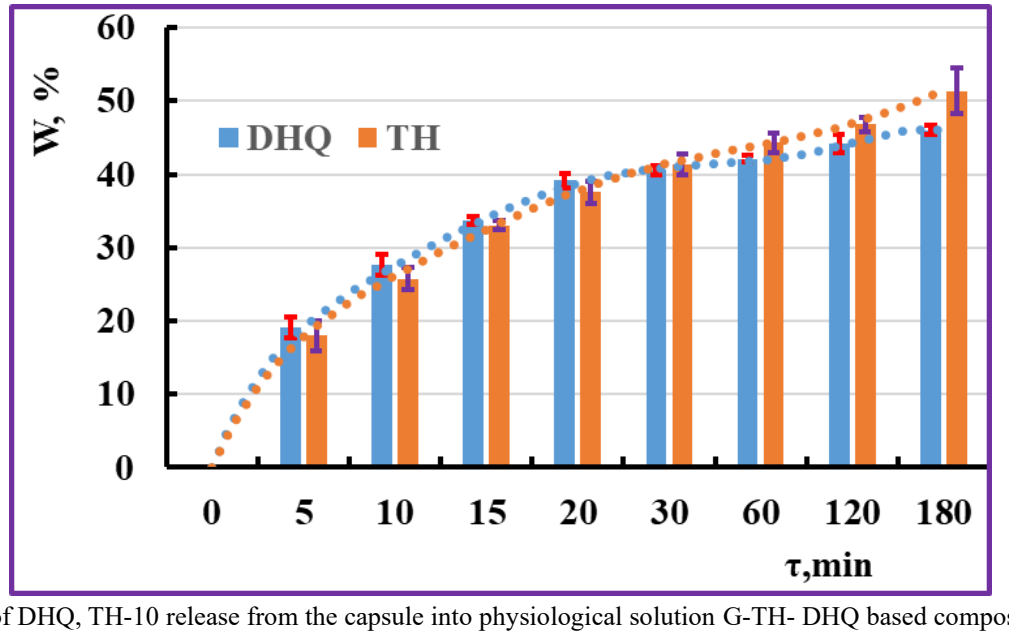


Fig. 3: Kinetics of DHQ, TH-10 release from the capsule into physiological solution G-TH- DHQ based composite film samples

polymer interactions, electrostatic repulsion, hydrogen bonding, and ultimately the porosity and water uptake of the network. As a consequence, swelling and drug diffusion from gelatin matrices typically exhibit a pronounced pH sensitivity, which is a widely reported feature in pH-responsive hydrogels and gelatin-based delivery systems.

As shown in Fig. 4, the swelling behavior of the G-TH-DHQ films exhibited a non-monotonic dependence on pH. The highest swelling values were generally observed at pH 3 and pH 5, whereas the lowest swelling occurred at pH 9. This trend can be explained by the amphoteric nature of gelatin and the presence of an isoelectric point (pI) around pH ≈ 9, at which the net charge of the polymer chains is minimized, resulting in reduced electrostatic repulsion and a more compact network structure with limited water uptake. At pH values away from the pI (pH 3 and pH 5), increased ionization of gelatin functional groups leads to stronger electrostatic repulsion and higher osmotic pressure, promoting network expansion and swelling. Notably, swelling at pH 7 remained relatively lower during the early stage but increased at longer times, indicating slower hydration and polymer relaxation kinetics in alkaline medium.[32–34]

The pH-dependent swelling behavior translated directly into differences in TH-10 and DHQ release (Fig. 5). The films exhibited greater cumulative release under acidic conditions, whereas release was lower in alkaline media. This behavior is expected for diffusion-controlled systems because the diffusion coefficient of solutes in polymeric matrices increases with swelling and with the formation of wider transport pathways. In pH-responsive matrices, swelling therefore becomes a key driver of drug desorption and diffusion kinetics. From a biomedical perspective, pH-responsive performance is particularly relevant for wound care applications. Chronic, infected, or non-healing wounds are often associated with a more alkaline microenvironment, while wound healing progression is accompanied by a shift toward neutral and

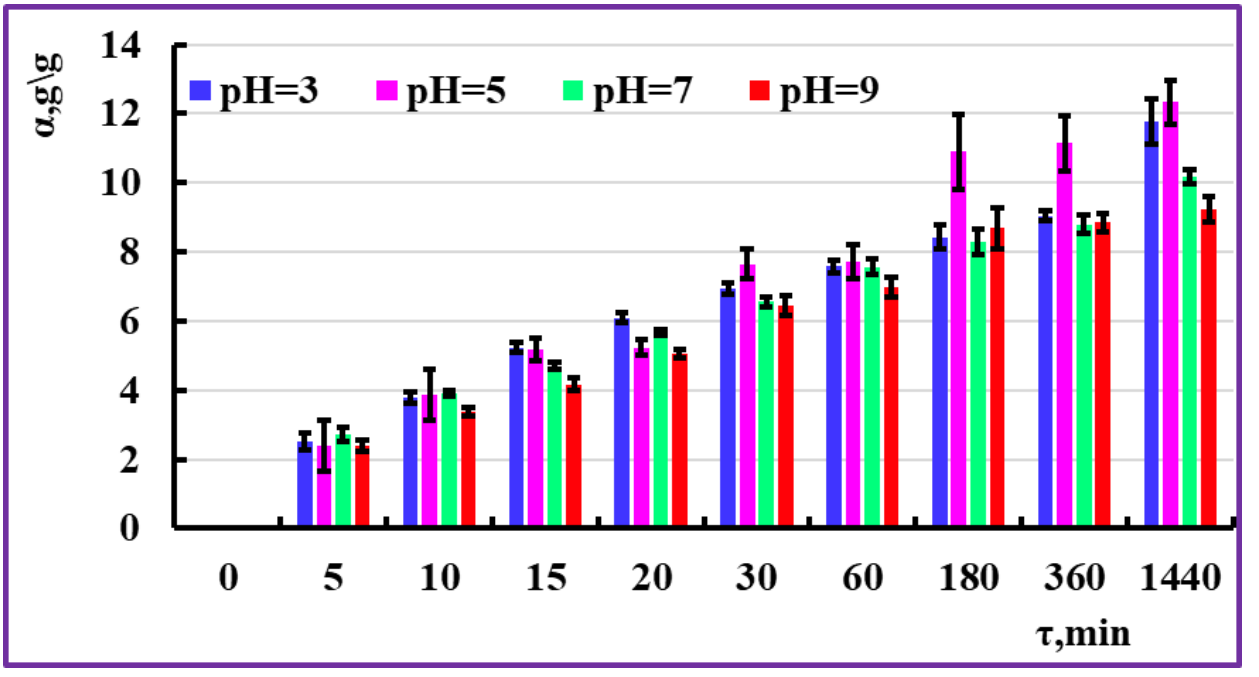


Fig. 4: G-TH- DHQ based composite film samples membrane swelling (1), (2), (3), (4) at different pH values.

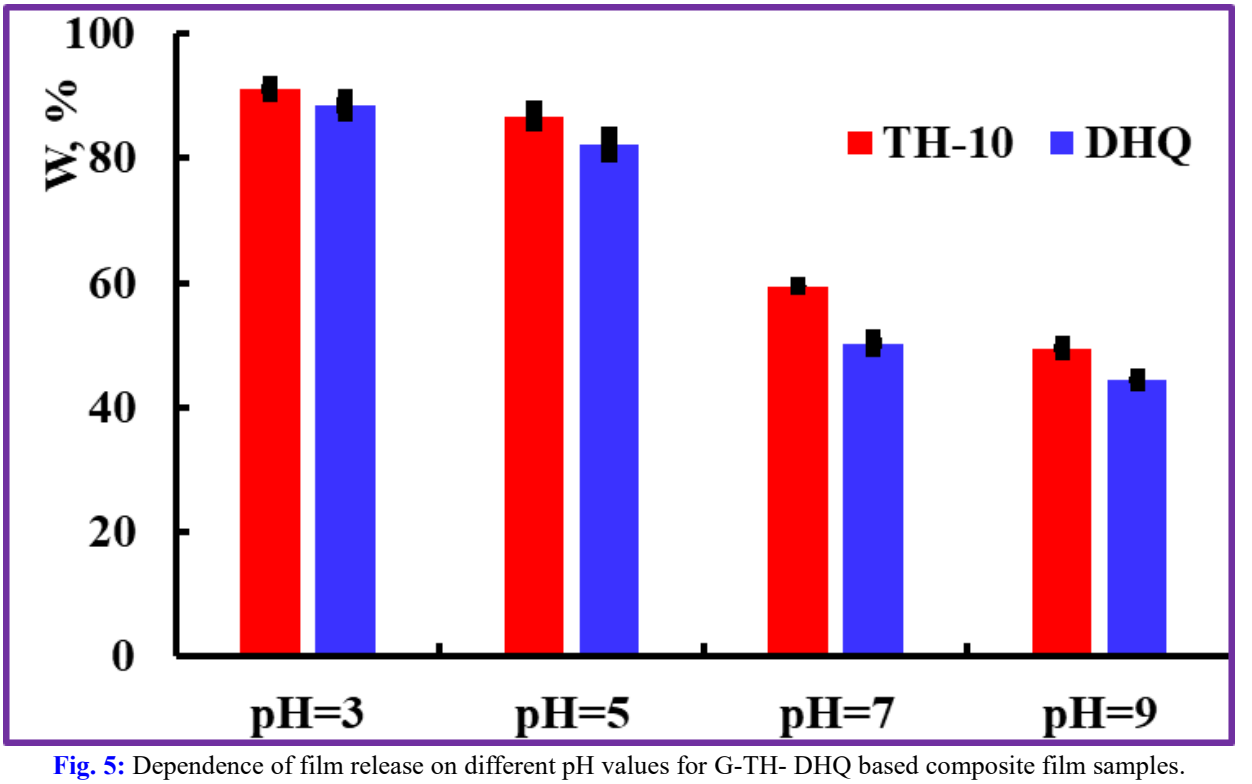


Fig. 5: Dependence of film release on different pH values for G-TH- DHQ based composite film samples.

mildly acidic pH. An alkaline pH can also favor protease activity and biofilm persistence, which are known to impair healing. Therefore, a dressing whose swelling and release behavior is modulated by pH may provide adaptive delivery releasing higher levels of active agents in alkaline conditions and reducing release as the wound environment normalizes during healing.[35–37] These results demonstrate that the developed G-TH-DHQ films possess pH-dependent swelling and release, which supports their suitability as smart multifunctional wound dressing materials capable of responding to wound microenvironment changes.

3.3 Study of the swelling properties of gelatin films in water and physiological solutions

Membranes are hydrophilic systems that absorb water to a certain extent when in contact with it, which leads to the dissolution of biologically active compounds. Water absorption of polymers significantly affects the physical properties of membranes. The moisture absorption properties of membranes depend on the composition and structure of the

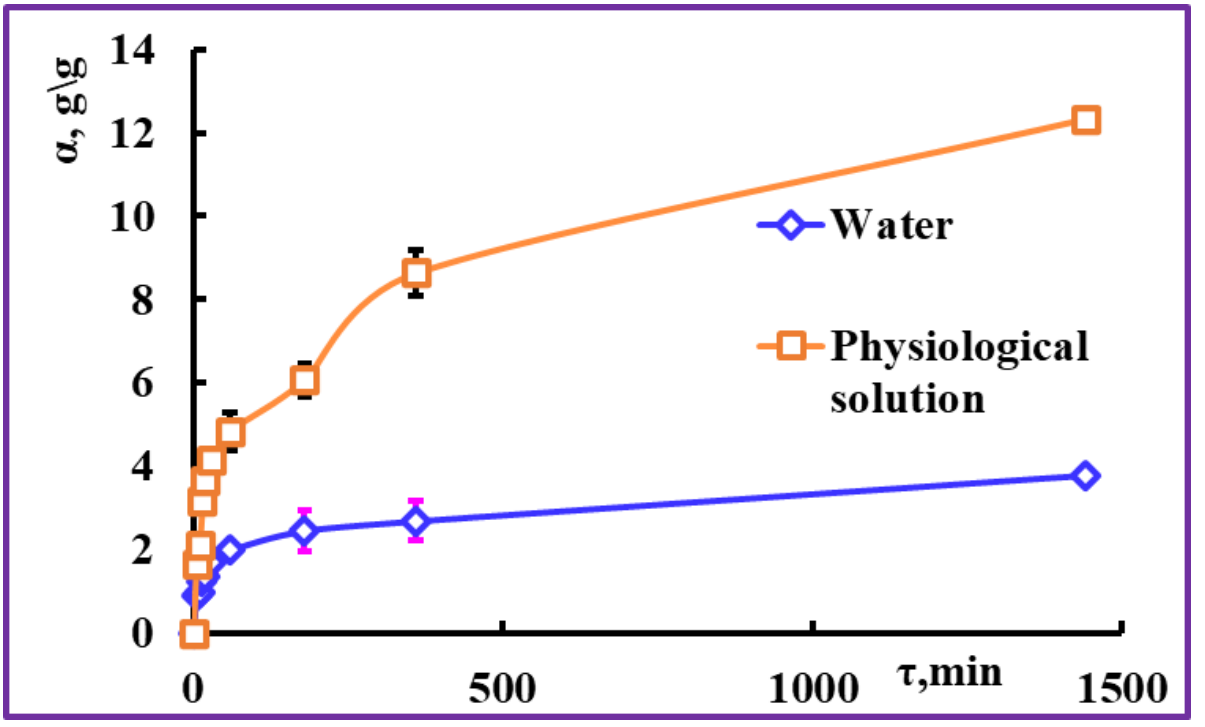


Fig. 6: Kinetics of the pulp swelling in water (1) and physiological solution (2) G-TH- DHQ based composite film samples.

components in them, the water concentration in their composition, and other chemical compounds. Fig. 6 shows the swelling of the membrane in water and in physiological solution (NaCl 0.8% sol.) The swelling was intense for the first 3 hours. The swelling of the polymer membrane in physiological solution is 3-4 times higher than its swelling ability in water. This is explained by the high ionic strength of the NaCl solution. That is, the opening of the polymer macromolecule under the influence of conformational ionic bonds, as well as hydrophilic bonds, can be explained. Whereas, with a decrease in the degree of swelling of the gelatin membrane in water, with the strengthening ofhydrogen bonds, the membrane is compacted and the macromolecule contracts.

3.4 Results of moisture permeability studies

Determination of the moisture permeability of films allows us to assess the moisture resistance of polymeric films used as dressing materials, as well as films with therapeutic properties. In general, the moisture permeability of polymers is the ability of natural and synthetic polymers to pass water vapor when their vapor pressure is reduced. Determination of the polymer films' moisture permeability of allows us to monitor the air passage or moisture to the skin during wound or severe burn injuries. Fig. 7 shows a table of moisture permeability coefficients of polymeric films. In the study of moisture permeability, polymer-based films and polymer films containing DHQ were cut into round shapes and weighed on an analytical balance. Then, we fill the inside of our glass containers with 5 g of calcium chloride, cut them, and fix the cut films with glue. After preparing the glue, we pour 10 ml of water into the desiccator and place our samples inside it. At certain specified times, the sample is removed from the desiccator and weighed on an analytical balance. The results obtained in the study of moisture permeability were stabilized and carried out on the basis of initial weights.

3.5 Mechanical properties of gelatin-based films

The mechanical properties of the prepared films, including tensile strength (TS), elongation at break (EB), and Young's modulus (YM), were determined using a texture analyzer (TA.XTPlus, Stable Micro Systems, UK) according to ASTM D882. The instrument was equipped with a 7.5 kg load cell and operated with two grips (a fixed lower grip and a movable upper grip).

Prior to testing, film specimens were cut into rectangular strips 50 mm × 10 mm. The initial grip separation (gauge length) was set to 30 mm, and the samples were stretched at a crosshead speed of 10 mm/min until failure. Film thickness was measured using a digital micrometer at five different positions, and the mean thickness was used in the calculations. Tensile strength, elongation at break and Young's modulus were determined from the stress–strain curves.

EB was calculated according to Eq. (3):

$$EB(\%) = \frac{L - L_0}{L_0} \times 100 \quad (3)$$

where L is the length at break and L_0 is the initial gauge length.

TS was calculated according to Eq. (4):

$$TS = \frac{F}{S} \quad (4)$$

where F is the maximum force at break (N) and S is the cross-sectional area of the specimen (m^2), calculated as film width × thickness.

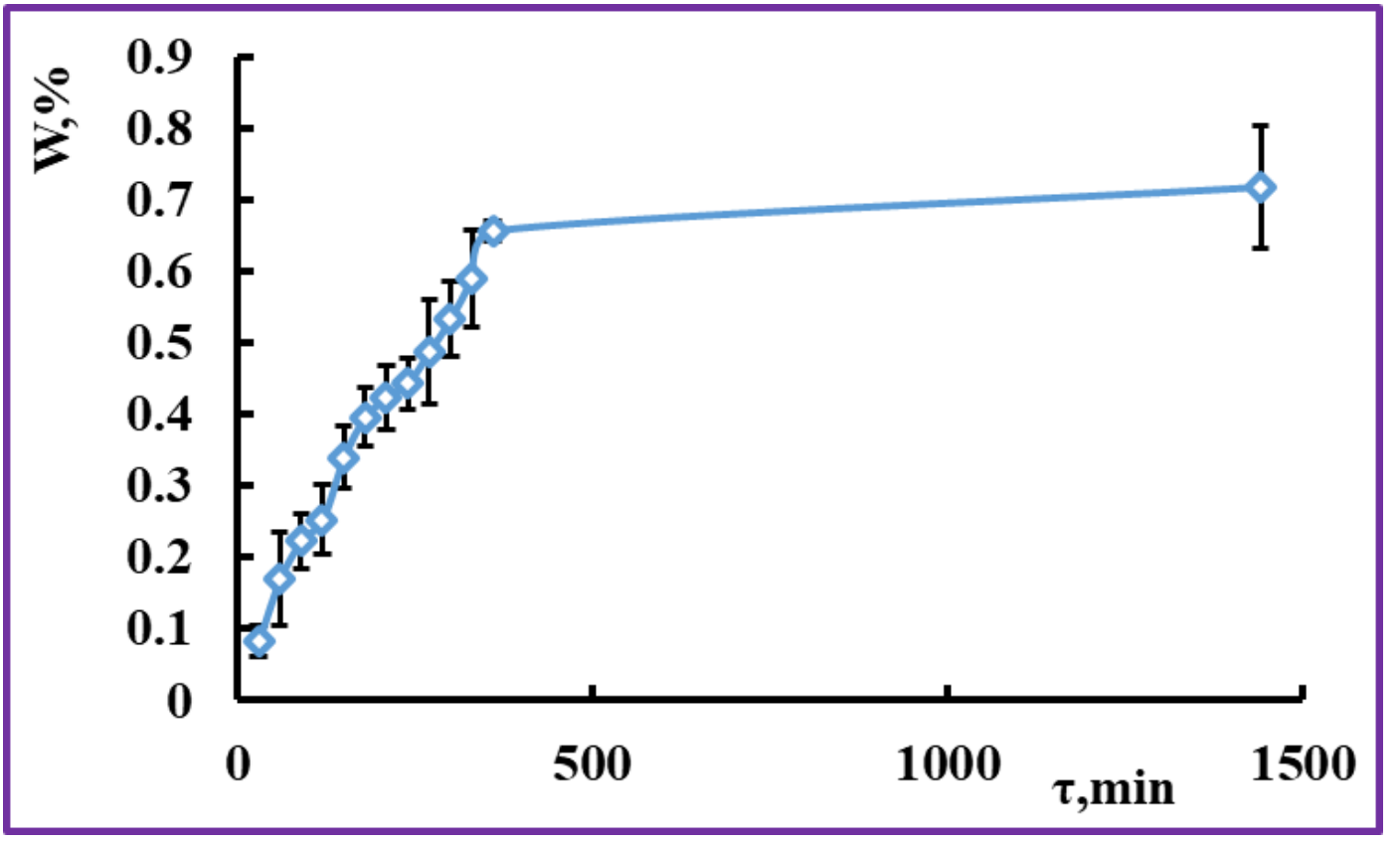


Fig. 7: Changes in moisture permeability coefficients of gelatin-based films with time. Gelatin (12 wt.%), TH-10 1wt.%, DHQ (0.1wt.%).

Table 1: Mechanical parameters of gelatin films.

Film composition	EB Elongation at break(%)	Tensile Strength, TS (MPa)	Young's modulus, YM (MPa)	Thickness (mm)
GF	70.55±1.77	3.10±0.22	4.39±0.40	0.50±0.03
G-TH-DHQ	34.76±4.35	4.62±0.12	13.46±1.80	0.51±0.04

Note: Mean ± standard deviation (n = 3) ($p < 0.05$).

Young's modulus (YM) was calculated according to Eq. (5) obtained from the slope of the initial linear (elastic) region of the stress–strain curve:

$$YM = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (5)$$

The mechanical parameters of the gelatin film (GF) and the composite film containing TH-10 and DHQ (G-TH-DHQ) are summarized in Table 1. Results are reported as mean ± standard deviation (n = 3). Statistical differences were considered significant at $p < 0.05$.

The G-TH-DHQ film exhibited higher tensile strength thanthe control gelatin film, while EB decreased, indicating the formation of a more rigid polymer network. This behavior can be attributed to enhanced intermolecular interactions between gelatin and the incorporated compounds (TH-10 and DHQ), including hydrogen bonding, which may increase cohesion of the matrix and limit chain mobility. In addition, glycerol (5 wt.%) acted as a plasticizer improving film flexibility by reducing brittleness and enhancing elongation during deformation.

3.6 Fourier transform infrared spectroscopy (FT-IR)

The absorption bands of the FT-IR spectra of the films (Fig. 8) showed a very intense intensity in the region of 3,292 cm^{-1}. This can be explained by the simultaneous displacement of the bonds in the -COOH and -NH_2 -amino groups in the polymer by O-H and N-H. As evidence, there was no intense activity beyond the 1634 cm^{-1} region. That is, the formation of displaced C-H bonds is observed at this time, as can be seen from the appearance of a shoulder-shaped absorption pattern. Hydroxo and imine groups lead to the simultaneous formation of charged ions and complexes with the following drug substance. In addition, all the characteristic bands of the functional groups in the film were observed: 3,292 (phenyl-OH), 2,930 (alkane C−H), and 1,634 cm^{-1} (ketone C=O). The C=O stretching (amide I) peak was observed at 1634 cm^{-1} and the N-H bending (amide II) peak at 1523 cm^{-1} and 1,240 cm^{-1}, respectively. In addition, the FT-IR spectrum of the C–H stretching region at 2930 cm^{-1} may be shifted by the asymmetric position of CH_2. A broad band was observed in the region of 2930–3292 cm^{-1}, which may be related to free −NH groups, hydroxyl groups, and weak hydrogen bonds between the components of the film.[1]

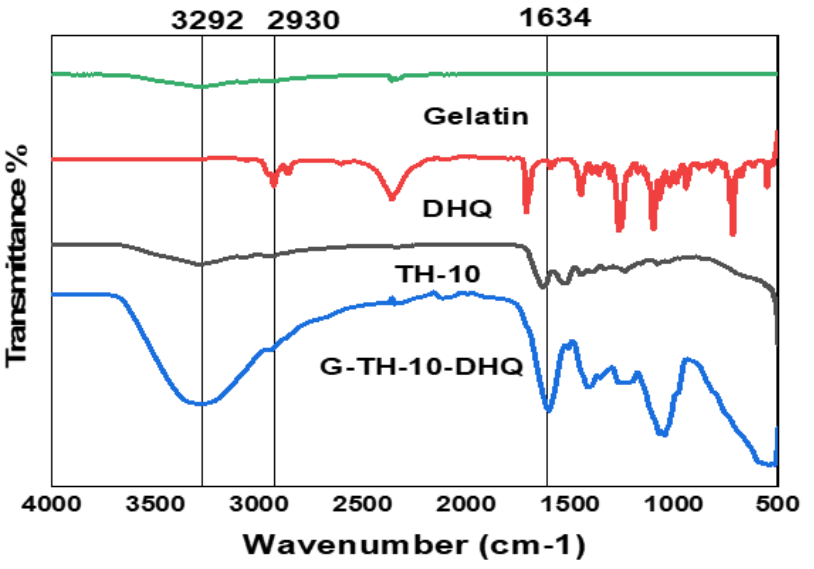


Fig. 8: FT-IR analysis of G-TH- DHQ based composite film samples.

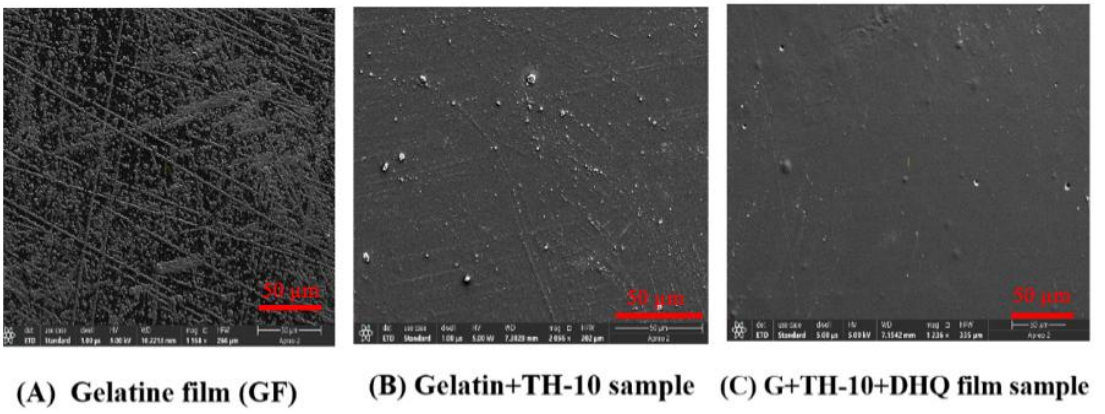


Fig. 9: SEM images of gelatin film (A) GF, (B) G+TH-10, (C) G+TH-10+DHQ based composite film samples.

3.7 SEM results

Gelatin films with extracts of *Tamarix Hispida* and DHQ were examined by scanning electron microscopy (SEM) using the APREO 2 THERMO SCIENTIFIC the film morphology. Fig. 9 shows characteristic SEM micrographs of the films' surface show that the outer layer of the control film was gelatin, uniform, ordered and in homogeneous structure without bubbles or pores Fig. 9A. This is due to a phase separation, because the gelatin has a hydrophilic and a hydrophobic nature, respectively.[38]

SEM analysis showed that the gelatin films containing the TH-10 plant extract had a modified structure with visible inhomogeneities and micro/nano-particle formation caused by the rapid evaporation of hydrophobic components Fig. 9B Similar structural disruptions have been reported in other biopolymer films enriched with hydrophobic extracts, such as propolis-based chitosan films described by *Pastor et al.*[39] and *Stefanowska et al.*[40]

And in the picture Fig. 9C it is observed that the micro dispersed particles are reduced in size, compacted and flattened in the film based on the TH-10 plant extract and the synthetic drug DHQ complex. The particles became smaller, more compact, and more uniformly distributed, indicating stronger interactions within the polymer matrix. This agrees with findings by *Kowalczyk et al.*[41] who reported that adding hydrophobic bioactive compounds to gelatin films can increase compactness and reduce surface roughness. SEM analysis revealed good intermolecular interactions between the polymers and G-TH-DHQ, resulting in a uniform, homogeneous, and compact structure suitable for medical film applications.

4. Conclusion

In this study, gelatin-based composite films containing *Tamarix hispida* (TH-10) extract and 1-amyl-2-methyl-4-benzoxy decahydroquinoline hydrochloride (DHQ) were successfully fabricated using solvent casting. The films exhibited uniform and defect-free morphology as confirmed by SEM, while FT-IR analysis revealed hydrogen-bond interactions between gelatin, TH-10, and DHQ, indicating a stable composite structure. The mechanical properties of the films, including a tensile strength of 4,62 ± 0,12 MPa and elongation at break of 34,76± 4,35%, demonstrated their flexibility and robustness for potential wound dressing

applications. Swelling, moisture permeability, and drug-release studies showed controlled release of TH-10 (59 wt.%) and DHQ (50 wt.%), highlighting their suitability as drug carriers. Overall, the incorporation of natural and synthetic bioactive compounds enhanced the antioxidant, anti-inflammatory, and anesthetic properties of the films. These results suggest that TH-10 and DHQ-loaded gelatin films have promising potential as multifunctional wound dressings for biomedical applications.

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Conflict of Interest

The authors declare that they have no conflicts of interest. The authors are solely responsible for the content of this manuscript.

Supporting Information

Not applicable.

CRediT Statement

G. G. Abdikarim: Writing – Original draft, Investigation, Formal analysis, Data curation. **Sh. N. Zhumagaliyeva:** Supervision, Conceptualization, Validation. **Zh. A. Abylov:** Supervision, Conceptualization, Resources. **Joachim Koetz:** Supervision, Resources. **M. I. Choudhary:** Supervision, Resources. **M. Zh. Turmukhanova:** Resources. **N. P. Altynbay:** Technical support.

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