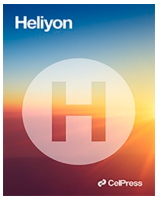
Heliyon 10 (2024) e30338

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Development and characterization of camel gelatin films: Influence of camel bone age and glycerol or sorbitol on film properties

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ARTICLE INFO

Keywords:
Gelatin
Food packaging
Aged
Film
Sorbitol
Glycerol

ABSTRACT

This study developed and evaluated camel bone gelatin films (CBGFs) with glycerol or sorbitol as plasticizers. Gelatin extracted from the bones of camels (*Camelus dromedarius*) at ages ranging from 2.5 to 7 years was used. A comprehensive analysis was conducted, evaluating a range of properties including thickness, moisture sorption capacity, water vapor permeability (WVP), infrared spectral characteristics, light absorption behavior, solubility, as well as mechanical and thermal attributes. This thorough examination allowed for a nuanced understanding of the diverse characteristics exhibited by the camel gelatin samples across different age groups. The results indicated that camel age, glycerol, and sorbitol had a significant impact on the properties of the film ($P < 0.05$). Tensile strength ranged from 0.32 MPa to 3.99 MPa, while the percentage of elongation at break varied from 89.42 % to 2.68 %. Film color (lightness, L) ranged from 21.39 to 41.33. Glycerol and sorbitol plasticized films were 100 % water soluble. Moisture sorption increased with temperature (25 °C, 35 °C, and 45 °C), with sorbitol films retaining less water. WVP was low in films from old camel bones and high in glycerol-plasticized CBGF-2.5Y and CBGF-4.5Y. Thermal analysis showed a melting temperature between 158.60 °C and 174.10 °C, depending on bone age and plasticizer. These films demonstrate promise for use in food packaging, coatings, and pharmaceutical applications.

1. Introduction

Gelatin films, along with other biopolymer films, are a viable option for food preservation and shelf-life extension because they act as effective barriers for gases and water vapor. Gelatin originates from the breakdown of collagen present in animal bones and connective tissue through hydrolysis, which are often discarded during animal processing and slaughter. Recently, there has been growing interest in the utilization of by-products, which directly impact the economy and environment, has been growing [1]. Bovine and porcine gelatin sources are the most commonly used commercially [2]. Several attempts to achieve alternative sources of gelatin to develop films, such as fish and plant-based sources, have been made to address concerns related to religious and cultural dietary restrictions and ethical and environmental concerns [3]. However, the properties of gelatin could affect the characteristics of the developed gelatin films, and further research is needed to explore their potential applications. Extraction conditions can impact gelatin characteristics, which depend on the length of the polypeptide chains [4]. The properties of gelatin films, which depend on the source of gelatin, substances used in preparation, and preparation conditions, vary accordingly [5].

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https://doi.org/10.1016/j.heliyon.2024.e30338
Received 27 February 2024; Received in revised form 24 April 2024; Accepted 24 April 2024
Available online 27 April 2024
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Abbreviation full name

CBGF	Camel bone gelatin films
Gly	Glycerol
Sorb	Sorbitol
TS	Tensile strength
%EAB	Percentage of elongation at break
Tm	Melting temperature
Tg	Glass transition
WVP	Water vapor permeability
ATR-FTIR	Attenuated total reflection-Fourier Transform Infrared

Biopolymer films are developed by mixing gelatin with plasticizers, which enhance their film-forming ability and flexibility. However, gelatin is recognized for its exceptional film-forming properties, making it an ideal material for this application [6]. Gelatin films can also serve as carriers for active materials and nanoparticles that inhibit changes in food quality during storage, although the incorporation of materials such as nanoparticles and essential oils can affect gelatin film properties. Gelatin-based films, which are derived from mammalian, fish gelatin, and plant sources, these possess the capability to act as carriers for functional components, thereby aiding in the preservation of food quality and the extension of shelf life [7].

Gelatin films are often used as a biodegradable and edible packaging material due to their good mechanical properties, high water vapor permeability (WVP), and ability to incorporate various additives. Glycerol and sorbitol are commonly used plasticizers to improve the flexibility and elasticity of gelatin films. Glycerol as a plasticizer can form hydrogen bonds with the polar groups in gelatin, reducing the intermolecular attraction between gelatin chains and allowing the chains to move freely, resulting in increased flexibility and reduced brittleness of the films. Incorporating glycerol or sorbitol into gelatin films at different ratios improved the films' workability and flexibility [8]. Furthermore, the ratio of plasticizer used in their study was found to have an impact on the film characteristics. A separate study examined the use of sorbitol, mannitol, ethylene glycol, diethylene glycol, and triethylene glycol, on gelatin film characterizations [9]. The findings demonstrated significant effect on WVP and water content (WC) values. Given the functionality and sustainability of gelatin films, they are currently being widely employed in food packaging applications. In a recent study, gelatin films were developed and characterized using gelatin extracted from camel skin of varying ages, and it was found that the age of the camel and the type of plasticizer used had a significant effect ($P < 0.05$) on the strength and extensibility of the resulting films [10]. The incorporation of glycerol was observed to decrease the tensile strength (TS) of the films but increase the percentage of elongation at break (%EAB) in comparison with films containing sorbitol. The aim of this study was to investigate how the age of camel bones and the type of plasticizer influence the properties of camel bone gelatin films (CBGFs).

2. Materials and methods

2.1. Materials

Bone camel gelatin from different camels aged 2.5, 4.5, and 7 years (bloom 120, 122, and 72), respectively. The gelatin was extracted previously in the lab [4]. All bones were collected from a slaughterhouse in Buraydah City, Saudi Arabia. Glycerol and sorbitol were from Panreac, Castellar del Vallès (Spain). The chemicals used in the research were all of analytical grade purity.

2.2. Preparation films

The CBGF-forming solutions were prepared by adding plasticizers (glycerol or sorbitol) in accordance with the procedures outlined by Ref. [11]. Gelatin (3 g) with 33 % glycerol and 75 % sorbitol (w/w) in 100 mL of distilled water were used for preparing the film. Film casting method was used (95 g) onto polyacrylic plates (16 cm × 16 cm × 3 mm) and oven drying at 60 °C for 24 h. The dry films were peeled off and stored with 56 % relative humidity at 30 °C until further analysis.

2.3. Film thickness and light absorption

The measurement of the film thickness was performed by using a manual micrometer (Etopoo, QFC28-100-China) with an accuracy of 0.001 mm. The average thickness was calculated from six different positions of the samples. Hunter Lab instruments (USA) was used for measuring the Light absorption of the films.

2.4. Mechanical properties

The TS and %EAB of the camel gelatin films were evaluated using the ASTM D882-00 guidelines [12]. Film specimen strips measuring 14 cm × 2 cm were stored in 56 % relative humidity at 30 °C for 48 h. The tension test was applied using the texture analyzer TA XT2 (Stable Microsystems, Surrey, UK) with a load cell of 30 kg and crosshead speed of 60 mm/min. The film samples were

10 cm long and 2 cm wide. The results were expressed in MPa and percentage (%).

2.5. Solubility of the films

To determine the films solubility, this study employed the methodology described in Ref. [13]. Samples 2 × 3 cm were cut from each film and submerged in 80 mL of deionized water, with continuous stirring for 1 h at room temperature (approximately 25 ± 2 °C). The samples went under filtration with a Whatman® 4 filter paper, then dried in an oven at 60 °C until a constant weight was achieved. The results expressed as Solubility% = [(Initial dry weight−Final dry weight)/Initial dry weight] × 100.

2.6. Moisture sorption isotherm

Small pieces of the films were scanned and equilibrated at different RH percentage (0%–60 %) and different temperatures (25 °C, 35 °C, and 45 °C) using QS5000 equipment (TA Instruments Ltd., USA).

2.7. WVP

The method described in ASTM E 96-00 [14] was followed to determine the WVP of the camel films obtained. The test was carried out using gas permeation cells (4.5 cm diameter and 2.8 cm height). The cells were filled with 25 g of silica gel (0 % RH) and the films were sealed on top of it and placed in a desiccator containing sodium bromide (56 % RH) at 30 °C. The weight of the permeation cells was taken at 24-h intervals over a seven-day period, and the results were plotted as a function of time. The slope of each line was calculated by linear regression ($r2 \geq 0.99$). The measured WVP of the films was determined using the following formula: WVP = (WVTR. L)/ΔP, where WVTR is the water vapor transmission rate ($g.m^{-2}.h^{-1}$) through a film; L is the film thickness (mm); and ΔP is the partial water vapor pressure difference (Pa) across the two sides of the film. The WVP measurements were replicated three times.

2.8. FTIR spectroscopy

Infrared spectra of gelatin powder samples were obtained by ATR-FTIR using an ALPHA-Eco FT-IR spectrometer with an Eco-ZnSe sampling module (Bruker Optics, Germany). The range of the spectral region was 4000–600 cm^{-1}.

2.9. Thermal analysis

The films thermal properties were determined using the differential scanning calorimetry (DSC) a TA Instruments Calorimeter Q20 (TA Instruments Ltd., USA). Samples weighing approximately 15 mg ± 2 mg placed in a T-zero hermetic aluminum pans were conditioned at 56 % relative humidity at 30 °C for 48 h, hermetically sealed, and then heated from 0 °C to 200 °C at a scanning rate of 3 °C/min with an empty pan as a reference. The glass transition (Tg), the transition temperature (Tm) and the enthalpy (ΔH) were calculated. The results were analyzed using the TA Instrument Universal analysis 2000 software.

2.10. Statistical analyses

The results analysis was performed as one-way variance analysis using Duncan's test with the confidence level as $P \leq 0.05$. The Statistic Package for Social Science (SPSS 18.0, SPSS Inc, Chicago, IL, USA) was used to determine the significant differences among the data. Each assay of the CBGF was conducted three times.

3. Results and discussion

3.1. Film thickness and mechanical properties

Gelatin films with plasticizers, which were transparent, homogeneous, flexible, and easily removed from acrylic plates, were developed at a thickness ranging from 1.4 mm to 2.1 mm. The obtained results, which evaluated the effect of camel bone gelatins

Table 1
The tensile strength, the percentage of elongation at break (%EAB) and the lightness values of the camel bone gelatin films.

Gelatin	Plasticizer	TS (MPa)	EAB (%)	Lightness (L-Value)
CSGF-2.5Y	G	0.48 ± 0.08^{e}	89.42 ± 3.53^{a}	26.57 ± 0.81^{c}
	S	2.08 ± 0.29^{c}	2.56 ± 0.21^{d}	30.73 ± 5.14^{b}
CSGF-4.5Y	G	0.69 ± 0.15^{d}	45.44 ± 17.57^{c}	21.39 ± 0.59^{d}
	S	3.21 ± 0.26^{b}	3.19 ± 0.47^{d}	41.33 ± 1.49^{a}
CSGF-7Y	G	0.32 ± 0.06^{f}	58.44 ± 5.11^{b}	29.83 ± 1.03^{b}
	S	3.99 ± 0.41^{a}	2.68 ± 0.18^{d}	31.32 ± 0.59^{b}

Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p < 0.05$). G: Glycerol; S: Sorbitol.

extracted from camels of different ages (2.5, 4.5, 7 years) and type of plasticizer (glycerol or sorbitol) on mechanical properties (TS and %EAB) and lightness value (L-value), are presented in Table 1. The age of camels and the type of plasticizer significantly affected the prepared films ($P < 0.001$). The TS of films showing variability across the samples with glycerol ranged from 0.32 ± 0.06 MPa to 3.99 ± 0.41 MPa, while the %EAB ranged from 2.56 ± 0.21 % to 89.42 ± 3.53 %, and lightness (L-value) ranged from 21.39 ± 0.59 % to 41.33 ± 1.49 %. Among the prepared films, CBGF-7Y plasticized with sorbitol showed the highest TS value of 3.99 ± 0.41 MPa, while, the CBGF-4.5Y incorporating sorbitol exhibited a tensile strength (TS) value of 3.21 ± 0.26 MPa due to the film physical characteristics. Sorbitol, with its higher molecular weight and greater number of hydroxyl groups compared to glycerol, resulted in increased film hardness when compared to films plasticized with glycerol. This difference may stem from sorbitol's reduced plasticizing effect, possibly due to its interaction with gelatin molecules [11].

Data also revealed that the CBGF-2.5Y film exhibited the highest %EAB value, recording the highest value at 89.42 ± 3.53 %. The films with glycerol exhibited the lowest TS values. Specifically, CBGF-7Y recorded a TS of 0.32 ± 0.06 MPa with %EAB of 58.44 ± 5.11 %, followed by CBGF-4.5Y with a TS of 0.69 ± 0.15 MPa and %EAB of 45.44 ± 17.57 %. This result suggests a significant effect on the glycerol gelatin film properties including the tensile strength and %EAB with the variation of camel age. However, there was a noticeable impact on the properties of glycerol gelatin films, particularly concerning TS and %EAB, due to differences in the age of the camels from which the gelatin is derived. This implies that the age of the camels influences the characteristics of the gelatin films, potentially affecting their performance and suitability for various applications [15,16].

The mechanical properties of gelatin films can be significantly affected by factors, such as the proportion of gelatin within a composite solution and changes in gelatin concentration and plasticizers [17]. These observations may be due to a lower protein content with slightly lower hydroxyproline, resulting in reduced gel strength [4]. In terms of transparency, gelatin films plasticized with sorbitol generally exhibited greater transparency compared to those plasticized with glycerol. The films transparency was observed to increase with the age of the camel bones giving that (L* factor) of films plasticized with glycerol showed a significant increase from 24.39 ± 0.59 to 29.83 ± 1.03 as the age of the bones increased from 2.5 years to 7 years, respectively. However, no significant differences were found between CBGF-2.5Y and CBGF-4.5Y ($P < 0.05$). Incorporating sorbitol as a plasticizer generally enhances the transparency of gelatin films. This improvement is attributed to the reduction in light scattering within the film, leading to increased clarity. Specifically, films plasticized with sorbitol demonstrated an increase in transparency (L* factor) from 30.73 ± 1.14 to 41.33 ± 1.49 as the age of the camel bones progressed from 2.5 years to 4.5 years, respectively. The observations indicated that no significant differences between CBGF-2.5Y and CBGF-7Y; however, the variation observed may depend on factors, such as the concentration of the plasticizer and the amino acid content of the bone gelatin, which can vary with age. The transparency of gelatin films can vary depending on the source of the gelatin used [18]. Additionally, the use of natural additives and nanoparticles as composite materials can affect the transparency of the films, potentially causing them to appear darker in color [19]. The values varied significantly due to the interaction of multiple factors such as the gelatin source, the age of the camels, and the type of plasticizer used.

3.2. Solubility of the films

All developed film sample with glycerol and sorbitol were fully dissolved (100 %) in water, which is a crucial aspect to consider when assessing the biodegradability potential of the film. Highly soluble films can be hydrolyzed easily, resulting in small molecules, making them desirable for use in edible materials. The enhanced solubility of protein-based films could stem from reduced interactions between proteins and other elements present in the polymer matrix [20]. When considering the consumption of films with food products, solubility is a crucial factor and highly desirable. Additionally, it serves as an indicator of the material's biodegradability [21]. The complete dissolution of films composed of camel gelatin, polyols, and water suggests that their particular bonding and interaction are responsible for the solubility of the films.

Table 2
Effect of the camel bone gelatin, the plasticizers and the temperature levels on moisture sorption isotherm of the gelatin films.

Films	Plasticizer	Sorption Isotherm %		
		T_1 (25 °C)	T_2 (35 °C)	T_3 (45 °C)
CBGF-2.5Y	NP	7.1 ± 0.3^{c}	9.6 ± 0.5^{d}	10.3 ± 0.7^{d}
CBGF-4.5Y	NP	7.6 ± 0.4^{c}	9.1 ± 0.6^{d}	11.1 ± 0.6^{d}
CBGF-7Y	NP	6.1 ± 0.7^{c}	8.1 ± 0.3^{e}	9.8 ± 0.6^{d}
CBGF-2.5Y	G	20.3 ± 1.7^{a}	26.0 ± 2.4^{a}	29.5 ± 2.1^{a}
CBGF-4.5Y	G	20.6 ± 2.1^{a}	25.5 ± 2.5^{a}	26.1 ± 2.6^{a}
CBGF-7Y	G	21.7 ± 1.8^{a}	23.8 ± 2.3^{ab}	26.1 ± 1.9^{a}
CBGF-2.5Y	S	18.2 ± 1.9^{a}	20.8 ± 2.1^{b}	20.0 ± 1.8^{b}
CBGF-4.5Y	S	9.8 ± 0.7^{b}	$13.8 + 1.6^{c}$	14.1 ± 2.3^{c}
CBGF-7Y	S	11.4 ± 1.4^{b}	14.9 ± 1.3^{c}	16.9 ± 2.1^{cb}

T: Temperature, G: Glycerol; S: Sorbitol. Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p < 0.05$).

3.3. Moisture sorption isotherm

The evaluation of the sorption–desorption isotherm of CBGFs at different temperatures 25 °C, 35 °C, and 45 °C as well as different relative humidity levels (0%–60 %) are presented in Tables 2 and 3. The obtained results indicated that increasing the temperature raised the sorption and desorption percentage. In addition, films treated with glycerol from bone showed the highest percentages of sorption and desorption. The glycerol-based films revealed water sorption values ranging from 20.3 % to 21.7 %, 23.8 %–26.1 %, and 26.1 %–29.5 % at temperatures of 25 °C, 35 °C, and 45 °C, respectively. These results suggest that raising the temperature leads to an increase in the water sorption values. Nevertheless, when subjected to same temperatures, the films formulated with sorbitol exhibited water sorption levels ranging from 9.8 % to 18.2 %, 13.8 %–20.8 %, and 14.1 %–20.0 %, correspondingly. In relation to the desorption behavior of water, it was observed that the films did not completely release the absorbed water. The films made using glycerol at temperatures of 25 °C, 35 °C, and 45 °C exhibited desorption values ranging from 12.5 % to 12.9 %, 14.0 %–17.7 %, and 14.1 %–20.8 %, respectively. In comparison, the films that were made utilizing sorbitol exhibited a lower water retention rate in comparison to those that were plasticized with glycerol. Water desorption values ranging from 4.4 % to 10.2 %, 6.3 %–11.4 %, and 8.6 %–12.1 % were reported at temperatures of 25 °C, 35 °C, and 45 °C, respectively. The observed differences may be attributed to the plasticizer characteristics, as previous studies have extensively documented reduced hygroscopic variations in gelatin films [22]. Furthermore, the utilization of glycerol as a plasticizer in films resulted in a decrease in intermolecular forces. This can be attributed to the reduced formation of hydrogen bonds by glycerol and the weak interchain interactions facilitated by the gelatin chains. These molecules, which possess hydrophilic properties, were rather tiny in size [22]. Incorporating essential oil and nanoparticles in gelatin-based films might decrease the monolayer and free-water content in the equilibrium-adsorption isotherm, hence influencing the moisture of the films [19]. Furthermore, the origin of the gelatin employed in the process of film formation may have an impact on the values of the moisture sorption and desorption isotherm. This is attributed to alterations in the characteristics of the gelatin within the films that are formed [17]. The observed variances may also be attributed to the influence of camel bone ages, which in turn impacted the morphological characteristics of the gelatin and the resulting films.

3.4. WVP

The WVP values of the developed films are presented in Table 4. The recorded values exhibited a range of 2.75 ± 07 to 8.62 ± 07 (g mm h^{-1} m^2 Pa^{-1}). The film composed of gelatin derived from a 2.5-year-old camel bone combined with sorbitol demonstrated the greatest value, followed by 5.62 ± 08 (g mm h^{-1} m^2 Pa^{-1}) in the film formulated using gelatin from a 7-year-old camel bone with sorbitol. However, the WVP values in produced films with sorbitol decreased as the age of the bone increased. In both formulated films, CBGF-2.5Y with glycerol and sorbitol showed lower WVP values possibly due to age. The choice of plasticizer used can sometimes bind with the gelatin, producing more robust films with enhanced interactions, resulting in an elevated level of protein molecular arrangement. Consequently, the films exhibit a significant increase in structural density, preventing water vapor penetration more effectively [23]. The phenomena under observation can be linked to the transmission occurring within the protein-based film, which is influenced by the elevated concentration of polar amino acid residues present in the film's structure. The effects also are further enlarged by the inclusion of hydrophilic plasticizers. The observed phenomena can be attributed to the transmission through the protein-based film, which is influenced by the higher concentration of polar amino acid residues in the film's structure. The presence of hydrophilic plasticizers further contributes to these effects. Moreover, the inherent hydrophilicity of gelatin plays a role in the altered water vapor transmission when these components are incorporated into the films [24]. The WVP is influenced by the configuration of the polymers within the film matrix. The observed fluctuations in WVP readings can be attributed to the varying levels of proline and hydroxyproline amino acids present within the gelatin matrix. The amino acids proline and hydroxyproline are essential for preserving the structured triple helical arrangement of gelatin films during the process of denaturation, hence promoting the formation of a gel network [25]. The importance of hydroxyproline in stabilizing the triple-stranded collagen helix is widely acknowledged, mostly attributed to its ability to form hydrogen bonds with the hydroxyl group. It has been noted that the elevated levels of proline,

Table 3
Effect of camel bone gelatin, plasticizers and the temperature levels on moisture desorption isotherm of the camel bone gelatin films.

Films	Plasticizer	Desorption Isotherm %		
		T_1 (25 °C)	T2 (35 °C)	T3 (45 °C)
CBGF-2.5Y	NP	7.1 ± 0.3^{b}	9.6 ± 0.5^{c}	10.3 ± 0.7^{d}
CBGF-4.5Y	NP	7.6 ± 0.4^{b}	9.1 ± 0.6^{c}	11.1 ± 0.6^{cd}
CBGF-7Y	NP	6.1 ± 0.7^{b}	8.1 ± 0.3^{d}	9.8 ± 0.6^{d}
CBGF-2.5Y	G	12.5 ± 1.1^{a}	17.7 ± 1.4^{a}	20.8 ± 1.2^{a}
CBGF-4.5Y	G	12.9 ± 1.2^{a}	14.0 ± 1.7^{b}	15.0 ± 1.4^{b}
CBGF-7Y	G	12.8 ± 1.6^{a}	14.0 ± 1.3^{b}	14.1 ± 1.2^{b}
CBGF-2.5Y	S	10.2 ± 1.3^{a}	11.4 + 1.4^{c}	12.1 ± 1.1^{c}
CBGF-4.5Y	S	4.8 ± 0.4^{c}	7.5 ± 1.6^{d}	8.6 ± 1.5^{d}
CBGF-7Y	S	4.4 ± 0.2^{c}	6.3 ± 0.9^{d}	10.1 ± 1.1^{d}

T: Temperature, NP: no plasticizer added, G: Glycerol; S: Sorbitol. Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p < 0.05$).

Table 4
Thermal properties and water vapor permeability (WVP) of the camel bone gelatin films with plasticizes.

Films	Plasticizer	T_g °C	T_m °C	WVP (g.mm h^{-1} m^2 Pa^{-1})
CBGF-2.5Y	NP	130.31 ± 4.35[b]	179.81 ± 7.44[a]	–
CBGF-4.5Y	NP	110.23 ± 6.11[d]	181.11 ± 8.21[a]	–
CBGF-7Y	NP	107.27 ± 5.15[d]	184.42 ± 7.12[a]	–
CBGF-2.5Y	G	149.90 ± 10.14[a]	172.70 ± 11.40[b]	2.86 ± 06[d]
CBGF-4.5Y	G	133.20 ± 15.10[b]	159.50 ± 16.10[c]	2.75 ± 07[d]
CBGF-7Y	G	128.20 ± 17.21[b]	158.60 ± 15.26[c]	2.83 ± 07[d]
CBGF-2.5Y	S	145.10 ± 11.80[a]	165.90 ± 16.50[b]	8.62 ± 07[a]
CBGF-4.5Y	S	137.50 ± 10.70[b]	174.10 ± 12.70[b]	4.92 ± 06[c]
CBGF-7Y	S	144.90 ± 12.74[a]	169.10 ± 14.56[b]	5.62 ± 08[b]

NP: no plasticizer added, T_g: glass transition, T_m: melting temperature, G: Glycerol; S: Sorbitol. Values were given as mean ± standard deviation. Values with the same superscript letters within a column are not significantly different ($p < 0.05$).

hydroxyproline, and alanine in mammalian gelatins are a significant contributing factor to their comparatively higher viscosity qualities in comparison to fish gelatins [26]. The observed findings are likely to be ascribed to the interplay of gelatin molecules, leading to reductions in the presence of hydrophilic functional groups and subsequently impacting the accessibility of water for absorption.

3.5. Thermal properties

Table 4 presents an evaluation of the thermal stability of films produced from camel bone gelatins with plasticizers, encompassing the glass transition (Tg) and melting temperature. The study revealed that thermal stability varied depending on both the age of the bones from which the gelatin was derived and the type of plasticizer used. The Tg temperature varied between 107.27 °C and 149.90 °C, suggesting a potential relationship with the size of the triple helices found in gelatins from different bone ages as a results of the variation of the proline and hydroxyproline amino acids content. The films showed variations in their melting points (Tm) depending on the type of plasticizer used. However, the films containing sorbitol demonstrated a propensity for their Tm to drop upon its introduction compared to un-plasticized ones. The sorbitol films had Tm values between 165.90 °C and 174.10 °C, whereas the glycerol films had Tm values between 158.60 °C and 172.70 °C compared to un-plasticized films that were in the range of 179.81 °C and 184.42 °C. The observed effects can be attributed to the action of the plasticizer, which introduces chemical compounds into the films, hence affecting the development of triple helices in the gelatins and disrupting hydrogen bonds and hydrophobicity. However, the addition of a plasticizer can stimulate the formation of strong and compact network structures, hence improving thermal stability [27].

3.6. Infrared spectra

Infrared spectra were collected via ATR-FTIR (Figs. 1 and 2) to compare the effect of camel bone gelatins and the type of plasticizer used (glycerol and sorbitol) on the produced films. The plasticized films exhibited slightly higher absorbance bands in comparison with the un-plasticized films. The spectra showed a broad band at 3310.19 cm^{-1} (O–H stretching) and the band at 2941.08 cm^{-1} representing C–H stretching, while amide A band (3100–3500 cm^{-1}). Amide I occurred as a result of C═O stretching, which was observed at 1645.77 cm^{-1}. This band is considered the most useful indicator of protein secondary structure by infrared spectroscopy [28]. The band at 1415.45 cm^{-1} represented the –NH twisting mode (amide II), ranging between 1560 and 1335 cm^{-1} and 1230–670 cm^{-1} (amide III) [29], which is caused by an NH group's bending vibration and a CN group's stretching vibration. The peak centered at

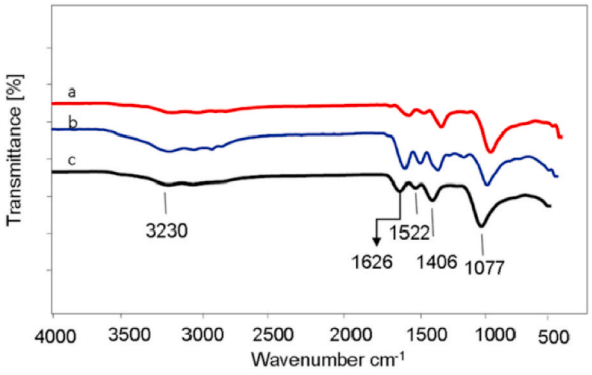

Fig. 1. The FTIR spectra of camel bone gelatin films with no plasticizers added: (a) CBGF-2.5Y, (b) CBGF-4.5Y, and (c) CBGF-7Y.

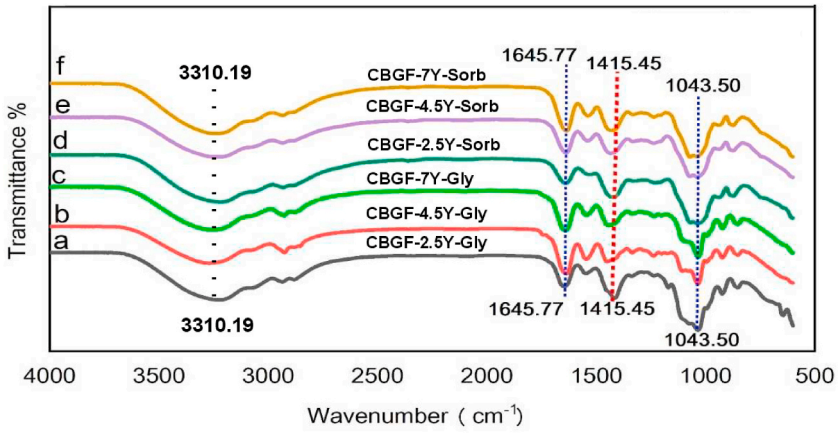

Fig. 2. The FTIR spectra of camel bone gelatin films: (a) CBGF-2.5Y-Gly, (b) CBGF-4.5Y-Gly, (c) CBGF-7Y-Gly, (d) CBGF-2.5Y-Sorb, (e) CBGF-4.5Y-Sorb, and (f) CBGF-7Y-Sorb.

1043.50 cm^{-1} (amide III) with variation in band intensity could potentially indicate the interactions between the plasticizer (specifically, the OH group of glycerol and sorbitol) and the structure of the film. The OH groups of glycerol and sorbitol can potentially interact with polymer chains through hydrogen bonding and affect the film's structure and properties. The presence of Amide III was confirmed by many spectrum characteristics, including a stretching vibration of the CN bond, a deformation of the NH bond due to amide linkages, and a wagging vibration indicating the presence of CH2 groups from the amino acids glycine and proline [30]. Based on the spectra, the amide-I, amide-II, and amide-III peaks for all films produced as camel gelatin films with both plasticizers remained unchanged in their vibrational wavenumber, with the exception of the amide-A peak. The presence of hydrogen bonding connections between polymer molecules in the film can be inferred from a decrease in the vibrational wavenumber and an increase in the width of the OH and NH vibration bands.

4. Conclusion

The study involved the development and evaluation of the physical, mechanical, and thermal properties of CBGFs using glycerol (33 %) or sorbitol (75 %) as plasticizers. The findings demonstrated that the strength and extensibility of the films were significantly influenced by the age of the camel bones and the type of plasticizer used. Specifically, the %EAB for the films with glycerol CBGF-2.5Y was 89.42 %, followed by 58.44 % for CBGF-7Y and 45.44 % for CBGF-4.5Y, in comparison to films plasticized with sorbitol, which presented 2.56 %, 3.19 %, and 2.68 %, respectively. The inclusion of glycerol in the films resulted in a decrease in the TS values, with the lowest being 0.32 MPa, compared to films containing sorbitol, which had the highest TS of 3.99 MPa for CBGF-7Y films. Vapor sorption values exhibited a positive correlation with temperature, depending on the origin of the gelatin and the plasticizers employed. Films plasticized with sorbitol exhibited a lower water retention rate compared to those plasticized with glycerol. The films show promising potential for use in various food processing applications, including but not limited to food packaging, coatings, and medicinal materials.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

Data availability statement

The author declares that the data will be made available on request.

CRediT authorship contribution statement

A.A. Al-Hassan: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used OpenAI. (2021). GPT-3.5 in order to proofreading. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The researcher would like to thank the Deanship of Scientific Research, Qassim University for funding publication of this project. Also, the author would like to express gratitude to the King Abdul-Aziz City for Science and Technology (KACST) in Saudi Arabia for their financial support under the project no: A.T. 35–305.

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