Indonesian Journal of Science & Technology

Journal homepage: http://ejournal.upi.edu/index.php/ijost/

# Comprehensive Characterization of Gelatin Films from Goat Skin Incorporating Konjac Glucomannan: Physical, Mechanical, and Molecular Properties

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## ABSTRACT

This study aimed to comprehensively investigate and characterize the physical, mechanical, and molecular properties of gelatin films made from goat skin incorporated with konjac glucomannan. The study involved three treatment groups, labeled GG/KG1, GG/KG2, and GG/KG3, which included konjac glucomannan at concentrations of 0, 10, and 20% (w/w), respectively. Glycerol at 20% (w/w) was also included as a plasticizer. All samples underwent homogenization and ultrasonic treatment. The addition of konjac glucomannan to the gelatin-based film resulted in changes such as increased thickness (0.033 - 0.093 mm), opacity (0.9910 - 1.0433 mm-1), color L* (92.45 - 92.77), color difference (48.13 - 48.38), swelling (65.53 - 69.47%), and contact angle (86.92 - 127.85o). Conversely, a decrease was observed in water activity (0.521 - 0.463 Aw), moisture content (9.87 - 9.62%), tensile strength (0.0171 - 0.0118 N/mm2), elongation at break (5.91 - 4.52%), young's modulus (0.0029 - 0.0026 N/mm$^2$), WVTR (118.99 - 116.82 g/m$^2$. day), transparency (81.59 - 67.33%), and water resistance (34.47 - 30.53 %). Additionally, the peaks of amides A, B, I, II, and III exhibit both a shift and an increase in intensity, suggesting structural modifications and molecular interactions. The microstructure also indicated the presence of goat skin gelatin and konjac glucomannan cross-linked in the film formation. Therefore, the addition of konjac glucomannan modifies gelatin-based films, enhancing their suitability for food packaging.



## ARTICLE INFO

***Article History:***
*Submitted/Received 06 Jul 2024*
*First Revised 29 Aug 2024*
*Accepted 06 Oct 2024*
*First Available Online 07 Oct 2024*
*Publication Date 01 Dec 2024*

***Keyword:***
*Film,*
*Gelatin,*
*Goat skin,*
*Mechanical properties,*
*Molecular properties,*
*Physical properties.*

## 1. INTRODUCTION

In the food industry, there is a growing demand for the development of innovative and environmentally friendly packaging materials that enhance the appeal of the product. An interesting approach involves using films or thin layers as packaging materials for food products. The films can be produced from various natural materials, such as proteins, polysaccharides, lipids, or their combinations. They help protect food from contamination, damage, and nutrient loss while also enhancing taste, color, and aroma (Chhikara & Kumar, 2021). One important benefit of protein films is their ability to diminish the reliance on environmentally detrimental plastic packaging. An emerging concern in this area involves the quest for suitable compositions and natural sources of film materials that align with the packaged product's specific traits, are readily accessible, have reasonable production costs, and align with consumer preferences (Azeredo *et al*., 2022; Gaspar & Braga, 2023; Kumar *et al*., 2022; Luo *et al*., 2022; Rather *et al*., 2022). This quest highlights the importance of finding sustainable and practical solutions for packaging materials that are both functional and eco-friendly.

Gelatin derived from goat skin is an excellent natural material for creating films. This hydrocolloid is produced through the partial hydrolysis of animal collagen and has been utilized in numerous food and pharmaceutical applications for many years (Luo *et al*., 2022). Goat skin gelatin has excellent functional properties, including gel strength, viscosity, texture, and film-forming ability. It is also biodegradable and biocompatible, making it easy to transform into an edible, environmentally friendly, safe film for consumption. Gelatin serves as a prevalent raw material in film production; however, it exhibits limitations, including inadequate water vapor barrier properties and susceptibility to moisture (Ulfariati *et al*., 2023). These constraints prevent it from being suitable as both a film and a biomaterial. To enhance the properties of gelatin films, the incorporation of additional materials becomes essential (Rather *et al*., 2022; Said *et al*., 2023; Tyuftin & Kerry, 2021).

One effective approach to address the limitations of gelatin is to add other materials. Konjac glucomannan (KG) is a great choice, as it is a natural polysaccharide derived from the tuber of the konjac plant (*Amorphophallus* sp.) (Zhou *et al*., 2022). KG has attributes such as thickening, gel formation, and high water-binding capacity, which can improve the quality and functionality of films (Yan *et al*., 2020). Additionally, it acts as a prebiotic, supporting intestinal health (Sun *et al*., 2023a). The effect of adding KG without plasticizer to gelatin films was investigated by (Xiao *et al*., 2000), who found that it increased the tensile strength and elongation of the films but reduced swelling and moisture uptake as the KG content increased. Li *et al*. (2006) reported that adding KG and glycerin (0.01% w/w) to the gelatin films decreased their water vapor transmission rate and optical transmittance but increased their tensile strength. The solubility of the films was high (99.33% to 99.7%), and they dissolved in less than 30 seconds, regardless of the KG content. However, these studies did not achieve optimal elasticity, compatibility, and smooth structure of the films, which we improved in this study by using homogenization and ultrasound techniques, dried at low temperature and humidity, resulting in improved film elasticity, compatibility, and optical transmittance. Therefore, this study aims to create a gelatin film made from goat skin, incorporating konjac glucomannan at varying concentrations. The resulting films were also investigated and characterized for quality enhancements and properties.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

## 2. METHODS

### 2.1. Materials

Goat skin (*Capra aegagrus hircus*) was obtained from Minburi District, Bangkok, Thailand. Konjac glucomannan was purchased from Chemirich (Thailand). Analytical-grade chemicals, including NaOH, HCl, acetic acid, and glycerol, were obtained from Sigma-Aldrich, located in St. Louis, MO, USA.

### 2.2. Preparation of Gelatin from Goat Skin

Gelatin was prepared from goat skin according to the method described by Hasdar *et al*. (2024a) with some modifications. Goat skin was pretreated with NaOH (0.5 M) to remove hair and fat and then neutralized with tap water until the pH of the skin was maintained. The pretreated skin was treated with acetic acid (0.5 M) for 24 h and neutralized again. Subsequently, the swollen skin was subjected to ultrasound treatment (model VC 750, Sonic and Materials INC, USA) at an amplitude of 80% for 2 h before extraction (ratio of 1:10 for skin sample: distilled water) in a water bath (Model WNB 14, Memmert, Germany) at 60 °C for 24 h. The gelatin extract was first frozen in the freezer. After it hardened, it was then placed in the freeze-dryer (DK-3450 Lynge, Labogene ApS, Denmark). The resultant freeze-dried gelatin from goat skin was in the form of foam, which had a Bloom value of 226 and a pH of 7.0 ± 0.1. For long-term use, goat skin gelatin was stored in the freezer to maintain its quality.

### 2.3. Preparation of Film Forming

Treatments were divided into three groups: GG/KG1, GG/KG2, and GG/KG3. Each group contained konjac glucomannan at 0%, 10%, and 20% (w/w), respectively. A film-forming and casting process followed method of Qiao *et al*. (2020), with minor adjustments. To prepare the film-forming solution, 2 g of goat skin gelatin was dissolved in 50 mL of distilled water using a magnetic stirrer (Model: C-MAG HS 7, IKA-Werke GmbH and Co. KG, Germany) at 50°C for 10 min. Glucomannan was then gradually added along with 20% glycerol (w/w) and the volume was adjusted to 100 mL using distilled water. The mixture was stirred for 15 min until all the materials were dissolved. Then, it was further processed with a homogenizer (Model AM200S-P, China) at 10,000 rpm for 1 min to create a perfect hydrogel solution. Next, the film solution was placed in a 40 kHz ultrasonicator (Model: WUC-A02H, DAIHAN-brand Digital Ultrasonic Cleaner Set, Korea) for 10 min to remove any bubbles that formed during stirring. Subsequently, a 50 mL aliquot of the film solution was poured into a mold (20 cm × 20 cm square) and dried in a humidity chamber (Binder World, Model FD023UL-120V, Binder GmbH, Germany) at 25 $^{o}$C and 45% RH for 24 h. The schematic of the film preparation process is shown in **Figure 1**.

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p- ISSN 2528-1410 e- ISSN 2527-8045

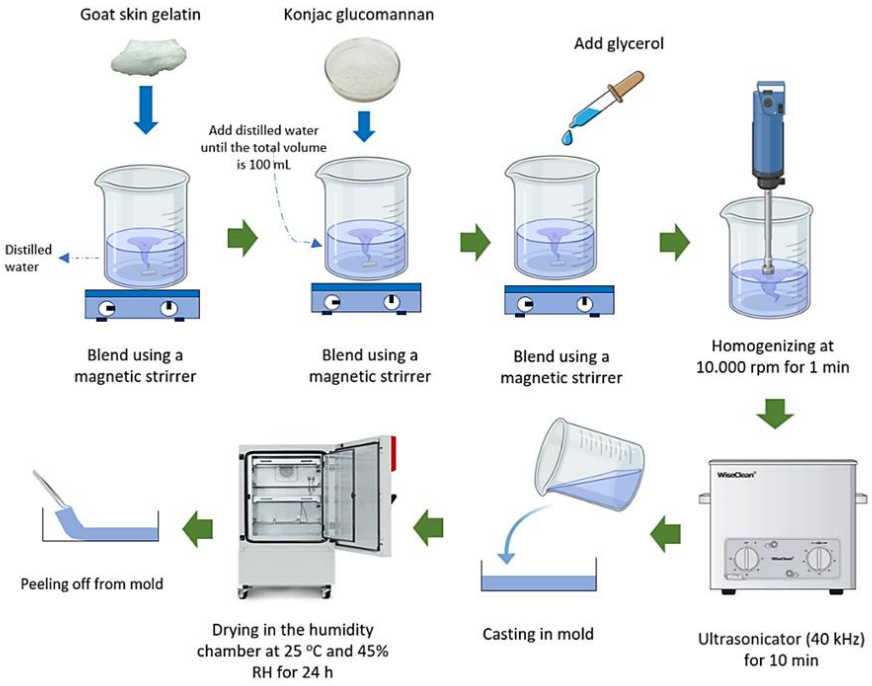


**Figure 1**. Schematic process of Gelatin film from goat skin incorporated with konjac glucomannan.

### 2.4. Characterization of Gelatin Film

#### 2.4.1. Thickness

The film thickness was determined using a micrometer screw (Mitutoyo CO, Japan) with a precision of 0.001 mm, following the procedure outlined by Hasdar *et al.* (2024b). Measurements were taken at five different points on the film, covering the four corners and the center point. The average thickness was calculated based on the measurements from each point.

#### 2.4.2. Water Activity and Moisture Content

Water activity and moisture content were measured following the method of Hasdar *et al.* (2024b). Water activity (Aw) was determined using an AquaLab 4TEV (Decagon Devices Inc., Washington, DC, USA), with samples cut into 2 × 2 cm squares for analysis. To measure moisture content, 3 g of the film samples were dried in a hot air oven (Model BINDER™ 9010-0303, Binder GmbH, Germany) at 105°C for 24 h until a constant weight was achieved.

#### 2.4.3. Tensile Strength and Elongation

The tensile strength and elongation of the film were determined according to the procedure based on Sun *et al.* (2020) using a texture analyzer (TA.XT2i, M/s Stable Micro System, Surrey, UK) calibrated at 1.00 kg. An A/TG tensile grip was used as the probe. The samples were cut to dimensions of 25 mm × 110 mm. The initial distance was set at 70 mm, with a test speed of 1.5 mm/s. The tensile strength and elongation are explained in Equations [1] and [2], respectively.

$$\text{Tensile strength (MPa)} = \frac{F}{A} \quad (1)$$

where $F$ is the force (N) and $A$ is the sample area ($cm^2$).

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

$$\text{Elongation}(\%) = \frac{\Delta l}{l} \quad (2)$$

where *Δl* is the length extended at the breakpoint of the sample and l is the initial length of the sample.

### 2.4.4. Water Vapor Transmission Rate (WVTR)

WVTR was measured with slight modifications. Silica gel (2 g) was placed in a dish (30 mL), covered with the sample at the edges of the dish, and secured using rubber bands. The dish was then placed in a desiccator containing a 40% NaCl solution at 25°C. The plate and sample were weighed every day for six days, and the weight change was calculated using a linear equation. The WVTR value was determined using Equation [3]:

$$\text{WVTR} = \frac{\Delta W}{t} \times A \quad (3)$$

where *ΔW* is the change in film weight after 24 h (g), *t* is the time (24 h), and *A* is the surface area ($cm^2$).

### 2.4.5. Color

The color parameters measured included L* (lightness), a* (redness), b* (yellowness), and color difference (ΔE) using the Chroma Meter CR-400/410 (Konica Minolta, Japan). The instrument was calibrated with a white background as the standard before use. The film's color was assessed according to the method of Hasdar *et al*. (2024b).

### 2.4.6. Opacity, Transparency, and Light Transmission

The transparency and opacity of the films were measured using the method described by Zhao *et al*. (2022). The film was cut into rectangles (0.5 cm × 1.5 cm) and then moved to a quartz cell for absorbance measurement with a spectrophotometer (Shimadzu UV-1800, Japan). The calculations of opacity, transparency, and light transmission of the film were based on equations [4], [5], and [6], respectively.

$$\text{Opacity} = \frac{A_{600nm}}{x} \quad (4)$$

where $A_{600}$ is the absorbance of light at 600 nm, and *x* is the thickness (mm) of the film.

$$\text{Transparency} = \%\,T = 10^{(2-A)} \quad (5)$$

here, *%T* is the percent transmittance of light, and *A* is the absorbance of light.

$$\text{Light transmission} = A_{300\text{-}800nm} \quad (6)$$

where $A_{300\text{-}800nm}$ is the absorbance of light at 300-800 nm

### 2.4.7. Swelling and Water Resistance

The swelling and water resistance were determined according to the method of Lee *et al.* (2020). The film was cut into 2 × 2 cm squares. The sample and filter paper were dried at 105°C for 24 h. They were then weighed separately to determine the initial weight of the sample (W1). Each sample was placed in a test tube with 10 mL of distilled water and soaked for 24 h. After soaking, the solution was filtered, and the undissolved filter paper and film

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p- ISSN 2528-1410 e- ISSN 2527-8045

were dried in an oven at 105°C for 24 h. The sample was then weighed (*W2*) to assess the dry matter's water insolubility. The percentages of swelling and water resistance were calculated using Equations [7] and [8], respectively.

$$\text{Swelling (\%)} = \frac{W1 - W2}{W1} \times 100 \quad (8)$$

$$\text{Water resistance (\%)} = 100\% - \frac{W1-W2}{W1} \times 100 \quad (9)$$

### 2.4.8. Contact Angle

The contact angle was determined following the method of Lan *et al.* (2020). The static drop method was used to measure the contact angle of deionized water using Theta Flex (Biolin Technology Co., Ltd., Gothenburg, Sweden) at 25°C by recording the side profiles of 10 µL drops on the film surface. The measurement was taken 1 s after drop deposition to ensure stabilization and to minimize absorption and evaporation.

### 2.4.9. Fourier Transform Infrared (FTIR) Spectroscopy

FTIR was measured using the method of Sharmin *et al.* (2022). FTIR spectra were performed using a Bruker INVENIO® Spectrometer (Bruker Optics, Germany), with data controlled by OPUS v8.5 software. FTIR spectra were collected in transmission mode in the wavenumber range of 4000-500 $cm^{-1}$ with a resolution of 4 $cm^{-1}$. The signals were auto-collected in 32 scans and normalized against background spectra recorded from clean blank cells at 25°C. The transmitted data were then converted to absorbance and analyzed by region and peak wavenumber using OriginPro®2023 software.

### 2.4.10. Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS)

SEM and EDS were used by Liu *et al.* (2022) to examine the surface and cross-sectional morphologies, as well as the chemical compositions of the films. Scanning electron microscopy (SEM) images were captured using a Quanta FEG 250 scanning electron microscope (FEI, USA) with an accelerating voltage of 15 kV. The films were intentionally fractured in liquid nitrogen to examine the fracture surfaces and affixed to an aluminum stub using conductive tape. The elemental composition and mapping of the films were determined using INCA Energy 250 X-Max 50 energy-dispersive X-ray spectroscopy (Oxford Instruments, UK).

### 2.4.11. Statistical Analysis

The analysis was performed three times to ensure data collection. The findings were averaged using the deviations. Data were assessed using one-way ANOVA in SPSS Version 26, and Duncan's test was used to identify any variances ($P<0.05$) among the treatment groups.

## 3. RESULTS AND DISCUSSION

### 3.1. Thickness

The thicknesses of the films used in this study are listed in **Table** 1. The results showed that the addition of KG increased the thickness from 0.033 to 0.093 mm ($P < 0.05$). When konjac glucomannan and gelatin were mixed in solution, the interaction between the glucomannan and gelatin chains formed a network structure. This interaction was caused by the hydroxyl

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groups (–OH) on glucomannan and the amino groups ($–NH_2$) on gelatin forming hydrogen bonds. These hydrogen bonds increased the viscosity of the solution and formed a denser network (Qiao *et al*., 2020). The thickness of films affects their physical, mechanical, and barrier properties, which in turn affect their quality and function (Das *et al*., 2022). The thickening of the film due to the addition of KG was attributed to the hydrogen bonds formed between the goat skin gelatin chains and konjac glucomannan chains, which increased the density and thickness of the network structure (Leuangsukrerk *et al*., 2014; Xiao *et al*., 2001).

**Table 1.** Thickness, water activity, and moisture content of gelatin films.

| Gelatin films | Thickness (mm) | Water activity (Aw) | Moisture content (%) |
|---|---|---|---|
| GG/KG1 | $0.033 \pm 0.001^a$ | $0.521 \pm 0.001^a$ | $9.87 \pm 0.19^a$ |
| GG/KG2 | $0.060 \pm 0.000^b$ | $0.481 \pm 0.001^b$ | $9.63 \pm 0.40^a$ |
| GG/KG3 | $0.093 \pm 0.000^c$ | $0.463 \pm 0.001^c$ | $9.62 \pm 0.38^a$ |

Distinct superscript letters in the same column signify a significant difference (P<0.05)

### 3.2. Water Activity and Moisture Content

Based on the results in **Table 1**, the gelatin film without konjac glucomannan (GG/KG1) has the highest water activity (Aw) (0.521). This indicates that the film contains a significant amount of free water, facilitating microbial growth and degradation reactions. On the contrary, gelatin films containing 10% (GG/KG2) and 20% (GG/KG3) konjac glucomannan have lower Aw values of 0.481 and 0.463, respectively. This suggests that these films are more stable and durable. The Aw indicates the ability of the gelatin films to maintain the moisture of packaged products. According to Chhikara & Kumar (2021); Jimenez *et al*., (2012), a low water activity value suggests that films possess strong barrier properties against water vapor, whereas a high-water activity value indicates that water vapor can easily penetrate the films. KG has a molecular structure full of hydroxyl groups. These groups can form hydrogen bonds with water and hold it in place in the gel or matrix structure (Zhou *et al*., 2022). This gel structure reduces the availability of free water in the film, which can easily move and diffuse (Azeredo *et al*., 2022). Moreover, KG can interact with goat skin gelatin, the main component of the film, through hydrogen and covalent bonds. These interactions form a denser and more homogeneous network, effectively decreasing the space for free water in the film (Qiao *et al*., 2020). Although the added concentrations of konjac glucomannan differ, there is no significant difference between GG/KG2 and GG/KG3 in Aw values ($P > 0.05$). This may be an effect of higher concentrations of KG (20%), its water absorption capacity reaches saturation, and further additions do not significantly affect Aw. Therefore, the addition of KG at both concentrations has the same effect on the Aw of the film. This occurs because the physicochemical properties of KG molecules modify the structure of the goat skin gelatin film (Huang *et al*., 2022).

Films with low moisture content are effective in preventing moisture loss or absorption in food products, thereby inhibiting the growth of microorganisms that can cause spoilage or damage. Additionally, low moisture content enhances the film's mechanical properties, including tensile strength, elongation, and elastic modulus, contributing to its overall durability and performance (Lei *et al*., 2019). As per the results in **Table 1**, the moisture content of the film in this study varies from 9.62 to 9.87%, which shows a slight decrease with the addition of GK to films based on goat skin gelatin but not significantly ($P > 0.05$). When konjac glucomannan was added to a film made from goat skin gelatin, it did not significantly affect the water content in any treatments. This is because konjac glucomannan is highly hydrophilic, meaning it can effectively absorb and retain water within its matrix structure

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

(Leuangsukrerk *et al*., 2014). Goat skin gelatin also has hydrophilic properties that can form hydrogen bonds with water and increase the moisture content of films (Luo *et al*., 2022). Therefore, incorporating KG does not notably alter the water content in goat skin gelatin films, as both components are already capable of retaining water within the film's structure.

### 3.3. Tensile Strength, Elongation at Break, and Young's Modulus

As shown in **Table 2**, the gelatin film without konjac glucomannan (GG/KG1) exhibited the highest tensile strength at 0.0171 N/mm², which was significantly different from that of the other treatments ($P < 0.05$). Gelatin films containing 10% (GG/KG2) and 20% (GG/KG3) konjac glucomannan exhibited reduced tensile strengths of 0.0134 N/mm² and 0.0118 N/mm², respectively, with no significant difference ($P < 0.05$) between them. When konjac glucomannan is added to films made from goat skin gelatin, it reduces the interaction between the gelatin molecules by filling the spaces between them. Consequently, the strength and elasticity of the film decreased, leading to lower tensile strength values. Furthermore, the higher the concentration of konjac glucomannan, the more space it occupies, resulting in fewer interactions between the goat skin gelatin molecules and further decreasing the tensile strength of the film (de Vargas *et al*., 2022). The maximum force that a film can withstand before fracturing when pulled in the opposite direction is called tensile strength. Tensile strength indicates the film's ability to withstand mechanical damage. Consequently, a higher tensile strength indicates greater durability (Bourtoom, 2008). However, the difference between the GG/KG2 and GG/KG3 groups was not statistically significant ($P < 0.05$). The addition of konjac glucomannan to gelatin films can reduce their tensile strength. This reduction occurs because the molecular interactions between gelatin, a protein, and konjac glucomannan, a polysaccharide, can disrupt the protein network that typically provides strength to the gelatin film. Furthermore, the chemical and physical differences between gelatin and glucomannan tend to create phase separation within the film matrix, leading to uneven stress distribution when the film is stretched, thereby lowering its tensile strength. The incorporation of glucomannan may also decrease the compactness of the gelatin film structure, as glucomannan can absorb water and form a gel, increasing the film's moisture content and weakening its mechanical strength. Additionally, the high hydrophilicity of glucomannan leads to increased water content in the film, making it softer and less resistant to tension (Li *et al*., 2006b).

Elongation at break denotes the percentage increase in a film's length before it fractures when subjected to opposing forces. This parameter indicates the film's flexibility under mechanical stress. A higher elongation at the break value implies enhanced flexibility of the film (Sanyang *et al*., 2015). The elongations at the break for the prepared gelatin films are presented in **Table 2**. When konjac glucomannan is added to films made from goat skin gelatin, the elongation at break (%) decreases because it changes the structure and mechanical properties of the film. In GG/KG1, which does not contain konjac glucomannan, the high break value (5.91%) indicates that the goat skin gelatin film can stretch well before breaking. However, in GG/KG2 (with 10% konjac glucomannan) and GG/KG3 (with 20% konjac glucomannan), there is a significant decrease in elongation at break values (4.60 and 4.52%, respectively). The addition of konjac glucomannan causes structural changes in the film, making it less flexible and more rigid (Huang *et al*., 2015). There may be molecular interactions between konjac glucomannan and goat skin gelatin, such as the formation of hydrogen bonds, which could make it harder for film molecules to move around (Xiao *et al*., 2001). This could make them less able to stretch, lowering the elongation at break. Although different amounts of konjac glucomannan were added, there was no significant difference

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

between GG/KG2 and GG/KG3. This indicates that increasing the amount of konjac glucomannan does not significantly impact the mechanical properties of the film compared to using a smaller amount. This is due to the variations in the overall properties of the film, which are influenced by the degree of molecular interaction among its components.

Young's modulus is the ratio of stress to strain experienced by a film when it is stretched in opposite directions. This parameter represents the film's stiffness in response to mechanical deformation. A higher Young's modulus indicates a stiffer film. In **Table 2**, it is observed that Young's modulus in GG/KG3 (0.0026 N/mm²) is lower than in GG/KG1 and GG/KG2 (both at 0.0029 N/mm²), which can be attributed to the addition of konjac glucomannan. This decrease in elastic modulus may be due to konjac glucomannan, a hydrocolloid, which adds more flexibility and plasticity to the film, thus making the material more easily deformed under pressure, resulting in a lower elastic modulus. Additionally, the addition of konjac glucomannan can change intermolecular interactions within the film matrix, affecting the resistance of the film to deformation (Sun *et al*., 2023). Another possibility is that konjac glucomannan might influence the overall mechanical properties of gelatin-based films. However, there are no significant differences between GG/KG1, GG/KG2, and GG/KG3 in Young's modulus values ($P > 0.05$), suggesting that the addition of konjac glucomannan at concentrations of 10 and 20% does not significantly affect the stiffness of the film. Some factors that may account for this include the existence of a saturation point, where the addition of konjac glucomannan has already reached a saturation level that does not significantly alter mechanical properties (Qiao *et al*., 2022). The presence of 10% konjac glucomannan could be sufficient to impart the desired properties to the film. Increasing the concentration to 20% does not seem to result in significant changes or improvements. Moreover, the interaction between gelatin and konjac glucomannan may not be strong enough to cause notable changes in mechanical properties at higher concentrations. The results show that konjac glucomannan influences film-based gelatin, which is more noticeable at higher concentrations, lowering the elastic modulus. However, the difference in mechanical properties between 10 and 20% concentrations may be unimportant.

**Table 2**. Tensile strength, elongation at the beak, and Young's modulus of gelatin films.

| Gelatin films | Tensile strength (N/mm²) | Elongation at break (%) | Young's modulus (N/mm²) |
|---|---|---|---|
| GG/KG1 | 0.0171 ± 0.0012[a] | 5.91 ± 0.05[a] | 0.0029 ± 0.0002[a] |
| GG/KG2 | 0.0134 ± 0.0005[b] | 4.60 ± 0.07[b] | 0.0029 ± 0.0001[a] |
| GG/KG3 | 0.0118 ± 0.0008[b] | 4.52 ± 0.06[b] | 0.0026 ± 0.0002[a] |

Distinct superscript letters in the same column signify a significant difference ($P < 0.05$).

### 3.4. Water Vapor Transmission Rate (WVTR)

**Figure 2** shows the WVTR of gelatin films made from goat skin incorporated with konjac glucomannan. When konjac glucomannan is added, the WVTR changes significantly ($P < 0.05$) for treatments GG/KG1, GG/KG2, and GG/KG3. Gelatin, which is derived from collagen hydrolysis, gives the film a hydrophilic character with a triple-helix collagen structure. The film has a lower WVTR when konjac glucomannan is added, especially in the GG/KG3 treatment, with a ratio of 20%. Adding so much konjac glucomannan to the film could change its molecular structure, leading to different molecular interactions between gelatin and konjac glucomannan. Homogenization and ultrasonication may also affect the distribution of particles and molecular interactions. The WVTR indicates how quickly water vapor can pass through a film. It demonstrates the packaging's ability to retain the moisture of the packaged

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

product. A low WVTR value suggests that the film provides strong resistance against water vapor. An effective film should have a low WVTR to minimize the loss or uptake of moisture from the packaged product. The films with low WVTR can help maintain the quality, freshness, taste, aroma, and nutritional value of the packaged products (Wu *et al*., 2021). The film becomes more brittle and has a lower WVTR due to the hydrophilic properties of konjac glucomannan. These differences reveal the complexity of the molecular interactions between film components and emphasize the need for a deeper understanding of the structure and barrier properties of the film for optimal design. The amount of konjac glucomannan changes the number of water-loving and water-hating networks in the film, affecting the WVTR. The number of hydrophilic networks in the film increases as the concentration of konjac glucomannan increases. This lowers the WVTR. The number of hydrophobic networks in the film increases as the amount of konjac glucomannan decreases. This raises the WVTR. Konjac glucose has long, branched chains of polysaccharides that can bond strongly with water through hydrogen bonds (Haruna *et al*., 2019; Sun *et al*., 2023). These hydrophilic networks can bind water effectively, reducing the rate of transmission of water vapor through the film (Xiao *et al*., 2001; Zhou *et al*., 2022). Goat skin gelatin has short and unbranched protein chains that can form weak hydrophobic networks with covalent bonds. These hydrophobic networks cannot bind water effectively, thus increasing the water vapor transmission rate through the film (Cui *et al*., 2023; Haruna *et al*., 2019).

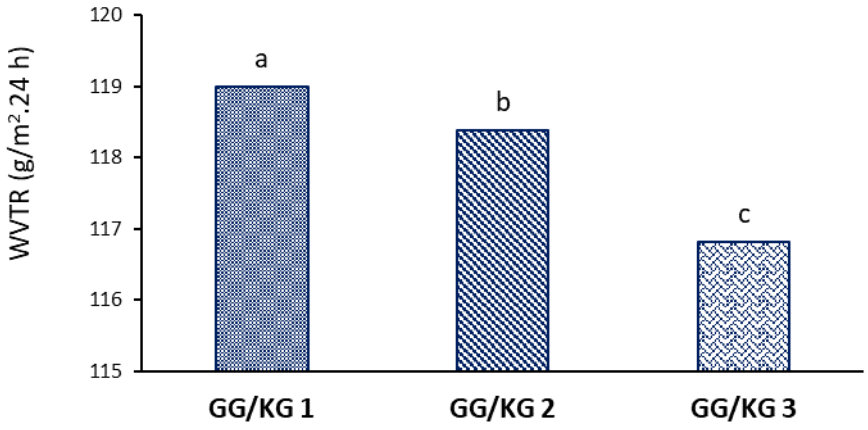


**Figure 2**. Water vapor transmission rate (WVTR) of gelatin films from goat skin incorporated with konjac glucomannan.

### 3.5. Opacity, Transparency, and Light Transmission of the Film

The results presented in **Table 3** indicate that the opacity values of gelatin films from goat skin increase with the addition of konjac glucomannan. Specifically, GG/KG2 (1.0115 ± 0.03 $mm^{-1}$) and GG/KG3 (1.0433 ± 0.01 $mm^{-1}$) show higher opacity compared to GG/KG1, which does not contain konjac glucomannan (0.9910 ± 0.07 $mm^{-1}$). This increase is likely due to the different optical properties or brightness of konjac glucomannan compared to gelatin, resulting in added optical density or opacity to the film. In addition, when konjac glucomannan and gelatin are mixed, they can change the molecular structure and phase distribution. This can change how light interacts with the film and make it less see-through. The opacity of the film is a measure of the amount of light that the film absorbs. Several factors, such as composition, thickness, and the film manufacturing process, can affect the opacity of film (Kumar *et al*., 2022). A film with high opacity absorbs a significant amount of light, making it non-transparent. Conversely, a film with low opacity absorbs less light,

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

resulting in greater transparency (Zhao *et al*., 2022). Films with low opacity are frequently favored because they enhance the visual appeal of wrapped products. However, this reduced opacity can also lessen the film's light-blocking capability, potentially impacting the quality and freshness of the products (Jeevahan & Chandrasekaran, 2019). Therefore, the opacity of the film should be adjusted according to the needs and characteristics of the packaged product. There are no significant differences between GG/KG1, GG / KG2, and GG/KG3 in the opacity values ($P$ > 0.05). This could be because the optimal concentration of konjac glucomannan has reached 10% and increasing the concentration to 20% does not significantly change film opacity. Furthermore, the interaction between gelatin and konjac glucomannan at the concentrations used may not be strong enough to create noticeable differences in opacity. Therefore, this study shows that adding konjac glucomannan can make a film based on goat skin gelatin opaquer. However, the differences between concentrations may not matter much when it comes to the optical properties of the film at some concentration levels. When konjac glucomannan is added to the film, transparency values significantly decrease, as shown in **Table 3**. This is evident in GG/KG1 (81.59 ± 0.51 $mm^{-1}$), GG/KG2 (72.19 ± 0.35 $mm^{-1}$), and GG/KG3 (67.33 ± 0.89 $mm^{-1}$). The decrease in transparency may be due to the change in the film's molecular structure resulting from the addition of konjac glucomannan. This change can lead to uneven phase distribution, reducing light transmission and transparency. When gelatin and konjac glucomannan interact, an uneven phase distribution within the film matrix can occur, altering the film's refractive index and clarity. Additionally, konjac glucomannan can affect the optical density of the film, impeding light passage and increasing resistance to transparency (Huang *et al*., 2022). However, the notable distinctions between GG/KG1, GG/KG2, and GG/KG3 may be related to the optimal concentration of konjac glucomannan. The addition of konjac glucomannan at a 10% concentration (GG/KG2) may have already maximized the transparency change. Increasing the concentration to 20% (GG/KG3) could result in a more noticeable effect. The stronger molecular interactions and higher prevalence of konjac glucomannan at higher concentrations can account for the significant differences in clarity among the different groups. These findings enhance our understanding of how adding konjac glucomannan affects the optical properties of films made from goat skin gelatin.

**Table 3**. Opacity and transparency of gelatin films from goat skin incorporated with glucomannan.

| Treatment | Opacity ($mm^{-1}$) | Transparency (%) |
|---|---|---|
| GG/KG1 | 0.9910 ± 0.07$^{a}$ | 81.59 ± 0.51$^{a}$ |
| GG/KG2 | 1.0115 ± 0.03$^{a}$ | 72.19 ± 0.35$^{b}$ |
| GG/KG3 | 1.0433 ± 0.01$^{a}$ | 67.33 ± 0.89$^{c}$ |

Distinct superscript letters in the same column signify a significant difference ($P$ < 0.05).

In **Figure 3**, it is evident that adding konjac glucomannan (KG) to gelatin films made from goat skin significantly reduces light transmission. GG/KG1 has a higher level of light transmission than GG/KG2 and GG/KG3. Furthermore, **Figure 3** confirms the findings presented in **Figure 4** and **Table 3**, showing that the addition of konjac in goat skin gelatin-based films alters their transparency or opaqueness. Despite the variations, all film samples in the study maintained their clarity and transparency. The combination of gelatin and konjac glucomannan facilitates the formation of hydrogen bonds, van der Waals forces, and possibly water-free interactions. These interactions can influence the structure and phase distribution of the film, leading to changes in optical properties and transparency (Fahrullah *et al*., 2020). At higher concentration levels, significant molecular interactions may reduce the

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

transparency of the film. Differences in transparency between film groups may be linked to the extent of molecular interactions and structural changes caused by the addition of konjac glucomannan (Leuangsukrerk *et al*., 2014).

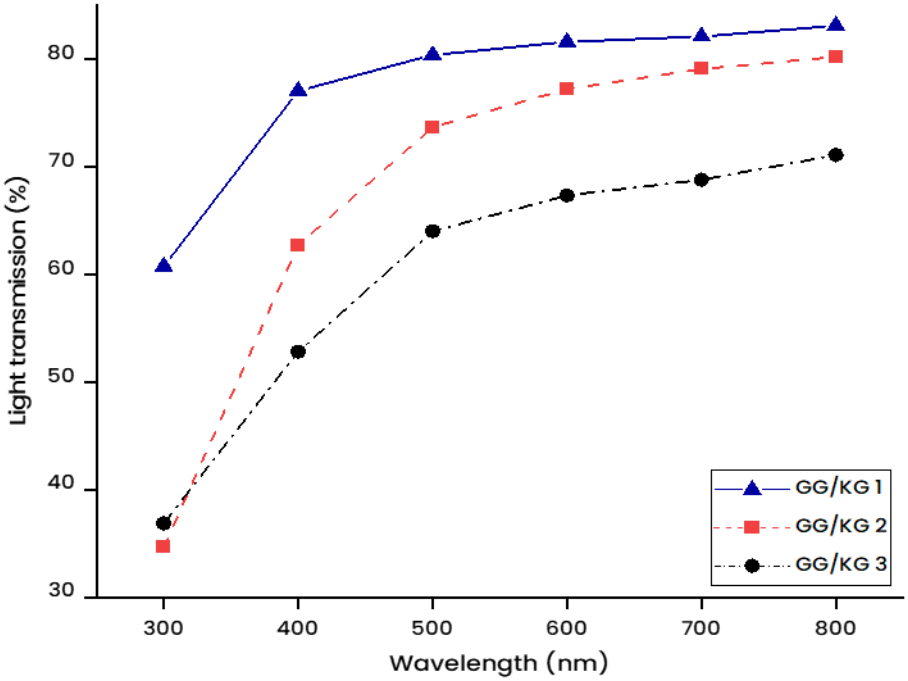


**Figure 3**. Light transmission of gelatin films from goat skin incorporated with konjac glucomannan.

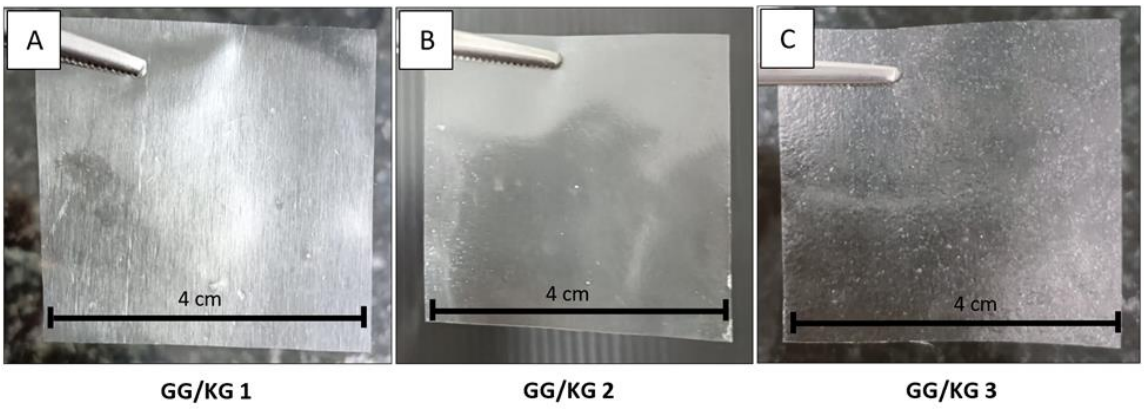


**Figure 4**. The appearance of gelatin films from goat skin incorporated with different levels of konjac glucomannan A) 0%, B) 10%, C) 20%.

### 3.6. Film Colors

The colors of gelatin films made from goat skin and konjac glucomannan can indicate their quality, attractiveness, and light-blocking ability. According to **Table** 4, the *L** values representing brightness in the films based on goat skin gelatin containing konjac glucomannan (GG/KG1, GG/KG2, and GG/KG3) increased after the drying process at 25°C with 45% humidity. The *L** value is a parameter that indicates the brightness level of films, with higher values denoting greater brightness. Several factors contributed to the increase in *L** color values. The drying process under specific conditions altered the molecular interactions and matrix structure of the film, thus affecting its light-reflecting capacity (Galus *et al*., 2020).

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Adding konjac glucomannan, especially at higher concentrations (GG/KG3), likely improved the film's brightness by reflecting light. The *L** colors of GG/KG1, GG/KG2, and GG/KG3 represented the combined effects of these factors. The a* value indicates the level of greenness or red tendency in an object. The positive *a** values indicate green, while negative values indicate red. In this study, the film without konjac glucomannan (GG/KG1) had *a** value of -0.31 ± 0.02, indicating a red color. In contrast, the film with 10% konjac glucomannan (GG/KG2) had an *a** value of -0.41 ± 0.01, indicating a more dominant green color. This is further evident in the film with 20% konjac glucomannan (GG/KG3), which had *a** value of -0.46 ± 0.02. Moreover, compared to the standard white background with an *a** value of -0.89, the films with konjac glucomannan tended to have a brighter green color. These results indicate that konjac glucomannan has a significant influence ($P < 0.05$) on the color of the films, and these differences provide valuable information about the optical properties and aesthetics of the material. However, the drying process at 25 °C and 45% humidity can affect the *a** values of the films made from goat skin gelatin. The drying rate at this temperature can impact the structure of the film, influencing its optical properties and color (Peng *et al*., 2022a). Chemical reactions that occur during the drying process, like oxidation or molecular changes, can cause shifts in color values. It's essential to control humidity during this process, as high or low humidity levels can affect how films absorb or release water. This, in turn, can change the optical properties and color of the film. Moreover, temperature and humidity fluctuations during drying can also impact the film's dimensional stability, which influences how people perceive the color due to changes in the film's optical properties resulting from its dimensional variations (da Costa *et al*., 2019). The *b** value is used to determine the degree of yellowness or blueness in films. Positive values of *b** indicate a yellow color, while negative values indicate a blue color. In this study, it was observed that the inclusion of konjac glucomannan did not significantly affect the films' b* value. However, the drying process influenced the b* value, resulting in a slight blue color. Yellow and blue are complementary colors, meaning they are opposite on the color wheel (Lim *et al*., 2021).

**Table 4**. Colors of gelatin films made from goat skin incorporated with konjac glucomannan.

| Samples | Colors | | | |
|---|---|---|---|---|
| | ***L**** | ***a**** | ***b**** | **Color difference (Δ*E**)** |
| White Background | 93.16 | -0.89 | 7.43 | 1.45 |
| GG/KG1 | 92.45 ± 0.07$^{a}$ | -0.31 ± 0.02$^{a}$ | 5.18 ± 0.18$^{a}$ | 48.13 ± 0.05$^{a}$ |
| GG/KG2 | 92.60 ± 0.15$^{ab}$ | -0.41 ± 0.01$^{b}$ | 5.77 ± 0.40$^{a}$ | 48.03 ± 0.33$^{a}$ |
| GG/KG3 | 92.77 ± 0.05$^{b}$ | -0.46 ± 0.02$^{c}$ | 5.52 ± 0.10$^{a}$ | 48.38 ± 0.07$^{a}$ |

Distinct superscript letters in the same column signify a significant difference ($P < 0.05$).

The color difference (ΔE) is a measure used to describe the color distinction between two objects. Low ΔE values indicate similar colors, while high values suggest distinct colors. In this study, gelatin films from goat skin incorporated with konjac glucomannan were dried at 25°C with 45% humidity. The results indicated that there were no significant differences in the ΔE values among the treatments GG/KG1, GG/KG2, and GG/KG3. This suggests that adding konjac glucomannan does not impact the color difference of the films. The ΔE values ranged from 48.03 ± 0.33 to 48.38 ± 0.07, reflecting a considerable color variation. One factor affecting film ΔE is the measurement of background color. Different background colors can create different color contrasts. In this study, a standard white background was used as a reference to measure the color of the films. The standard white background had an ΔE value of 1.45, indicating a color almost identical to white. Gelatin films exhibited high ΔE values, indicating a color difference from white. The color of films is influenced by the composition,

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

structure, and thickness of the material, as well as the drying process used (Galus & Kadzińska, 2016; Wang *et al*., 2021).

### 3.7. Swelling and Water Resistance

Water resistance and swelling are key parameters in assessing the physical properties of films. Water resistance measures the film's ability to repel water, which is essential for applications exposed to moisture. Conversely, swelling evaluates the extent to which a film absorbs water and expands, impacting its structural integrity and performance. **Table 5** displays the swelling and water resistance of gelatin films made from goat skin incorporated with glucomannan. Konjac glucomannan, as a hydrocolloid, has a high-water absorption capacity. The percentage of gelatin films that swelled significantly increased as the amount of added konjac glucomannan went from GG/KG1 (no konjac glucomannan) to GG/KG3 with 20% more. The swelling properties of GG/KG1, GG/KG2, and GG/KG3 were affected by their chemical compositions, the molecular interactions between konjac glucomannan and the film matrix, the film's physical properties, including porosity and water retention capacity, as well as the amount of konjac glucomannan added. The gel structure formed by konjac glucomannan within the gelatin film matrix played a vital role in enhancing the film's swelling properties (Ji *et al*., 2017; Yan *et al*., 2012; Zhou *et al*., 2022). When konjac glucomannan was incorporated into the gelatin matrix, it formed a gel network involving gelatin molecules (Li *et al*., 2006b; Xiao *et al*., 2001). Consequently, the water absorbed by konjac glucomannan formed a gel, which expanded the entire film matrix. This gel network enriched the film matrix with more water, which was reflected in higher swelling properties. Gel formation also improved water retention in the film, providing better moisture properties (Li *et al*., 2006b; Zhou *et al*., 2022). Furthermore, hydrocolloid-like konjac glucomannan molecules could form bonds with water molecules, creating a hydrating gel. This process caused structural changes in the film matrix, creating larger spaces to accommodate water, and leading to an increase in swelling properties (Huang *et al*., 2015). Because konjac glucomannan could become a gel within the gelatin matrix, this was a major factor in affecting the film's physical properties, especially the swelling properties observed in this study.

This study found that the film's water resistance decreased as the concentration of konjac glucomannan (GG/KG1, GG/KG2, and GG/KG3) increased, as shown in **Table 5**. Konjac glucomannan, a hydrocolloid with high water-absorbing capacity, was found to reduce the film's water resistance by absorbing and binding it to a large amount of water. This weakens the film's ability to resist water penetration and decreases its overall resistance to water. At higher concentration levels, especially in GG/KG3, konjac glucomannan changed the film's matrix structure by forming a gel and increasing porosity, thus making the film more permeable to water. The molecular interactions between gelatin and konjac glucomannan, including hydrogen bonding and hydrophobic interactions, can influence the film's physical properties, potentially reducing its water resistance. Furthermore, there were significant differences ($P < 0.05$) between GG/KG1, GG/KG2, and GG/KG3, which can be attributed to variations in konjac glucomannan concentration. GG/KG3 significantly reduced water resistance compared to GG/KG1 and GG/KG2. Water resistance is a measure of the film's resistance to dissolution or breakdown when exposed to water (Lee *et al*., 2020). Swelling quantifies the film's capacity to absorb water and expand upon immersion (Khodaei *et al*., 2020). Water resistance and swelling affect the quality, freshness, taste, aroma, and nutritional value of food products packaged with films. Integrating KG into gelatin-based films diminishes their ability to resist water or act as a water barrier (Li *et al*., 2015). This is because KG exhibits high hydrophilic properties, which allow it to absorb water easily (Sun *et al*.,

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

2023b; Zhou *et al*., 2022). KG can form a robust and elastic gel when exposed to water, which expands the film matrix and enhances water retention within the film (Lei *et al*., 2019; Ma *et al*., 2021). Water resistance and swelling are inversely related. As the resistance to water of the film increases, its swelling decreases, and vice versa. The structure and intermolecular relationships of the molecules comprising the film are impacted by its properties (Galus *et al*., 2020; Matloob *et al*., 2023). A film with a solid, homogeneous, and nonporous structure has high water resistance and low swelling because their molecules bind strongly, reducing their water permeability (Jimenez *et al*., 2012; Said *et al*., 2023). On the contrary, films with a loose, heterogeneous, and porous structure have low water resistance and high swelling because their molecules bind weakly, allowing water to penetrate easily (Jeevahan & Chandrasekaran, 2019; Kumar *et al*., 2022).

**Table 5**. Swelling and water resistance of gelatin films incorporated with glucomannan.

| Gelatin films | Swelling (%) | Water resistance (%) |
|---|---|---|
| GG/KG1 | 65.53 ± 0.27$^{a}$ | 34.47 ± 0.27$^{a}$ |
| GG/KG2 | 67.21 ± 0.15$^{b}$ | 32.79 ± 0.15$^{b}$ |
| GG/KG3 | 69.47 ± 0.01$^{c}$ | 30.53 ± 0.01$^{c}$ |

Distinct superscript letters in the same column signify a significant difference ($P < 0.05$).

### 3.8. Contact Angle Measurement

Contact angle measurement assesses whether films are hydrophobic or hydrophilic. The contact angle is the angle created between the film's surface and a water droplet placed on it. The contact angle of gelatin films from goat skin incorporated with konjac glucomannan is depicted in **Figure 5**. It shows the contact angle data of 86.92 ± 0.46°, 86.87 ± 0.58°, and 127.85 ± 0.76° for GG/KG1, GG/KG2, and GG/KG3 respectively. In the GG/KG1 treatment, the film consists only of goat skin gelatin without konjac glucomannan. Goat skin gelatin contains amino (-$NH_2$) and carboxyl (-COOH) groups that are polar, allowing interactions with water molecules through hydrogen bonding. As a result, the film has a low contact angle of 86.92 ± 0.46$^{o}$, indicating high hydrophilicity. In the GG/KG2 treatment, the film contains goat skin gelatin with 10% konjac glucomannan. A larger contact angle implies greater hydrophobicity, meaning that the film resists water penetration (Liu *et al*., 2021). On the contrary, a smaller contact angle indicates higher hydrophilicity, which means that the film allows water penetration (Cui *et al*., 2023). Glucomannan from Konjac also has hydroxyl polar groups (-OH) that make it easier for it to interact with water molecules by hydrogen bonding (Zhou *et al*., 2022). So, the gelatin film still maintains high hydrophilicity, as demonstrated by a contact angle almost identical to the GG/KG1 treatment at 86.87 ± 0.58°. This suggests that the addition of 10% konjac glucomannan does not significantly affect the hydrophobic properties of the film. In the GG/KG3 treatment, the film comprises goat skin gelatin with 20% konjac glucomannan. Adding 20% konjac glucomannan changes the shape and structure of the film, which means that the polar groups are less likely to encounter the surface. As a result, the film has a larger contact angle of 127.85 ± 0.76°. This indicates that incorporating 20% konjac glucomannan has a substantial impact on the film's hydrophobic properties. The film is made from gelatin, which comes from the hydrolysis of collagen protein. Proteins have amino (-$NH_2$) and carboxyl (-COOH) groups that are polar, allowing interactions with water molecules through hydrogen bonding (Khan *et al*., 2022). Additionally, proteins contain nonpolar side chains (R groups) such as methyl (-$CH_3$), ethyl (-$CH_2CH_3$), phenyl (-$C_6H_5$), and others. These nonpolar side chains can make proteins hydrophobic, meaning they repel water. However, in films made from goat skin gelatin, the nonpolar side chains are not prominently exposed on

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

the surface, so they do not overshadow the dominant polar groups. Therefore, these films have a low contact angle of less than 90°, indicating high hydrophilicity.

Konjac glucomannan (KG) serves as a filler in gelatin films, enhancing their rigidity and strength. KG has exceptionally high hydrophilicity due to its glucose and mannose chains, which can interact with water molecules. As a result, KG increases the solubility and swelling of films. Glycerol acts as a plasticizer in films, enhancing their flexibility and elasticity. Glycerol also has high hydrophilicity, containing three hydroxyl (-OH) groups that can interact with water molecules (Peng *et al*., 2022). Glycerol enhances the solubility and swelling of films, but it can also lower the contact angle and decrease moisture resistance. The gelatin films made from goat skin mixed with KG and glycerol display a large contact angle due to the interactions between KG and glycerol, creating a crystalline structure within the film. This crystalline structure reduces the film's attraction to water, thus improving its hydrophobic properties. However, these gelatin films also have poor resistance to moisture because of their high water, KG, and glycerol content, causing them to dissolve easily in water and result in a contact angle greater than 90° (Dong *et al*., 2023).

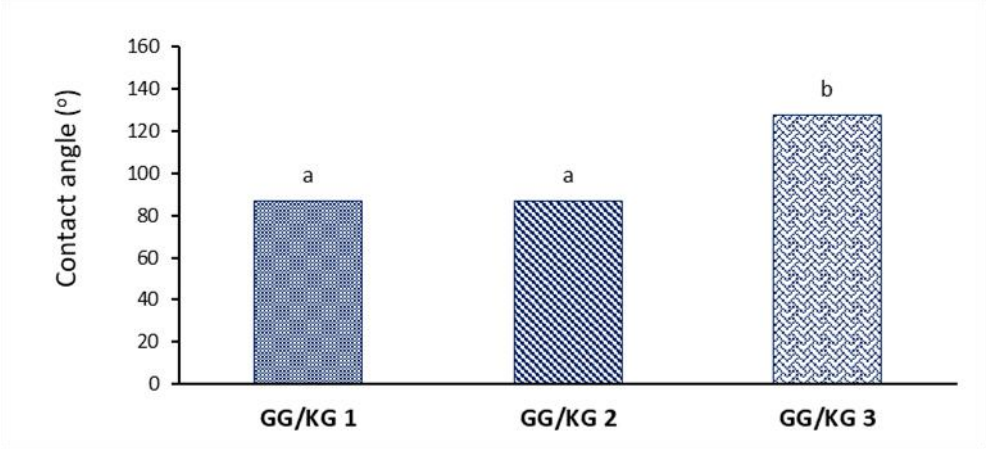


**Figure 5**. The water contact angle of gelatin films from goat skin incorporated with different levels of konjac glucomannan A) 0%, B) 10%, C) 20%.

### 3.9. FTIR

The FTIR spectra of gelatin films from goat skin incorporated with konjac glucomannan are illustrated in **Figure 6**. Generally, the spectra for all film samples exhibit slight differences. The entire infrared spectrum displays the main characteristic vibrational peaks of proteins: Amide A (3275.91 - 3288.50 $cm^{-1}$), Amide B (2927.51 - 2932.58 $cm^{-1}$), Amide I (1629.08 - 1630.66 $cm^{-1}$), Amide II (1535.49 - 1551.22 $cm^{-1}$), and Amide III (1233.50 - 1236.64 $cm^{-1}$). The characteristic positions and assignments of the group contributions for these peaks have been well documented, as presented in **Table 6**. The FTIR spectra of the gelatin film show differences in the Amide A region. The amide A band in the films ranged from 3275.91-3288.50 $cm^{-1}$. This band corresponds to the stretching vibration of H, which usually occurs between 3400 - 3440 $cm^{-1}$, and when NH peptide groups form hydrogen bonds, their frequency decreases (Sancakli *et al*., 2021). The addition of konjac glucomannan (KG) to goat skin gelatin films increases the intensity of the peak of amide A. Although the frequency shift is insignificant, this change implies interactions between goat skin gelatin (GG) and konjac glucomannan (KG) that can affect the structure of the final films. The variation in the peak of amide A indicates possible changes in the molecular arrangement within the mixed films. The NH angles attached to the

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

gelatin polypeptide chain and the NH angles attached to the KG polysaccharide chain move and change shape (BenBettaïeb *et al.*, 2015).

Amide B usually appears in the range of 3000 - 2800 $cm^{-1}$. The frequency changes in all treatments indicate interactions between GG and KG in the film. Incorporating KG into GG-based films significantly enhances the hydrogen bonding interactions between the NH groups and the carbonyl groups along the polymer chain (Xiao *et al.*, 2001). This hydrogen bonding can change the vibration frequency of NH groups (Chambi & Grosso, 2011), leading to a shift in frequency towards lower wavenumbers in the peak corresponding to amide B. The drying process was executed under controlled conditions, maintaining a temperature of 25°C and relative humidity of 45%, which can potentially alter the crystalline and amorphous structures of GG and KG, consequently impacting the frequency shift in the peak related to amide B.

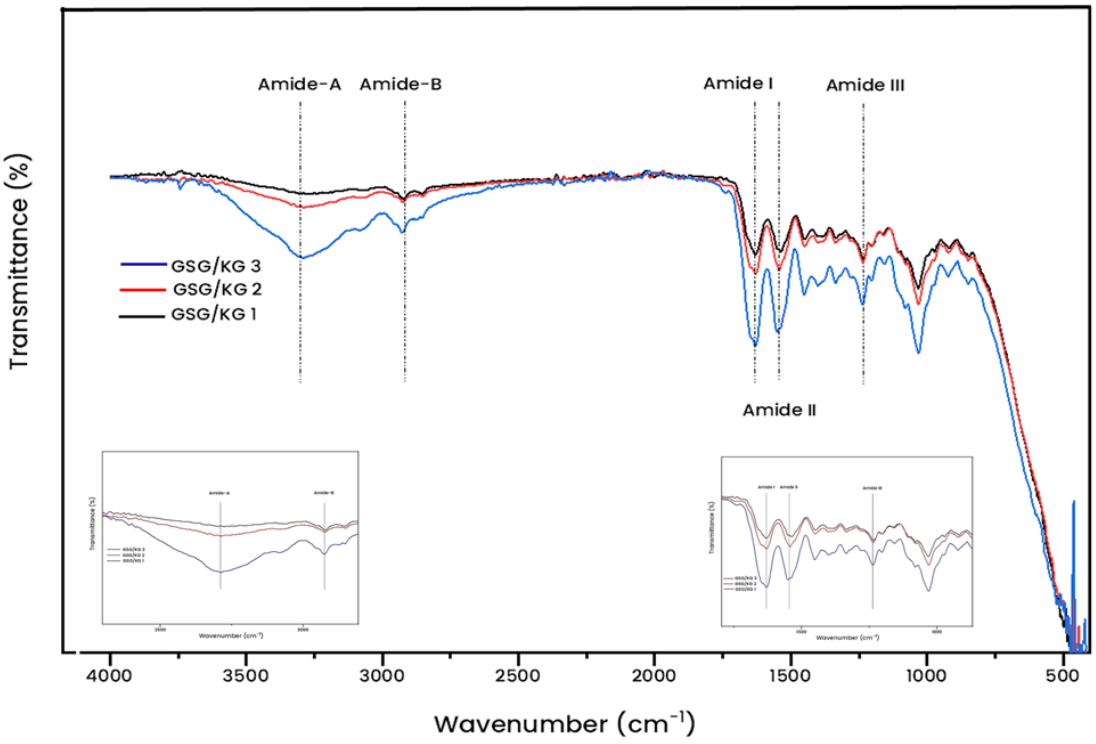


**Figure 6**. FTIR spectra of gelatin films from goat skin incorporated with konjac glucomannan.

The films exhibit peak shifts in amide I, indicating molecular level changes. In GG/KG1, the peak of the amide I is at 1629.08 $cm^{-1}$. This minimal shift is likely due to intermolecular interactions between gelatin chains during the homogenization and drying processes. In GG/KG2, the amide I peak remains at 1629.08 $cm^{-1}$, indicating that the addition of konjac glucomannan in small amounts does not significantly affect the C=O bond structure of gelatin. However, in GG/KG3, a peak shift to 1630.66 $cm^{-1}$ occurs, possibly resulting from stronger intermolecular interactions between gelatin and konjac glucomannan at higher concentrations. In the case of gelatin, amide I is linked to C=O bonds in the polypeptide chains. On the other hand, when it comes to konjac glucomannan, amide I is related to C=O bonds in polysaccharide chains (Qiao *et al.*, 2020). These differences show that adding konjac glucomannan can change the C=O bond vibration frequencies in each part (Xiao *et al.*, 2001). This shows how the protein and polysaccharide structures in the film interact with each other.

The amide II spectrum results in this study show peak shifts that indicate changes at the molecular level of the film. In GG/KG1 without konjac glucomannan, the amide II peak is at 1535.49 $cm^{-1}$. The shift in the peak of amide II to 1541.79 $cm^{-1}$ in GG/KG2 with 10% konjac

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

glucomannan suggests that there are molecular-level interactions between gelatin and konjac glucomannan. This shift becomes 1551.22 $cm^{-1}$ in GG/KG3 with 20% konjac glucomannan, indicating stronger intermolecular interactions at higher concentrations. In gelatin, amide II is associated with N-H and C-N bond vibrations in protein amide groups, while konjac glucomannan is linked to N-H and C-N bonds in the structure of the glucomannan polysaccharide. These interactions are likely due to the homogenization and drying processes. The amide II peaks show that the protein and polysaccharide structures in the film interact in a complex way (Qiao *et al*., 2020). This helps us understand how the gelatin and konjac glucomannan molecules change shape and interact when the film forms. These amide II peaks result from the vibration of C-N bonds combined with the vibration of N-H (Li *et al*., 2006).

**Table 6**. Peak positions of the FTIR spectra of films produced from goat skin gelatin incorporated with konjac glucomannan.

| Regions | Peak wavenumber ($cm^{-1}$) | | | Assignments |
|---|---|---|---|---|
| | GG/KG1 | GG/KG2 | GG/KG3 | |
| Amide III | 1233.50 | 1234.28 | 1236.64 | NH bend coupled with CN stretch |
| - | 1032.17 | 1030.59 | 1030.59 | C-O stretch |
| Amide II | 1535.49 | 1541.79 | 1551.22 | NH bend |
| - | 1488.99 | 1488.99 | 1451.34 | $CH_2$ bend |
| - | 1398.65 | 1398.65 | 1401.80 | COO− symmetrical stretch |
| - | 1344.16 | 1344.16 | 1335.74 | $CH_2$ wag |
| Amide I | 1629.08 | 1629.08 | 1630.66 | C=O stretch/hydrogen bond coupled with COO− |
| Amide A | 3275.91 | 3287.71 | 3288.50 | NH stretch coupled with hydrogen bond |
| Amide B | 2932.58 | 2924.37 | 2927.51 | $CH_2$ asymmetrical stretch |

The amide III showed peak shifts that indicate changes at the molecular level of the film. The amide III peak in gelatin appears in the range of 1200 - 1300 $cm^{-1}$ and exhibits vibrations of amide bonds, particularly the amide III type in the protein structure. In this study, in GG/KG1 without konjac glucomannan, the peak of the amide III peak is observed at 1233.50 $cm^{-1}$. In GG/KG2, with the addition of 10% konjac glucomannan, there is a slight increase in the peak value of the amide III to 1234.28 $cm^{-1}$, indicating the influence of konjac glucomannan on the amide structure in gelatin. In GG/KG3 with 20% konjac glucomannan, there is a further increase in the peak value of amide III to 1236.64 $cm^{-1}$, suggesting that a higher concentration of konjac glucomannan can more significantly affect the amide structure in gelatin. Gelatin amide III is usually related to NH and CH bonds in peptide chains (Sancakli *et al*., 2021). Conversely, konjac glucomannan comprises fundamental polysaccharides linked by β-glycosidic bonds (Ji *et al*., 2017). Variations in the amide III peak indicate the interactions between gelatin and konjac glucomannan components, potentially involving hydrogen bonds or other molecular interactions (Asiyanbi *et al*., 2017; Wang *et al*., 2018). Quantifying amide III is crucial as it provides insights into structural changes and molecular interactions within films. This information is vital for understanding the functional properties and quality of the resulting products, thereby serving as a foundation for the development of enhanced products.

### 3.10. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometer (EDS)

The SEM results shown in **Figure 7** demonstrate that the film examined in this study, especially GG/KG1, had a smooth, uniform surface without any pores or irregularities. However, higher concentrations of konjac glucomannan caused changes in the structure of the film, as observed in sample GG/KG3. This study identified the formation of polymer

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

aggregation layers as a result of the addition of GK, which led to an increase in the film's viscosity. Changes in the surface morphology of the film also occurred due to the integration of GK into the gelatin-based film matrix, resulting in significant alterations in features such as thickness, tensile strength, elongation, solubility, and permeability. These changes significantly affect the physical and functional properties of the film. Analysis using SEM revealed the presence of pores, cracks, and aggregations on the film surface, indicating the quality and homogeneity of the film due to the mixing of GK and GG. These findings suggest that the addition of GK not only affects viscosity but also substantially alters the physical and mechanical characteristics of the film, which may have implications for practical applications and further product development (Haruna *et al*., 2019; Wang *et al*., 2007). There is the possibility of incomplete molecular compatibility between gelatin and konjac glucomannan, leading to phase separation and agglomeration (Fahrullah *et al*., 2020). Moreover, the GG/KG3 films exhibited a higher contact angle and increased swelling, while demonstrating a reduced WVTR. These changes were likely due to stronger molecular interactions at higher concentrations, resulting in a denser structure. At the molecular level, gelatin and konjac glucomannan may not fully dissolve in each other, leading to segregation rather than a uniform blend formation (Xiao *et al*., 2001).

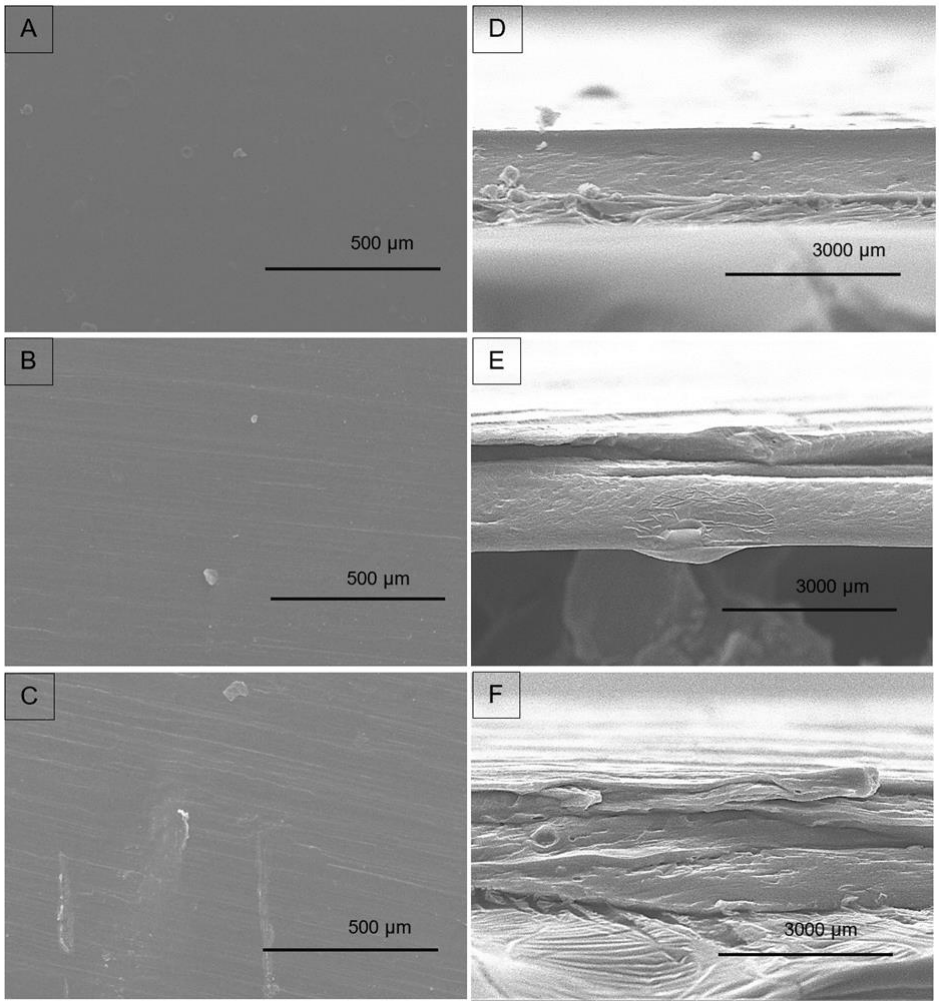


**Figure 7**. Morphology of GG/KG films. (A-C) SEM images of GG/KG1, GG/KG2, and GG/KG3, respectively, showing surface morphology; (D-F) cross-sectional SEM images of GG/KG1, GG/KG2, and GG/KG3, respectively, illustrating the internal structure. The scale bar is 500 µm for the surface images and 3000 µm for the cross-sectional images.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

The EDS spectrum was captured on the surface of the films (**Figure 8**). EDS measurements can also be utilized for elemental mapping, illustrating the spatial distribution of elements within the sample (Qiao *et al*., 2022). The EDS results of the gelatin films revealed the presence of elements such as C, O, Al, Si, Cl, K, Ca, Cu, and Mo. This indicates that the cross-linking of gelatin and konjac glucomannan effectively formed the film. These elements originate from the raw materials used in the film, as well as potential contaminants. For instance, C (carbon) and O (oxygen) derive from gelatin, konjac glucomannan, citric acid, and glycerol, which are organic compounds rich in these elements and commonly found in natural materials (Sobhana *et al*., 2009; Zhou *et al*., 2007). Al (aluminum) and Si (silicon) are sourced from konjac glucomannan, a polysaccharide with acetate groups bound to Al and Si atoms (Wardhani *et al*., 2020), typically found in soil and rocks. Chlorine (Cl) is derived from citric acid, a weak acid containing Cl ions, and is also commonly found in seawater and table salt. Potassium (K) and calcium (Ca) originate from konjac glucomannan, which contains K+ and Ca2+ ions. Copper (Cu) and molybdenum (Mo) may be contaminants from the raw materials or equipment used during the film manufacturing process.

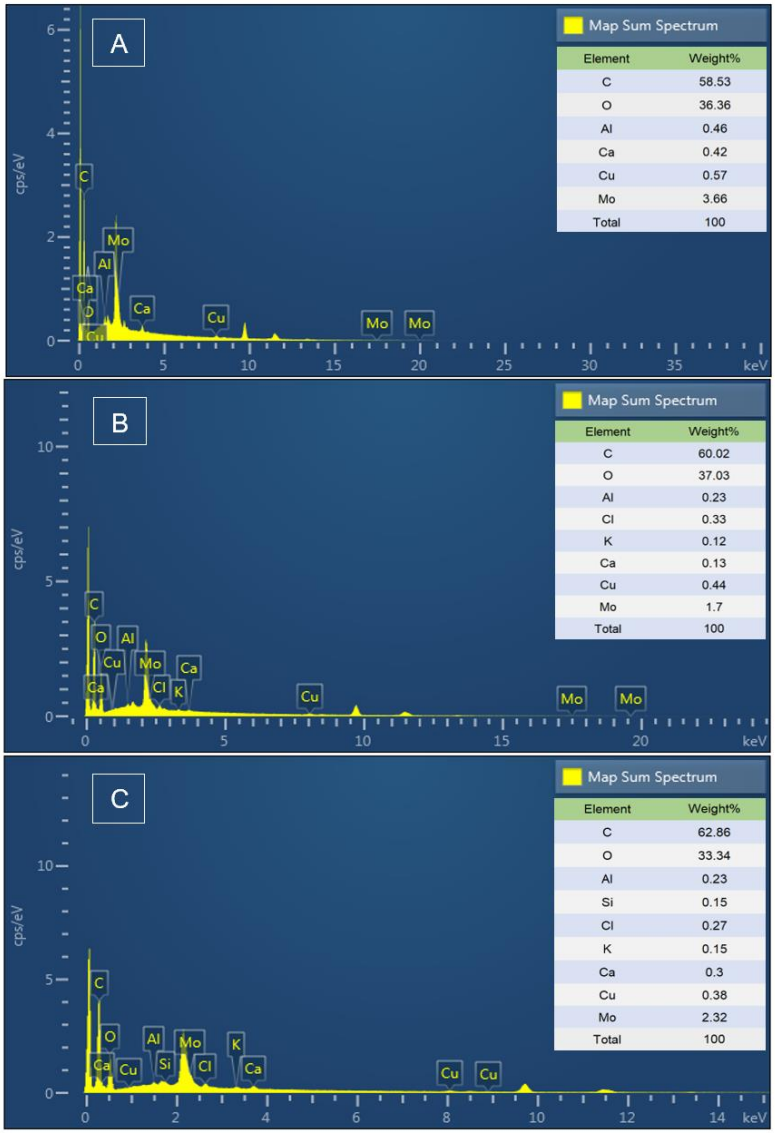


**Figure 8**. Energy dispersive spectrometer (EDS) spectrum of gelatin films from goat skin incorporated with konjac glucomannan. (A, B, C) SEM surface image of GG/KG1, GG/KG2, and GG/KG3, respectively.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

## 4. CONCLUSION

Adding konjac glucomannan to gelatin-based films made from goat skin enhances various properties, such as thickness, opacity, and swelling behavior. This is because konjac glucomannan interacts with gelatin chains, forming a cohesive network structure through hydrogen bonding. This affects the matrix structure and the light-scattering properties of the film during drying. The branched polysaccharide structure of konjac glucomannan reduced the water activity, moisture content, tensile strength, and water resistance of the films. Gelatin films from goat skin containing 20% konjac glucomannan maintained clarity and effective water vapor transmission rates, making them suitable for food packaging applications.

## 5. ACKNOWLEDGMENT

This work was financially supported by King Mongkut's Institute of Technology Ladkrabang Research Fund (Grant No. KDS2020/029) under the KMITL Doctoral Scholarship program.

## 6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

## 7. REFERENCES

Asiyanbi, T. T., Bio-Sawe, W., Idris, M. A., and Hammed, A. M. (2017). Gelatin-polysaccharide based materials: A review of processing and properties. *International Food Research Journal*, *24*, 313–319.

Azeredo, H. M. C., Otoni, C. G., and Mattoso, L. H. C. (2022). Edible films and coatings – Not just packaging materials. *Current Research in Food Science*, *5*, 1590–1595.

BenBettaïeb, N., Karbowiak, T., Bornaz, S., and Debeaufort, F. (2015). Spectroscopic analyses of the influence of electron beam irradiation doses on mechanical, transport properties and microstructure of chitosan-fish gelatin blend films. *Food Hydrocolloids*, *46*, 37–51.

Bourtoom, T. (2008). Edible films and coatings: Characteristics and properties. *International Food Research Journal*, *15*, 237–248.

Chambi, H., and Grosso, C. (2011). Effect of surfactants on the functional properties of gelatin–polysaccharide-based films. *European Food Research and Technology*, *232*, 63–69.

Chhikara, S., and Kumar, D. (2021). Edible coating and edible film as food packaging material: A review. *Journal of Packaging Technology and Research*, *6*, 1–10.

Cui, C., Gao, L., Dai, L., Ji, N., Qin, Y., Shi, R., Qiao, Y., Xiong, L., and Sun, Q. (2023). Hydrophobic biopolymer-based films: Strategies, properties, and food applications. *Food Engineering Reviews*, *15*, 360–379.

da Costa, R. D. S., da Cruz Rodrigues, A. M., Borges Laurindo, J., and da Silva, L. H. M. (2019). Development of dehydrated products from peach palm–tucupi blends with edible film characteristics using refractive window. *Journal of Food Science and Technology*, *56*, 560–570.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Das, D., Panesar, P. S., Saini, C. S., and Kennedy, J. F. (2022). Improvement in properties of edible film through non-thermal treatments and nanocomposite materials: A review. *Food Packaging and Shelf Life*, *32*, 100843.

de Vargas, V. H., Flôres, S. H., Mercali, G. D., and Marczak, L. D. F. (2022). Effect of OHMIC heating and ultrasound on functional properties of biodegradable gelatin-based films. *Polymer Engineering and Science*, *62*, 1890–1906.

Dong, Y., Rao, Z., Liu, Y., Zheng, X., Tang, K., and Liu, J. (2023). Soluble soybean polysaccharide/gelatin active edible films incorporated with curcumin for oil packaging. *Food Packaging and Shelf Life*, *35*, 101039.

Fahrullah, F., Radiati, L. E., and Rosyidi, D. (2020). The physical characteristics of whey based edible film added with konjac. *Current Research in Nutrition and Food Science Journal*, *8*, 333–339.

Galus, S., and Kadzińska, J. (2016). Moisture sensitivity, optical, mechanical and structural properties of whey protein-based edible films incorporated with rapeseed oil. *Food Technology and Biotechnology*, *54*, 78–89.

Galus, S., Arik Kibar, E. A., Gniewosz, M., and Kraśniewska, K. (2020). Novel materials in the preparation of edible films and coatings—A review. *Coatings*, *10*, 674.

Gaspar, M. C., and Braga, M. E. M. (2023). Edible films and coatings based on agrifood residues: A new trend in the food packaging research. *Current Opinion in Food Science*, *50*, 101006.

Haruna, M. H., Wang, Y., and Pang, J. (2019). Konjac glucomannan-based composite films fabricated in the presence of carnauba wax emulsion: Hydrophobicity, mechanical and microstructural properties evaluation. *Journal of Food Science and Technology*, *56*, 5138–5145.

Hasdar, M., Nalinanon, S., and Sriket, C. (2024a). Impact of pretreatment with acid and ultrasound on the production and characteristics of goat skin gelatin. *Current Research in Nutrition and Food Science Journal*, *12*(2), 890-910.

Hasdar, M., Nalinanon, S., and Sriket, C. (2024b). Sheepskin gelatin-based edible film: The use of soybean oil as a plasticizer12. *IOP Conference Series: Earth and Environmental Science*, *1360*(1), 012028.

Huang, T., Qin, Y., Li, M., Gao, S., and Shen, C. (2022). Preparation and characterization of deacetylated konjac glucomannan/pectin composite films crosslinked with calcium hydroxide. *Journal of Polymer Research*, *29*, 238.

Huang, Y.-C., Yang, C.-Y., Chu, H.-W., Wu, W.-C., and Tsai, J.-S. (2015). Effect of alkali on konjac glucomannan film and its application on wound healing. *Cellulose*, *22*, 737–747.

Jeevahan, J., and Chandrasekaran, M. (2019). Nanoedible films for food packaging: A review. *Journal of Materials Science*, *54*, 12290–12318.

Ji, L., Xue, Y., Feng, D., Li, Z., and Xue, C. (2017). Morphology and gelation properties of konjac glucomannan: Effect of microwave processing. *International Journal of Food Properties*, *20*, 3023–3032.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Jimenez, A., Fabra, M. J., Talens, P., and Chiralt, A. (2012). Edible and biodegradable starch films: A review. *Food and Bioprocess Technology*, *5*, 2058–2076.

Khan, S., Rehman, A., Shah, H., Aadil, R. M., Ali, A., Shehzad, Q., Ashraf, W., Yang, F., Karim, A., and Khaliq, A. (2022). Fish protein and its derivatives: The novel applications, bioactivities, and their functional significance in food products. *Food Reviews International*, *38*, 1607–1634.

Khodaei, D., Oltrogge, K., and Hamidi-Esfahani, Z. (2020). Preparation and characterization of blended edible films manufactured using gelatin, tragacanth gum, and Persian gum. *LWT - Food Science and Technology*, *117*, 108617.

Kumar, L., Ramakanth, D., Akhila, K., and Gaikwad, K. K. (2022). Edible films and coatings for food packaging applications: A review. *Environmental Chemistry Letters*, *20*, 1–26.

Lan, W., Li, S., Shama, S., Zhao, Y., Sameen, D. E., He, L., and Liu, Y. (2020). Investigation of ultrasonic treatment on physicochemical, structural, and morphological properties of sodium alginate/AgNPs/apple polyphenol films and its preservation effect on strawberry. *Polymers*, 12, 2096.

Lee, J.-S., Lee, E., and Han, J. (2020). Enhancement of the water-resistance properties of an edible film prepared from mung bean starch via the incorporation of sunflower seed oil. *Scientific Reports*, *10*, 13622.

Lei, Y., Wu, H., Jiao, C., Jiang, Y., Liu, R., Xiao, D., Lu, J., Zhang, Z., Shen, G., and Li, S. (2019). Investigation of the structural and physical properties, antioxidant and antimicrobial activity of pectin-konjac glucomannan composite edible films incorporated with tea polyphenol. *Food Hydrocolloids*, *94*, 128–135.

Leuangsukrerk, M., Phupoksakul, T., Tananuwong, K., Borompichaichartkul, C., and Janjarasskul, T. (2014). Properties of konjac glucomannan–whey protein isolate blend films. *LWT - Food Science and Technology, 59*, 94–100.

Li, B., Kennedy, J. F., Jiang, Q. G., and Xie, B. J. (2006). Quick dissolvable, edible and heat-sealable blend films based on konjac glucomannan–gelatin. *Food Research International*, *39*, 544–549.

Li, B., Xu, Z., and Xie, B. J. (2006). Preparation and temperature effect on the swelling behavior of konjac glucomannan—methylcellulose blend film. *European Food Research and Technology*, *223*, 132–138.

Li, X., Jiang, F., Ni, X., Yan, W., Fang, Y., Corke, H., and Xiao, M. (2015). Preparation and characterization of konjac glucomannan and ethyl cellulose blend films. *Food Hydrocolloids*, *44*, 229–236.

Lim, L. I., Tan, H. L., and Pui, L. P. (2021). Development and characterization of alginate-based edible film incorporated with hawthorn berry (Crataegus pinnatifida) extract. *Journal of Food Measurement and Characterization*, *15*, 2540–2548.

Liu, J., Ma, Z., Liu, Y., Zheng, X., Pei, Y., and Tang, K. (2022). Soluble soybean polysaccharide films containing in-situ generated silver nanoparticles for antibacterial food packaging applications. *Food Packaging and Shelf Life*, *31*, 100800.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Liu, Z., Shen, R., Yang, X., and Lin, D. (2021). Characterization of a novel konjac glucomannan film incorporated with Pickering emulsions: Effect of the emulsion particle sizes. *International Journal of Biological Macromolecules*, *179*, 377–387.

Luo, Q., Hossen, M. A., Zeng, Y., Dai, J., Li, S., Qin, W., and Liu, Y. (2022). Gelatin-based composite films and their application in food packaging: A review. *Journal of Food Engineering*, *313*, 110762.

Ma, S., Zheng, Y., Zhou, R., and Ma, M. (2021). Characterization of chitosan films incorporated with different substances of konjac glucomannan, cassava starch, maltodextrin and gelatin, and application in Mongolian cheese packaging. *Coatings*, *11*, 84.

Matloob, A., Ayub, H., Mohsin, M., Ambreen, S., Khan, F. A., Oranab, S., Rahim, M. A., Khalid, W., Nayik, G. A., and Ramniwas, S. (2023). A review on edible coatings and films: Advances, composition, production methods, and safety concerns. *ACS Omega*, 8*,* 28932–28944.

Peng, L., Dai, H., Wang, H., Zhu, H., Ma, L., Yu, Y., Fu, Y., Feng, X., Du, J., and Zhang, Y. (2022). Effect of different dehydration methods on the properties of gelatin films. *Food Chemistry*, 374, 131814.

Peng, S., Zhang, J., Zhang, T., Hati, S., Mo, H., Xu, D., Li, H., Hu, L., and Liu, Z. (2022a). Characterization of carvacrol incorporated antimicrobial film based on agar/konjac glucomannan and its application in chicken preservation. *Journal of Food Engineering*, *330*, 111091.

Qiao, D., Shi, W., Luo, M., Jiang, F., and Zhang, B. (2022). Polyvinyl alcohol inclusion can optimize the sol-gel, mechanical and hydrophobic features of agar/konjac glucomannan system. *Carbohydrate Polymers*, *277*, 118879.

Qiao, D., Wang, Z., Cai, C., Yin, S., Qian, H., Zhang, B., Jiang, F., and Fei, X. (2020). Tailoring multi-level structural and practical features of gelatin films by varying konjac glucomannan content and drying temperature. *Polymers*, *12*, 385.

Rather, J. A., Akhter, N., Ashraf, Q. S., Mir, S. A., Makroo, H. A., Majid, D., Barba, F. J., Khaneghah, A. M., and Dar, B. N. (2022). A comprehensive review on gelatin: Understanding impact of the sources, extraction methods, and modifications on potential packaging applications. *Food Packaging and Shelf Life*, *34*, 100945.

Said, N. S., Howell, N. K., and Sarbon, N. M. (2023). A review on potential use of gelatin-based film as active and smart biodegradable films for food packaging application. *Food Reviews International*, *39*, 1063–1085.

Sancakli, A., Basaran, B., Arican, F., and Polat, O. (2021). Effects of bovine gelatin viscosity on gelatin-based edible film mechanical, physical and morphological properties. *SN Applied Sciences*, *3*, 1–11.

Sanyang, M. L., Sapuan, S. M., Jawaid, M., Ishak, M. R., and Sahari, J. (2015). Effect of plasticizer type and concentration on tensile, thermal and barrier properties of biodegradable films based on sugar palm (Arenga pinnata) starch. *Polymers*, 7, 1106–1124.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Sharmin, N., Rosnes, J. T., Prabhu, L., Böcker, U., and Sivertsvik, M. (2022). Effect of citric acid cross linking on the mechanical, rheological and barrier properties of chitosan. *Molecules*, *27*, 5118.

Sobhana, S. S. L., Sundaraseelan, J., Sekar, S., Sastry, T. P., and Mandal, A. B. (2009). Gelatin–Chitosan composite capped gold nanoparticles: A matrix for the growth of hydroxyapatite. *Journal of Nanoparticle Research*, *11*, 333–340.

Sun, J., Jiang, H., Wu, H., Tong, C., Pang, J., and Wu, C. (2020). Multifunctional bionanocomposite films based on konjac glucomannan/chitosan with nano-ZnO and mulberry anthocyanin extract for active food packaging. *Food Hydrocolloids*, *107*, 105942.

Sun, Y., Xu, X., Wu, Z., Zhou, H., Xie, X., Zhang, Q., Liu, R., and Pang, J. (2023a). Structure, merits, gel formation, gel preparation and functions of konjac glucomannan and its application in aquatic food preservation. *Foods*, *12*, 1215.

Sun, Y., Xu, X., Zhang, Q., Zhang, D., Xie, X., Zhou, H., Wu, Z., Liu, R., and Pang, J. (2023b). Review of konjac glucomannan structure, properties, gelation mechanism, and application in medical biology. *Polymers*, *15*, 1852.

Tyuftin, A. A., and Kerry, J. P. (2021). Gelatin films: Study review of barrier properties and implications for future studies employing biopolymer films. *Food Packaging and Shelf Life*, *29*, 100688.

Ulfariati, C., Aprilia, S., and Munawar, A. A. (2023). Development of biocomposite edible film food packaging based on gelatin from chicken claw waste. *Case Studies in Chemical and Environmental Engineering, 8*, 100371.

Wang, C.-S., Virgilio, N., Wood-Adams, P. M., and Heuzey, M.-C. (2018). A gelation mechanism for gelatin/polysaccharide aqueous mixtures. *Food Hydrocolloids*, *79*, 462–472.

Wang, H., Ding, F., Ma, L., and Zhang, Y. (2021). Edible films from chitosan-gelatin: Physical properties and food packaging application. *Food Bioscience*, *40*, 100871.

Wardhani, D. H., Wardana, I. N., Ulya, H. N., Cahyono, H., Kumoro, A. C., and Aryanti, N. (2020). The effect of spray-drying inlet conditions on iron encapsulation using hydrolysed glucomannan as a matrix. *Food and Bioproducts Processing*, *123*, 72–79.

Wu, F., Misra, M., and Mohanty, A. K. (2021). Challenges and new opportunities on barrier performance of biodegradable polymers for sustainable packaging. *Progress in Polymer Science*, *117*, 101395.

Xiao, C., Gao, S., Wang, H., and Zhang, L. (2000). Blend films from chitosan and konjac glucomannan solutions. *Journal of Applied Polymer Science*, *76*, 509–515.

Xiao, C., Lu, Y., Gao, S., and Zhang, L. (2001). Characterization of konjac glucomannan–gelatin blend films. *Journal of Applied Polymer Science*, *79*, 1596–1602.

Yan, H., Cai, B., Cheng, Y., Guo, G., Li, D., Yao, X., Ni, X., Phillips, G. O., Fang, Y., and Jiang, F. (2012). Mechanism of lowering water activity of konjac glucomannan and its derivatives. *Food Hydrocolloids*, *26*, 383–388.

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045

Yan, Y., Duan, S., Zhang, H., Liu, Y., Li, C., Hu, B., Liu, A., Wu, D., He, J., and Wu, W. (2020). Preparation and characterization of Konjac glucomannan and pullulan composite films for strawberry preservation. *Carbohydrate Polymers*, *243*, 116446.

Zhao, J., Wang, Y., and Liu, C. (2022). Film transparency and opacity measurements. *Food Analytical Methods*, *15*, 2840–2846.

Zhou, G., Li, Y., Zhang, L., Zuo, Y., and Jansen, J. A. (2007). Preparation and characterization of nano-hydroxyapatite/chitosan/konjac glucomannan composite. *Journal of Biomedical Materials Research Part A, 83*, 931–939.

Zhou, N., Zheng, S., Xie, W., Cao, G., Wang, L., and Pang, J. (2022). Konjac glucomannan: A review of structure, physicochemical properties, and wound dressing applications. *Journal of Applied Polymer Science*, *139*, 51780

DOI: https://doi.org/10.17509/ijost.v9i3.75048
p- ISSN 2528-1410 e- ISSN 2527-8045