


ORIGINAL RESEARCH

Edible hyaluronic acid-rich burger separator discs prepared from slaughterhouse waste

Mahboubeh Kalantarmahdavi¹ | Amir Salari¹ | Zahra Pasdard² |
Mohamad Reza Amiryousefi³ 

¹Department of Food Hygiene and Aquaculture, Faculty of Veterinary Medicine, Ferdowsi University of Mashhad (FUM), Mashhad, Iran

²School of Medicine, Medical Science and Nutrition, University of Aberdeen, Aberdeen, UK

³Department of Food Science and Technology, Neyshabur University of Medical Sciences, Neyshabur, Iran

Correspondence

Mohamad Reza Amiryousefi, Department of Food Science and Technology, Neyshabur University of Medical Sciences, P.O. Box. 9314632814, Neyshabur, Iran.
Email: mramiryousefi@gmail.com

Funding information

Neyshabur University, Grant/Award Number: 97284

Abstract

In this study, edible films from chicken feet extract (CF), ovine muscle fascia extract (MF), and bovine bone gelatin powder (Gel) were prepared and their characteristics were analyzed. We also used the films as separators of burger cuts and evaluated the organoleptic characteristics of cooked burgers. Hyaluronic acid quantities of CF and MF were measured using colorimetric and spectrophotometry. Results indicated that the concentration of hyaluronic acid in CF (124.11 ppm) was greater than MF (101.11 ppm). The antioxidative property of the CF film (18.47%) was greater than the Gel (1.88%) and MF (Undetectable) films. The CF film was more resistant to water vapor permeability (2.75×10^{-9} g/m.s.pa) than the MF (1.57×10^{-8} g/m.s.pa) and Gel (1.5×10^{-7} g/m.s.pa) films. The Gel film had more appropriate mechanical properties than CF and MF films. The films kept burgers patties independent from one another and prevented them from sticking and freezing together. MF and CF films were able to promote the organoleptic properties of cooked burgers in taste and texture.

KEYWORDS

bovine bone gelatin, chicken feet, edible film, hyaluronic acid, ovine muscle fascia

1 | INTRODUCTION

Food packaging applications widely use biopolymers as film-forming materials. Extensive research and experiments on proteins and polysaccharides as the materials for films and coatings preparation have been performed. Nowadays, a variety of naturally derived polymers are accessible for application in the form of biomaterials. Examples include polysaccharides derived from plants, animals, fungi and bacteria, as well as proteins, lipids/surfactants, and other polymers (Rajeshkumar, 2022). Importantly, many of these polymers are extracted from sources which could be used for human consumption. In the meantime, using slaughterhouse waste as a rich source of protein and other nutrients such as hyaluronic acid can be a good idea for preparing food films.

Remains of carcass, butcher and slaughterhouse waste, blood, feathers, wool, hides, and skins are the major animal byproducts acquired from the animal processing industry. The quantity of animal byproducts in the animal industry typically surpasses 50% of the live weight, and the dressing percentages of carcasses range from 57% (standard cattle grades) to 70% (chicken), depending on the animal (Ferreira et al., 2016).

Slaughterhouses, like most food industries, produce waste that needs to be managed consistently. According to the Food and Agriculture Organization (FAO), 1000 heads per unit of chickens were produced in Iran during 2019 and 25% of this amount was a waste (Food and Agriculture Organization of the United Nation, 2020). In an endeavor to achieve greater sustainability, an investment in low-cost productivity support methods is essential. In addition, it is

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2022 The Authors. *Food Science & Nutrition* published by Wiley Periodicals LLC.

important to focus on the use of by-products in the poultry industry. Approximately 3.9 million metric tons/year of chicken feet are produced by the poultry processing industries (Chakka et al., 2017). Chicken feet collagen primarily comprises type I and type II collagen and also contains 8.70% proline, 16.30% glycine, and 14.15% hydroxyproline (Dhakal et al., 2018). According to Lee et al. (2015), chicken feet protein film had a tensile strength (TS) of 7.13 MPa and elongation of 21.78% (Lee et al., 2015). As a result, chicken feet extract seems to be an appropriate material for making edible films.

In mammals, Collagen encompasses 25%–30% of the total body protein content. Collagen is also an important constituent of muscle tissue (forming 1%–2% of muscle tissue) where it is a chief component of the endomysium (Silvipriya et al., 2015). Moreover, fascia, which is a continuous viscoelastic tissue synthesized from layers of dense connective tissue (collagen types I and III) and interfaced by loose connective tissue, has a prominent viscoelastic property (Cowman et al., 2015). Deep fasciae can be divided into two major categories: the epimysial fasciae and the aponeurotic fascia (Fede et al., 2018). The epimysial fasciae consist of all the connective tissues which surround and interpenetrate the muscles and tendon, and are tightly adherent to them, such as epimysium, perimysium, and endomysium. The aponeurotic fascia is fibrous connective tissue layers that cover muscles and connect different segments at a distance (Fede et al., 2018). This tissue is one of the by-products of discarded sheep muscles. To date, waste from various animals has been used to produce edible films, but in this study, for the first time, aponeurotic fascia extract was used as a rich source of collagen and hyaluronic acid to prepare an edible film. Chicken and ovine by-products, such as chicken feet and ovine muscle fasciae, have considerable amounts of collagen and hyaluronic acids (Hashim et al., 2014).

The incomplete hydrolysis of collagen during moist heating produces gelatin, the use of gelatin films for food preservation applications such as in coatings or films, has been broadly researched (Luo et al., 2022). Despite the very hydrophilic nature of gelatin, gelatin films have been demonstrated to have very good process ability and they possess appropriate barrier and mechanical properties. Moreover, the origin of the gelatin and its film-processing features have a substantial impact on the operational features of the ensuing gelatin-based films (Said et al., 2021).

One of the applications of edible films is to use them as separators between food pieces such as burgers. In the commercialization of burger products, the breaking of slices during separation just before consumption is a major problem. Slice separator films are commonly used to avoid sticking, such as oriented polypropylene, PET, or paper coated with PVDC dispersions or PE (Schneider et al., 2010). Slice separator edible films could be a good alternative to commercial separators due to the lack of negative interactions with the product and the probable good acceptance of consumers. However, the information about the application of edible films or coatings as separator layers is very limited (Cruz-Diaz et al., 2019). The aim of this study was to prepare films using chicken foot extract (CF) and sheep muscle fascia (MF) and to determine the amount of hyaluronic acid in them. In this study, the physical, mechanical and

chemical properties of the films prepared were compared with bovine gelatin powder film (as a typical film). In addition, in order to apply the films made, they were used as burger separators and the organoleptic properties of burgers were evaluated.

2 | MATERIALS AND METHODS

2.1 | Sample preparation

Frozen chicken feet (rooster) and ovine muscle fascia (male) were purchased from the slaughterhouse. The samples were immediately transferred to the lab and were washed thoroughly to remove any contaminations, and later chopped into 3–5 cm² pieces. The pieces were then stored in a freezer (–20°C) separately. Gelatin powder made from bovine bone was also purchased.

2.2 | Extraction

For extract preparation, the CF and MF samples were defrosted at 4–5°C. Approximately 1000g of CF and MF was combined with 5000 ml of water separately, and then boiled for 5 h. Afterwards, the extractions were filtered and autoclaved at 121°C for 20 min, then cooled at room temperature (23°C).

2.3 | Determination of hyaluronic acid concentration

2.3.1 | Standards and sample preparation

According to the Dong et al. (2014) method, to obtain the reference solution 50 mg of analytical grade D-glucuronic acid (Merck KGaA) was dissolved in 100 ml of distilled water (500 µg/ml). Varying volumes of reference solution 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0 ml were poured into the test tubes separately, and then distilled water has added until the final volume of each tube is 1.0 ml. The test tubes were then cooled to 4°C by placing them into ice water. 5 ml of freshly prepared sodium sulfate with sodium borate (Merck KGaA) was added to each test tube (4.77 g disodium tetraborate of analytical grade in 500.0 ml sulfuric acid of high-grade purity). The test tubes were sealed with caps and subsequently shaken then heated in a boiling water bath for 10 min. Afterwards, they were cooled to room temperature and 1.25 ml of carbazole (Merck KGaA) solution (0.125 g of carbazole in 100.0 ml of absolute alcohol) was added to each test tube. The test tubes were resealed, shaken and heated again for 15 min in a hot water bath (100°C). Later, they were cooled down in an ambient condition, and the color of the solution changed to purple. We measured the absorbance of solutions at 530 nm (Spectrophotometers-UV-Visible, Mecasys, Korea) against a blank sample. The hyaluronic acid concentration could then be determined based on the standard calibration curve and the dilution ratio (Dong et al., 2014).

2.4 | Film formation

The films were prepared using a casting method; 100 ml of the CF and MF's liquid extract was mixed with the concentration of glycerol as plasticizer (5% w/v). For the preparation of the gelatin film, 10 g of dry matter and 1 g of glycerol were dissolved into 100 ml of boiling water. Approximately 10 ml of each film solution was poured into an 8-cm Petri dish and dried at 37°C for 18 h. The dried films were placed in plastic zipper bags and stored in the refrigerator prior to testing.

2.5 | Characteristics of the films

2.5.1 | Film thickness

The thickness of the films was measured using a digital micrometer (Mitutoyo No.293-766, Tokyo, Japan) with exactness of 1 μm at 10 random positions on the film. The obtained thickness values were applied for calculating the films' water vapor permeability and tensile properties.

2.5.2 | Moisture content

The moisture content of the films was measured by drying the samples in an oven at 105°C until the weight remained constant. The weight loss of samples was determined before and after drying with a scale accuracy of 0.001 g (Khodaei et al., 2020).

2.5.3 | Solubility in water

Using the method outlined by Tongdeesontorn et al. (2012), the water solubility of the films was determined. Pieces of the films (3 cm × 3 cm) were dried in an oven (105°C for 5 h). Then, the films were placed in a beaker with 30 ml of distilled water and they were shaken for 24 h at 25°C. The undissolved remnants were filtered and dried at 105°C for 5 h (Tongdeesontorn et al., 2012).

2.5.4 | Water vapor permeability (WVP)

In line with the E96-00 method, we determined the WVP of films gravimetrically. The film samples with an effective area of 31.4 mm² were situated on test cups which each contained 3.0 g of anhydrous sodium chloride (0% relative humidity, RH, assay cup) and were then sealed. Each cup was placed in a desiccator containing a saturated solution of sodium chloride at 25°C. The weight of the cups was measured throughout 3 h intervals for 48 h (Standard ASTM, 1989). The WVP was calculated using the following formula:

$$WVP = (\Delta m / \Delta t A) \cdot (X / \Delta P)$$

where (A) represents the area of exposed film surface in m², (Δm/Δt) is the weight of moisture gain per unit of time (g/s), (X) represents film thickness m, and (Δp) is the difference of water vapor pressure between two films.

2.5.5 | Contact angle measurements

In line with Beigomi et al. (2018) the wetting characteristics of the films were evaluated by measuring the contact angle. We utilized the sessile drop method to measure the contact angle. This involves an optical contact-measuring device (OCA20, Data Physics, GmbH) supplied with a CCD camera, and an automatized syringe control system. To measure the contact angle, which is the angle the liquid creates with the solid when it is deposited on it, an image analysis software tool (SCA20) was utilized. To carry out the measurements, a drop of distilled water from a syringe was placed on the film surface, with dimensions measuring 4.0 mm × 4.0 mm. Up to 10 measurements were taken for each film type on different areas of the surface of the film, and mean values were determined. All measurements were taken in an open-air environment with room temperature and a relative humidity of 35 ± 5% RH (Beigomi et al., 2018).

2.5.6 | Tensile strength (TS) and elongation at break (EAB)

To evaluate the mechanical properties of the films, we utilized their tensile strength (TE) and Elongation at Break (EAB) as proxy measures. These mechanical qualities were evaluated at 25°C and 50% RH. In this study, we utilized the D882-18 standard test method and the H5KS Stable Micro System, UK, was used as the testing instrument. The films were conditioned in 50% RH in a desiccator containing saturated solutions of Mg(NO₃)₂ for 48 h. Film samples measuring 20 mm × 100 mm, were cut from each film and were located between the grips of the testing instrument. The initial grip distance and the cross-head speed were set at 50 mm and 5 mm/min, respectively (ASTM International, 2012).

2.5.7 | Scanning electron microscopy (SEM)

To determine the film's microstructure, we utilized Scanning Electron Microscopy SEM (EM-3200, KYKY). The films were frozen in liquid nitrogen and fractured. After that they were mounted onto aluminum stubs with double-sided tape, and then were coated with a thin layer of gold using a BAL-TEC SCD 005 sputter coater (BALTEC AG, Balzers, Liechtenstein). Low pressure and an accelerating voltage at 20 kV were used for SEM imaging.

Extract	Moisture	Ash (%)	Fat (%)	Protein (%)
CF	8.67 ± 0.03 ^b	1.66 ± 0.05 ^a	10.71 ± 0.02 ^b	78.96 ± 0.07 ^a
MF	8.56 ± 0.03 ^b	1.66 ± 0.08 ^b	12.5 ± 0.00 ^a	77.28 ± 0.08 ^b

TABLE 1 Proximate compositions of extract from chicken feet and muscle fascia film

Note: Mean ± SD (in triplicate samples).

2.5.8 | FTIR spectra of the films

The infrared spectrum of absorption or emission of a matter was determined using Fourier Transform Infrared Spectroscopy (FTIR) (Thermo Nicolet, Avatar 370). At first, the films were powdered to set up the discs, and then 70mg of spectroscopic grade KBr was mixed fully with roughly 2mg of the film's powder. Subsequently, the powder was hard-pressed into pellets to obtain a transparent disc 15mm in diameter and 0.54mm in thickness. The FTIR spectra were obtained in the 4000–400 cm⁻¹ range, at 25°C, by co-adding 32 scans with 4 cm⁻¹ spectral resolution.

2.5.9 | Differential scanning calorimeter (DSC)

The thermal properties of films were analyzed with Mettler Toledo, DSC-1, Switzerland. Samples (approx. 7 mg) were weighed into the reference (an empty aluminium pan), and heating rate was programmed by setting the heater at 10°C/min between a range of -100°C and 200°C. Glass transition temperatures (T_g) and melting temperatures (T_m) of each film were established from resulting thermo grams as the midpoint temperature of the shift in the baseline due to the change in the heat capacity upon the glass transition. Readings of T_g were taken twice and the average of the results have been presented.

2.5.10 | Radical scavenging activity of the films

The DPPH radical scavenging activity was carried out according to the procedure of Brand-Williams et al. (1995) (Brand-Williams et al., 1995). A quantity of 25 mg of the sample was dissolved in 5 ml of distilled water. Later, 0.1 ml of the solution was mixed with 3.9 ml of the DPPH solution (0.1 mM methanol solution). They were then incubated in the dark for 30 min at 25°C. Whilst mixing the DPPH, a stable non-radical form of DPPH was obtained with simultaneous change of the violet color to a pale yellow. The Perkin-Elmer spectrophotometer was used to measure absorbance at 517 nm. We determined the percentage of DPPH radical-scavenging activity using the following equation:

$$\text{Radical scavenging activity (\%)} = ((A_{\text{reference}} - A_{\text{sample}}) / A_{\text{reference}}) \times 100$$

2.6 | Sensory analysis

Burgers (50g) were prepared manually with a round-shaped mold. Burgers were separated with films aseptically at room temperature.

Fresh burgers without films were used as controls. All samples were placed in trays covered with aluminium foil and stored at -20°C until analysis. Sensory analysis was performed by a group of 5 trained panelists using a 5-point hedonic scale ranging from "very strong like, score 5" to "very strong dislike, score 1." A score of 1–5 was assigned for the overall acceptability of the cooked samples (control, and wrapped), which was determined by assessing the appearance, color, odor, taste, texture, and flavor (Stone & Sidel, 2004).

2.7 | Statistical analysis

All tests were performed three or more times. We have presented the data as mean values with their standard deviation and these values were used in the statistical analysis. Significant differences were found by one-way ANOVA and the means were compared using Duncan's multiple range test $p < .05$. We used statistical software SPSS (Inc., Chicago, IL, Ver. 21) to carry out the statistical analysis.

3 | RESULTS AND DISCUSSION

3.1 | Proximate composition of extractions

The proximate composition of the extraction obtained from CF and MF in relation to protein, lipid, ash and moisture content, is presented in Table 1. The moisture content verified was 8.67% for CF, very close to that found by Almeida and Lannes (2013) of 9.74% for chicken feet gelatin and the moisture content of MF was 8.56%. As seen in Table 1, the CF and MF extract presented 1.66% ash. The CF protein content is 78.96%, but the MF has a higher protein content (77.28%). About the content of lipids, CF was 10.71%. Almeida and Lannes (2013) reported the presence of 12.8% lipid in chicken feet. The lipid content of MF extract was 12.5%.

3.2 | Determination of hyaluronic acid concentration

Based on the equation obtained from the standard diagram, the amount of hyaluronic acid in CF extract was 124.11 and in the extract obtained from MF was 101.40 ppm. The data show that the amount of hyaluronic acid in CF extract is significantly higher than in the MF extract. According to previous studies, the rooster comb has the highest amount of hyaluronic acid in living tissues. The amount of this substance in the rooster comb is about 7500 µg/mL (Kanchwala et al., 2005). This amount is about 60 times more than

the hyaluronic acid in CF. However, hyaluronic acid in the rooster comb is complex with proteoglycans, which makes extraction of high purity difficult and costly (Hanani et al., 2019). Of recent, *Streptococcus* species are used for microbial production of hyaluronic acid. In the study by Al-Saadia et al. (2016), hyaluronic acid was extracted from *Streptococcus pyogenes*, 67.9 ng/mL at 7.5 pH (Al-Saadia et al., 2016). However, genetic mutations in this genus of bacteria and the possibility of producing toxins have limited their application (Li et al., 2020). Nevertheless, the use of poultry and sheep by-products are not only inexpensive and more accessible than many sources, but also have a significant amount of hyaluronic acid, which can be used in food and packaging industries. The extracts of CF and MF generated in this work could simply result in homogeneous solutions, which provide translucent films that can be readily manipulated (Figure 1).

3.3 | Thickness

As can be seen in Table 3, the average thickness for the CF and MF films is 0.10 mm and for the Gel film is 0.17 mm which is significantly larger than the other films. Hanani et al. (2019) reported that the thickness of their fish gelatin film was 0.06 mm and Li et al. (2020) reported the thickness of their B type gelatin film to be 0.07 mm (Hanani et al., 2019; Li et al., 2020). As such, these materials were thin enough to be considered as films, and the effect of the observed

differences in thickness on the film's functional properties could be negligible. Controlling the film thickness is an essential factor which may influence the mechanical, barrier, and transparency properties of the films (Mir et al., 2018). Moreover, discrepancy in film thicknesses may result from the type of solid matter used as well as its amount. The film preparatory methods and drying conditions may also influence the thickness (Galus & Lenart, 2013).

3.4 | Moisture content

According to the data presented in Table 3, a significant difference was found between the average moisture content of the CF and Gel films (7.40% and 7.45%, respectively), and the MF film (5.90%). The moisture content of chicken feet was reported to be 65.08% in the study (Hashim et al., 2014). Lee et al. (2015) also reported that the moisture content of chicken feet protein film with glycerol and sorbitol as plasticizer to be 10.17% and Hanani et al. (2019) reported that the moisture content of a fish gelatin film was 11.05% (Hanani et al., 2019; Lee et al., 2015). The higher humidity in CF and Gel films are dependent on its hydrophilic nature which is mostly due to the tendency to form hydrogen bonds with water molecules. The reduction in moisture content is mainly related to the hydrophobicity of the fats present in the film components with gelatin base, which greatly reduces the film water absorption capacity (Li et al., 2020).

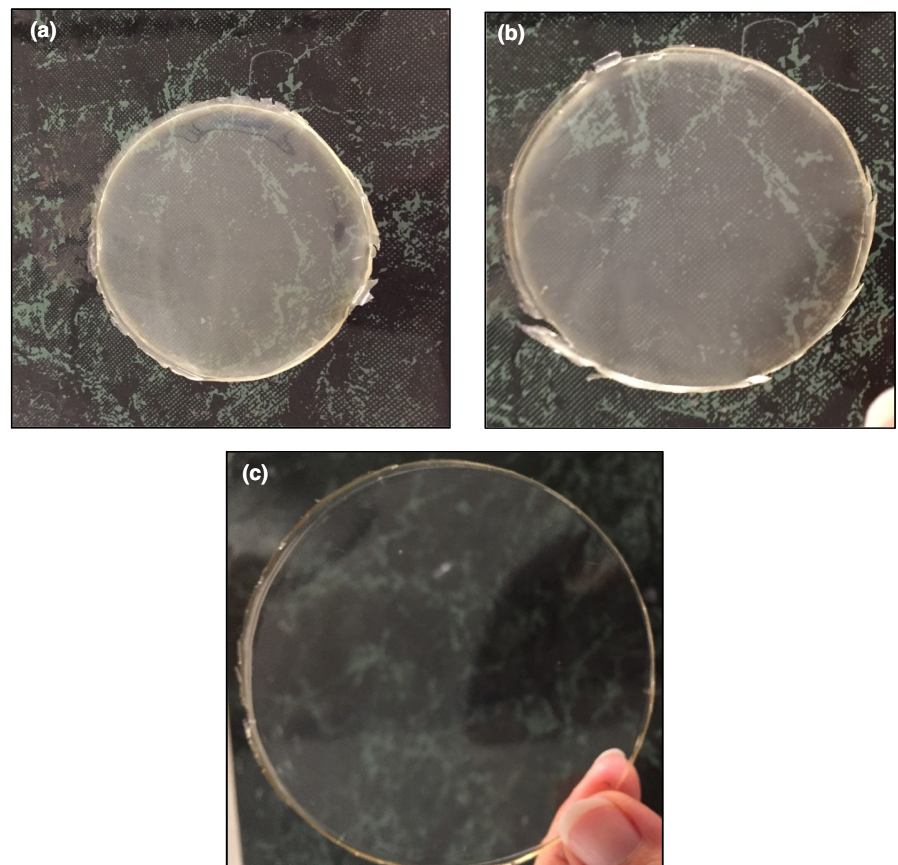


FIGURE 1 Images of films, chicken feet film (a), ovine muscle fascia film (b), and bovine bone gelatin film (c)

TABLE 2 Antioxidant activity of the films—DPPH method, mechanical, and thermal properties of films

Film	Radical-scavenging activity (%)	T_g (°C)	T_m (°C)	TS (Mpa)	EAB (%)
CF	18.47 ^a	33.80 ± 0.81 ^b	35.42 ± 1.91 ^b	2.49 ± 0.15 ^c	89.05 ± 1.08 ^a
MF	Undetectable ^c	28.54 ± 0.28 ^c	30.36 ± 1.55 ^c	3.9 ± 0.43 ^b	85.25 ± 0.90 ^b
Gel	1.88 ^b	38.55 ± 0.1 ^a	40.53 ± 0.55 ^a	5.7 ± 0.51 ^a	70.50 ± 1.70 ^c

Note: All measurements were performed at 25°C and RH = 50%. Different letters in the same column indicate significant difference ($p < .05$).

Abbreviations: EAB, elongation at break; T_g , glass transition; T_m , melting temperature; TS: tensile strength.

3.5 | Solubility in water

The solubility percentages of the films' after 24 h immersion in water has been detailed in Table 3. This was measured to be 99.09% for the MF film, 68.49% for the CF film, and 41.62% for the Gel film. After 24 h of incubation in water, the CF and MF films changed shape while the gelatin film completely retained its structure. Specifically, the solubility of MF films (99.08%) was significantly higher ($p < .05$) and the solubility of the Gel film (40.65%) was significantly lower ($p < .05$) than the other films. In one study, the film solubility levels for chicken skin gelatin was 94% (Loo & Sarbon, 2020), and in another, the solubility of fish skin gelatin film was 68.64% (Hanani et al., 2019). Moisture content, which depends on the wettability and free surface energy, increases the films solubility which is one of the major advantages of the films (Loo & Sarbon, 2020). Polypeptides cross-linkages and higher molecular weights in gelatin result in lower water solubility compared to muscle fascia and chicken feet. Lower water solubility of the films due to lower water activity and thus less possible contamination in the presence of water, are desirable characteristics for food packaging (Escamilla-García et al., 2019).

3.6 | Water vapor permeability (WVP)

Table 3 shows the WVP of the films. According to these results, the CF film had significantly lower WVP (2.75×10^{-9} g/m.s.Pa) than the MF film (1.57×10^{-8} g/m.s.Pa) and the Gel film (1.5×10^{-7} g/m.s.Pa). this data is consistent with findings by Lee et al. (2015) where they reported the WVP of chicken feet protein film without plasticizer to be 3.44×10^{-9} gm/m² sPa (Lee et al., 2015). In another study, Li et al. (2020), reports that the WVP of gelatin (type B) film to be 8.83×10^{-11} g/s. Pa (Li et al., 2020) According to a study by Hashim et al. (2014) the fat content of chicken feet was reported to be 3.9% (Hashim et al., 2014). The presence of lipids in the film structure resulted in a decrease in the WVP. The small fat particles lead to their homogeneous distribution in the film matrix, which can reduce WVP (Pérez-Gago & Krochta, 2001). Also, the incorporation of hydrophobic components (e.g., essential oils and plasticizers) resulted in a reduction of the WVP due to the increased hydrophobicity of biopolymer-based films (Almasi et al., 2020). Lower WVP values are preferred to reduce unacceptable alterations in product quality (Orozco-Parra et al., 2020).

3.7 | Contact angle measurements

The contact angle is one of the most frequently used measures when assessing surface properties of biopolymers. It provides information regarding films' surface wetting or non-wetting properties. The results have been demonstrated in Table 3. There is a significantly lower ($p < .05$) contact angle for the Gel film (79.20°) as opposed to the MF film (92.27°) and CF film (90.209°). The contact angle of a water droplet on a surface relates to the surface's hydrophobicity (Giovambattista et al., 2007). Bracco and Holst indicate that hydrophobic (non-wet table) surfaces have contact angles larger than 90° and hydrophilic surfaces (wet table property) tend to have contact angles below 90° (Bracco & Holst, 2013). Accordingly, the two films of CF and MF were hydrophobic, but the Gel film was hydrophilic. As shown in Table 1, the surface hydrophobicity for the CF and MF films were low but, they are hydrophobic films. A similar observation for the Gel film has been reported where the contact angle was found for B-type gelatin film (74.2°) (Li et al., 2020). A possible explanation for the results could be related to the fat content of the films, which would correlate with their hydrophobic qualities. For functional uses including food packaging, it is important that edible films have a low affinity to water.

3.8 | Tensile strength (TS) and elongation at break (EAB)

The TS and EAB of the films have been demonstrated in Table 2. The maximum tensile stress a film can sustain corresponds to its TS, whereas the maximum change in length of a test specimen before breaking is defined as EAB (Pereda et al., 2012). Mechanical strength is a general necessity to retain the integrity of packaging films and to be able to withstand external stress (Yang & Paulson, 2000). The TS of the Gel film (5.7 MPa) was significantly greater ($p < .05$) than the MF (3.9 MPa) and CF (2.49 MPa) films. Lee et al. (2015) reported that the TS of chicken protein film with sorbitol was 3.38 MPa and Hanani et al. (2019) reported that the TS of a pure fish gelatin film was 7.22 MPa (Hanani et al., 2019; Lee et al., 2015). The strength and weakness of the hydrogen bonds of the film molecules determine the TS, so the stronger the internal network and the cohesion of the film, the higher the TS. The increase of TS may also be due to

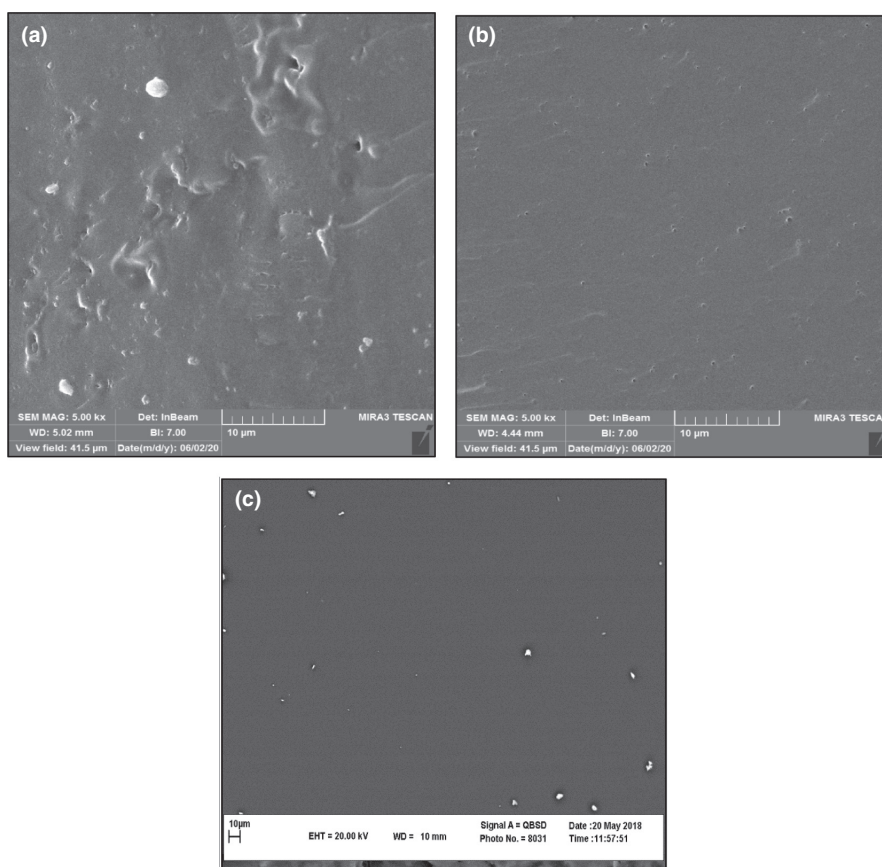
TABLE 3 Physical properties of the films

Film	Thickness (mm)	MC (%)	WS (%)	WVP (g/m.s.pa)	Water contact angle (degree)
CF	0.10 ± 0.02 ^b	7.40 ± 0.50 ^a	68.49 ± 0.06 ^b	2.75 × 10 ⁻⁹ ± 0.08 ^a	90.209 ± 0.91 ^b
MF	0.10 ± 0.03 ^b	5.90 ± 0.08 ^b	99.08 ± 0.00 ^a	1.57 × 10 ⁻⁸ ± 0.08 ^b	92.27 ± 0.23 ^a
Gel	0.17 ± 0.05 ^a	7.45 ± 0.02 ^a	40.65 ± 0.05 ^c	1.5 × 10 ⁻⁷ ± 0.10 ^c	79.2 ± 0.6 ^c

Note: Different letters in the same column indicate significant differences among formulations ($p < .05$). Values are means of three replicates ± standard deviation.

Abbreviations: CF, Chicken feet film; Gel, Bovine bone gelatin film; MC, moisture content; MF, muscle fascia film; WS, water solubility; WVP, water vapor permeability.

FIGURE 2 Scanning electron microscopy cross-section images of films, Chicken feet extraction film (a), muscle fascia extraction film (b), and bovine bone gelatin film (c)



differences in molecular weight, size, number of oxygen atoms, and hydrophilicity of the film matrix molecules.

Among the different films, the CF film had a greater EAB (89.05%) compared to the MF (85.25%) and Gel (70.50%) films, respectively. In contrast to the TS, the EAB of CF film increased significantly, implying that the film was more pliable when compared to the gelatin film. The occurrence of lipid in CF films resulted in increased EAB of films being observed (Table 3). It appears as though the presence of lipid globules throughout the film matrix leads to a decrease in continuity and interconnection of the protein network. Moreover, variability in molecular weight, hydrophilicity, number and size of oxygen atoms of the CF extract might be a result of the greater EAB. Thus, interruption in continuity in microstructure of the film caused by the occurrence of lipid globules may impact the film's ability to stretch (Wang et al., 2009).

3.9 | Scanning electron microscopy

The films' surface morphology was investigated by scanning electron microscopy (Figure 2). The cross-linked Gel film was observed to be uniform, compact and homogenous in appearance, while the microstructures of the MF film contained some bubbles. The surface of the CF film was rougher than the MF and Gel films. The increase in surface roughness of CF film is attributed to the migration of fat droplets towards the film surface during the film drying process.

3.10 | FTIR spectra of the films

FTIR spectroscopy has previously been extensively used for the identification of intermolecular interactions in polymers (Liu

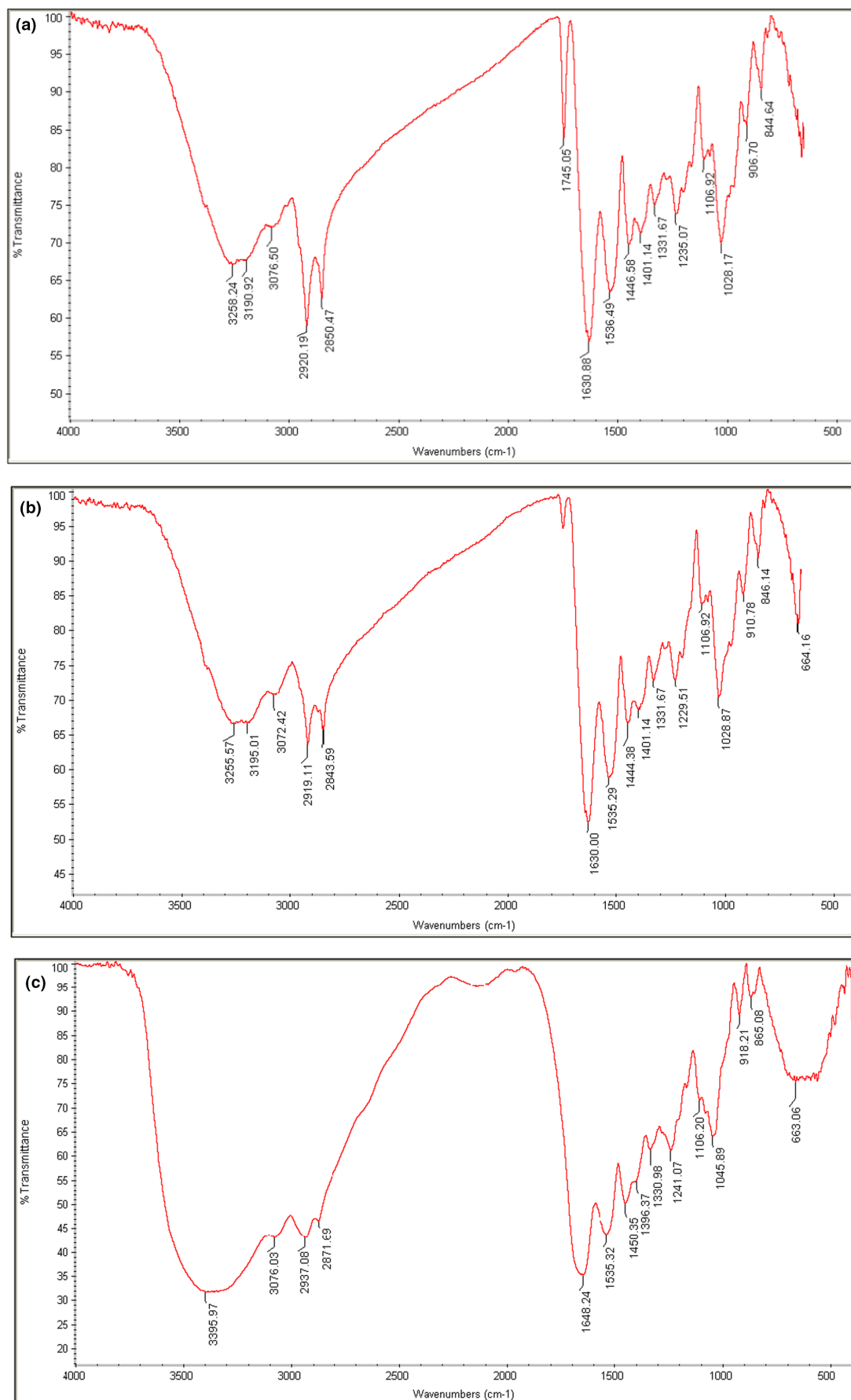


FIGURE 3 Fourier-transform infrared spectroscopy (FT-IR spectrum) of films. MF, muscle fascia film (a); CF, chicken feet film (b); Gel: bovine bone gelatin film (c)

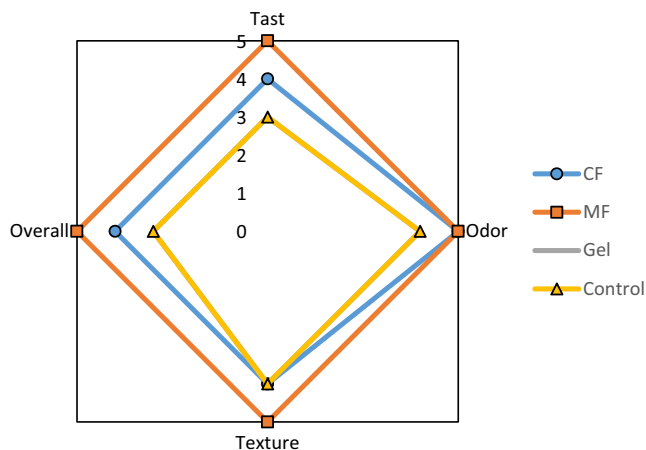


FIGURE 4 Sensory evaluation of films. MF, muscle fascia film (a); CF: chicken feet film (b); Gel, bovine bone gelatin film

et al., 2004; Sionkowska, 2011). The properties of polymers are the result of interactions by hydrogen bonds and/or electrostatic interactions between the functional groups of the various polymers. Fourier Transform Infrared (FTIR) spectroscopy studies depicted bands formed by four individual peaks: Amide A, Amide I, Amide III, and Aliphatic alcohol. Figure 3(a) shows the FTIR spectra of the MF film. Moreover, Figure 3(b) shows the FTIR spectra for the CF and Gel films. The FTIR spectra of the MF film showed major peaks in the amide region. The MF film showed vibration peak at wavenumber 1630.68 cm^{-1} for amide I, 1536.49 cm^{-1} for the amide II, 1235.07 cm^{-1} for amide III, 2920.19 cm^{-1} for amide B, and 3190.92 to 3258.24 cm^{-1} for amide A. Amide A peaks waxed more intensely, and both widened and sharpened with the increase of glycerol content in the films. This is likely due to the -OH group contributed by the plasticizer. The FTIR spectra of the CF film showed amide II at 1535.29 cm^{-1} , amide I at 1630.00 cm^{-1} , amide B at 2919.11 cm^{-1} , amide A in the range of 3195.01 to 3255.57 cm^{-1} , and amide III at 1229.51 cm^{-1} . The aliphatic alcohol group had glycerol content at a peak of 1028 cm^{-1} for both types of films. Our data are similar to da Almeida and Lannes (2013), and Nor et al. (2017) who investigated the FTIR characterization of chicken feet gelatin and the effects of plasticizer concentrations

on functional properties of chicken skin gelatin films, respectively (Almeida and Lannes 2013; Nor et al., 2017). The spectra for the Gel film showed that the band was formed by four individual peaks; situated at amide-A, and free water (3395.97 cm^{-1}), amide-I (1648.24 cm^{-1}), amide-II (1535.42 cm^{-1}) and amide-III (1241.07 cm^{-1}). The peak situated around 1045 cm^{-1} might be related to the possible interactions arising between plasticizer (OH group of glycerol) and film structure. These results were in line with previous studies (Hanani et al., 2019). Generally, similar spectra for the three types of films were observed.

3.11 | Differential scanning calorimeter (DSC)

Several phase transitions can occur when polymer materials are thermally processed, and each transition relates to a certain thermal property. The glass transition temperature (T_g), which is defined as "as the temperature at which a polymer undergoes a structural transition from a glassy to a rubbery state" is one of these transitions. Under the T_g value, the films are rigid, stiff, and glassy, in comparison to levels greater than T_g , where the films become elastic and soft (Yang & Paulson, 2000). Additionally, there is the melting transition (T_m), where at a temperature known as the melting temperature, there is a transition from a crystalline to an amorphous phase, a liquid-like state (Alavi et al., 2014). The results showed only one T_g for the films (Table 2). Corresponding to Ghasemlou et al. (2011), if a plasticizer is not homogenized with a polymer, the mixture would have two T_g values, corresponding to two pure phases (Ghasemlou et al., 2011). The glass transition, melting and deterioration peaks of the films prepared from CF, MF, and Gel films were around 33.80 – 35.42°C , 28.54 – 30.36°C , and 38.55 – 40.53°C , respectively. From the gelatin film, the T_g results reported may be explained by the block copolymer model for the amino acid content of gelatin. The T_g of gelatin takes place at $\sim 60^\circ\text{C}$ and is related with the T_g of its amino acid in the peptide chain. Additionally, native fish gelatin film was found to have a T_m of 76.5°C , which is found to be higher than films produced from bovine skin gelatin which have been shown to have a T_m of 65.06°C by De Carvalho and Grosso (2004). Furthermore, the dry film derived from pigskin gelatin has been shown to have a T_m of

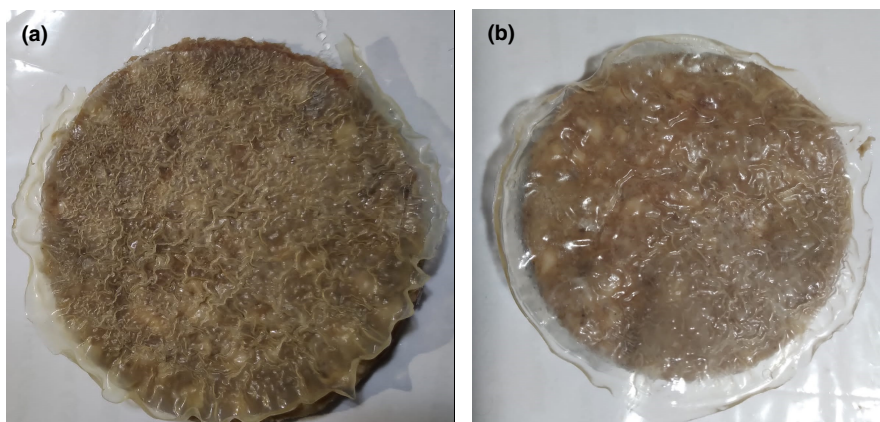


FIGURE 5 Berger covered with CF after defrosted (a), Berger cover with MF after defrosted (b)

91°C (Bigi et al., 2001). The variation in observed thermal properties is appreciable due to different versions of the gelatin source used. Moreover, Bigi et al. (2004) described that the initial transition is likely correlated with the evaporation of absorbed water in the gelatin sample, and a higher transition temperature is associated with the relative quantity of the triple helix in gelatin. As such, thermal properties of films are influenced by their source (Bigi et al., 2004).

3.12 | Radical scavenging activity of the films

Nowadays, there is a great deal of interest in food packaging that offers antioxidant properties to prevent or delay lipid oxidation. The DPPH method is a widely used method to evaluate antioxidant activity. This method of analyzing the ability of compounds to behave as free-radical scavengers or hydrogen donors, was established on the ability of DPPH, a stable free radical, to be satiated, and therefore, decolorized when antioxidants are present. Consequently, there is a reduction in absorbance values (Siripatrawan & Harte, 2010). The result indicated that the MF film had no antioxidant activity, while DPPH-scavenging activities of the CF film were 18.42% (Table 2) and 1.88% for the Gel film. Compared to edible films obtained from other sources, such as methyl-cellulose (<5%) (Noronha et al., 2014), and chitosan (<10% and 12%) (Moradi et al., 2012), the antioxidant activity of CF film is greater in comparison to other natural polymers and does not include antioxidant additives. As oxidative reactions result in substantial food wastage, there is growing use of synthetic antioxidants. However, synthetic antioxidants have questionable impacts on health. Therefore, natural antioxidants may have a more favorable outlook because of their safer qualities. Of note, CF film contains natural antioxidants, and this is an appropriate feature for use in food packaging.

3.13 | Sensory analysis

Results of the organoleptic evaluation of hamburger samples (control, and separated with films) have been presented in Figure 4. Compared to the control samples, the burgers with the film were easily separated from each other after freezing. During defrost, the films kept their shape and covered the burgers well (Figure 5). The MF film retained its clarity and uniformity while the CF and gel films were wrinkled during freezing. When cooking, the films were completely covered on the burgers. After cooking, the taste, odor, texture, and overall acceptance of burgers with MF and CF films revealed a higher score than the sample with the gel film and control. The presence of films on the surface of the burger seems to prevent the loss of moisture during cooking and creates a more juicy texture in the burger. The heat also melted the film and penetrated into the texture of the burger, which, due to the nature of the CF and MF films, helped to create a more meaty taste.

4 | CONCLUSION

Chicken feet and ovine muscle fascia extracts can be used as a precursor to edible films. Although the concentration of hyaluronic acid in CF was more than in the MF extract, the amount of hyaluronic acid in both extracts was acceptable. The CF film had better WVP, and antioxidant properties than the MF and Gel films. The physical, thermal, and mechanical properties varied depending on the type of film source. It appears that the TS of the Gel film was more acceptable than the CF and MF films. FTIR results clearly indicated intermolecular interactions between film components. These interactions are related to the presence of amine, hydroxyl, and/or carboxylic groups in the polysaccharides (hyaluronic acid) and collagen in the CF and MF films. Accordingly, the different mechanical and thermal properties of biopolymer films can be a result of hydrogen bonds between the reactive groups of components. From these results, it can be concluded that CF film could be an appropriate packaging material applied to food products. In relation preliminary study of CF and MF films for the utilization as separator for burger slices, promising results were obtained and further research is warranted.

ACKNOWLEDGMENT

We gratefully acknowledge the support of the Neyshabur University of medical science for funding this project (project number 97284, code of ethics IR.NUMS.REC.1398.002).

CONFLICT OF INTEREST

The authors declare no conflict of interests.

ORCID

Mohamad Reza Amiryousefi  <https://orcid.org/0000-0002-3832-9325>

REFERENCES

- Alavi, S., Thomas, S., Sandeep, K. P., Kalarikkal, N., Varghese, J., & Yaragalla, S. (2014). *Polymers for packaging applications*. CRC Press.
- Almasi, H., Azizi, S., & Amjadi, S. (2020). Development and characterization of pectin films activated by nanoemulsion and Pickering emulsion stabilized marjoram (*Origanum majorana* L.) essential oil. *Food Hydrocolloids*, 1(99), 105338. <https://doi.org/10.1016/j.foodhyd.2019.105338>
- Almeida, P. F., & Lannes, S. C. (2013). Extraction and physicochemical characterization of gelatin from chicken by-product. *Journal of Food Process Engineering*, 36(6), 824–833. <https://doi.org/10.1111/jfpe.12051>
- Al-Saadia, K. A., Naji, H. F., & Al-Saadi, A. H. (2016). Production and optimisation of hyaluronic acid extracted from *Streptococcus pyogenes*. *Journal of Contemporary Medical Sciences*, 1(4), 13–15.
- ASTM, E (96) *Standard test methods for water vapor transmission of materials*. ASTM International.
- ASTM International. (2012). *ASTM D882-12, Standard test method for tensile properties of thin plastic sheeting*. ASTM International.
- Beigomi, M., Mohsenzadeh, M., & Salari, A. (2018). Characterization of a novel biodegradable edible film obtained from Dracocephalum

- moldavica seed mucilage. *International Journal of Biological Macromolecules*, 108, 874–883. <https://doi.org/10.1016/j.ijbiomac.2017.10.184>
- Bigi, A., Cozzani, G., Panzavolta, S., Rubini, K., & Roveri, N. (2001). Mechanical and thermal properties of gelatin films at different degrees of glutaraldehyde crosslinking. *Biomaterials*, 22(8), 763–768. [https://doi.org/10.1016/S0142-9612\(00\)00236-2](https://doi.org/10.1016/S0142-9612(00)00236-2)
- Bigi, A., Panzavolta, S., & Rubini, K. (2004). Relationship between triple-helix content and mechanical properties of gelatin films. *Biomaterials*, 25(25), 5675–5680. <https://doi.org/10.1016/j.biomaterials.2004.01.033>
- Bracco, G., & Holst, B. (2013). *Surface science techniques*. Springer Science & Business Media.
- Brand-Williams, W., Cuvelier, M. E., & Berset, C. L. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology*, 28(1), 25–30. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)
- Chakka, A. K., Muhammed, A., Sakhare, P. Z., & Bhaskar, N. (2017). Poultry processing waste as an alternative source for mammalian gelatin: Extraction and characterization of gelatin from chicken feet using food grade acids. *Waste and Biomass Valorization*, 8(8), 2583–2593. <https://doi.org/10.1007/s12649-016-9756-1>
- Cowman, M. K., Schmidt, T. A., Raghavan, P., & Stecco, A. (2015). Viscoelastic properties of hyaluronan in physiological conditions [v1; ref status: awaiting peer review http://f1000r.es/5pw]. <https://doi.org/10.12688/f1000research.6885.1>
- Cruz-Díaz, K., Cobos, Á., Fernández-Valle, M. E., Díaz, O., & Cambero, M. I. (2019). Characterization of edible films from whey proteins treated with heat, ultrasounds and/or transglutaminase. Application in cheese slices packaging. *Food Packaging and Shelf Life*, 22, 100397.
- De Carvalho, R. A., & Grosso, C. R. (2004). Characterization of gelatin based films modified with transglutaminase, glyoxal and formaldehyde. *Food Hydrocolloids*, 18(5), 717–726. <https://doi.org/10.1016/j.foodhyd.2003.10.005>
- Dhakal, D., Koomsap, P., Lamichhane, A., Sadiq, M. B., & Anal, A. K. (2018). Optimization of collagen extraction from chicken feet by papain hydrolysis and synthesis of chicken feet collagen based biopolymeric fibres. *Food Bioscience*, 23, 23–30. <https://doi.org/10.1016/j.fbio.2018.03.003>
- Dong, Q., Zang, H., Zang, L., Liu, A., Shi, Y., & Zhang, H. (2014). Rapid determination of hyaluronic acid concentration in fermentation broth with near-infrared spectroscopy. *Journal of Innovative Optical Health Sciences*, 7(6), 1450012. <https://doi.org/10.1142/S1793545814500126>
- Escamilla-García, M., Delgado-Sánchez, L. F., Ríos-Romo, R. A., García-Almendárez, B. E., Calderón-Domínguez, G., Méndez-Méndez, J. V., Amaro-Reyes, A., Di Pierro, P., & Regalado-González, C. (2019). Effect of transglutaminase cross-linking in protein isolates from a mixture of two quinoa varieties with chitosan on the physicochemical properties of edible films. *Coatings*, 9(11), 736. <https://doi.org/10.3390/coatings9110736>
- Fede, C., Angelini, A., Stern, R., Macchi, V., Porzionato, A., Ruggieri, P., De Caro, R., & Stecco, C. (2018). Quantification of hyaluronan in human fascia: variations with function and anatomical site. *Journal of Anatomy*, 233(4), 552–556. <https://doi.org/10.1111/joa.12866>
- Ferreira, M. S., Linhares, R., & Martelli, M. (2016). Films and coatings from agro-industrial residues. In *Edible films and coatings* (pp. 211–232). CRC Press.
- Food and Agriculture Organization of the United Nation (FAO) 2020. <http://www.fao.org/faostat/en/#data/QL>
- Galus, S., & Lenart, A. (2013). Development and characterization of composite edible films based on sodium alginate and pectin. *Journal of Food Engineering*, 115(4), 459–465. <https://doi.org/10.1016/j.jfoodeng.2012.03.006>
- Ghasemlou, M., Khodaiyan, F., & Oromiehie, A. (2011). Physical, mechanical, barrier, and thermal properties of polyol-plasticized biodegradable edible film made from kefiran. *Carbohydrate Polymers*, 84(1), 477–483. <https://doi.org/10.1016/j.carbpol.2010.12.010>
- Giovambattista, N., Debenedetti, P. G., & Rossky, P. J. (2007). Effect of surface polarity on water contact angle and interfacial hydration structure. *The Journal of Physical Chemistry B*, 111(32), 9581–9587. <https://doi.org/10.1021/jp071957s>
- Hanani, Z. N., Yee, F. C., & Nor-Khaizura, M. A. (2019). Effect of pomegranate (*Punica granatum* L.) peel powder on the antioxidant and antimicrobial properties of fish gelatin films as active packaging. *Food Hydrocolloids*, 89, 253–259. <https://doi.org/10.1016/j.foodhyd.2018.10.007>
- Hashim, P., Ridzwan, M. M., & Bakar, J. (2014). Isolation and characterization of collagen from chicken feet. *International Journal of Bioengineering and Life Sciences*, 8(3), 250–254. <https://doi.org/10.5281/zenodo.1091484>
- Kanchwala, S. K., Holloway, L., & Bucky, L. P. (2005). Reliable soft tissue augmentation: A clinical comparison of injectable soft-tissue fillers for facial-volume augmentation. *Annals of Plastic Surgery*, 55(1), 30–35. <https://doi.org/10.1097/01.sap.0000168292.69753.73>
- Khodaei, D., Oltrogge, K., & Hamidi-Esfahani, Z. (2020). Preparation and characterization of blended edible films manufactured using gelatin, tragacanth gum and, Persian gum. *LWT*, 117, 108617. <https://doi.org/10.1016/j.lwt.2019.108617>
- Lee, J. H., Lee, J., & Song, K. B. (2015). Development of a chicken feet protein film containing essential oils. *Food Hydrocolloids*, 46, 208–215. <https://doi.org/10.1016/j.foodhyd.2014.12.020>
- Li, X., Yang, X., Deng, H., Guo, Y., & Xue, J. (2020). Gelatin films incorporated with thymol nanoemulsions: Physical properties and antimicrobial activities. *International Journal of Biological Macromolecules*, 150, 161–168. <https://doi.org/10.1016/j.ijbiomac.2020.02.066>
- Liu, H., Yin, Y., Yao, K., Ma, D., Cui, L., & Cao, Y. (2004). Influence of the concentrations of hyaluronic acid on the properties and biocompatibility of Cs-Gel-HA membranes. *Biomaterials*, 25(17), 3523–3530. <https://doi.org/10.1016/j.biomaterials.2003.09.102>
- Loo, C. P., & Sarbon, N. M. (2020). Chicken skin gelatin films with tapioca starch. *Food Bioscience*, 35, 100589. <https://doi.org/10.1016/j.fbio.2020.100589>
- Luo, Q., Hossen, M. A., Zeng, Y., Dai, J., Li, S., Qin, W., & Liu, Y. (2022). Gelatin-based composite films and their application in food packaging: A review. *Journal of Food Engineering*, 313, 110762. <https://doi.org/10.1016/j.jfoodeng.2021.110762>
- Mir, S. A., Dar, B. N., Wani, A. A., & Shah, M. A. (2018). Effect of plant extracts on the techno-functional properties of biodegradable packaging films. *Trends in Food Science & Technology*, 80, 141–154. <https://doi.org/10.1002/fsn.3.1206>
- Moradi, M., Tajik, H., Rohani, S. M., Oromiehie, A. R., Malekinejad, H., Aliakbarlu, J., & Hadian, M. (2012). Characterization of antioxidant chitosan film incorporated with Zataria multiflora Boiss essential oil and grape seed extract. *LWT-Food Science and Technology*, 46(2), 477–484. <https://doi.org/10.1016/j.lwt.2011.11.020>
- Nor, M. H., Nazmi, N. N., & Sarbon, N. M. (2017). Effects of plasticizer concentrations on functional properties of chicken skin gelatin films. *International Food Research Journal*, 24(5), 1910–1918.
- Noronha, C. M., de Carvalho, S. M., Lino, R. C., & Barreto, P. L. (2014). Characterization of antioxidant methylcellulose film incorporated with α -tocopherol nanocapsules. *Food Chemistry*, 159, 529–535. <https://doi.org/10.1016/j.foodchem.2014.02.159>
- Orozco-Parra, J., Mejía, C. M., & Villa, C. C. (2020). Development of a bioactive synbiotic edible film based on cassava starch, inulin, and *Lactobacillus casei*. *Food Hydrocolloids*, 104, 105754. <https://doi.org/10.1016/j.foodhyd.2020.105754>
- Pereda, M., Amica, G., & Marcovich, N. E. (2012). Development and characterization of edible chitosan/olive oil emulsion films. *Carbohydrate*

- Polymers., 87(2), 1318–1325. <https://doi.org/10.1016/j.carbp.2011.09.019>
- Pérez-Gago, M. B., & Krochta, J. M. (2001). Lipid particle size effect on water vapor permeability and mechanical properties of whey protein/beeswax emulsion films. *Journal of Agricultural and Food Chemistry*, 49(2), 996–1002. <https://doi.org/10.1021/jf000615f>
- Rajeshkumar, L. (2022). Biodegradable polymer blends and composites from renewable resources. In *Biodegradable polymers, blends and composites* (pp. 527–549). Woodhead Publishing. <https://doi.org/10.1016/B978-0-12-823791-5.00015-6>
- Said, N. S., Howell, N. K., & Sarbon, N. M. (2021). A review on potential use of gelatin-based film as active and smart biodegradable films for food packaging application. *Food Reviews International*, 1–23. <https://doi.org/10.1080/87559129.2021.1929298>
- Schneider, Y., Kluge, C., Weiß, U., & Rohm, H. (2010). Packaging materials and equipment. *Technology of Cheesemaking*, 2, 413–439.
- Silvipriya, K. S., Kumar, K. K., Bhat, A. R., Kumar, B. D., John, A., & Lakshmanan, P. (2015). Collagen: Animal sources and biomedical application. *Journal of Applied Pharmaceutical Science*, 5(3), 123–127. <https://doi.org/10.7324/JAPS.2015.50322>
- Sionkowska, A. (2011). Current research on the blends of natural and synthetic polymers as new biomaterials. *Progress in Polymer Science*, 36(9), 1254–1276. <https://doi.org/10.1016/j.progpolymsci.2011.05.003>
- Siripatrawan, U., & Harte, B. R. (2010). Physical properties and antioxidant activity of an active film from chitosan incorporated with green tea extract. *Food Hydrocolloids*, 24(8), 770–775. <https://doi.org/10.1016/j.foodhyd.2010.04.003>
- Standard, ASTM (1989). *Standard test methods for water vapor transmission of materials*. ASTM International.
- Stone, H., & Sidel, J. L. (2004). *Introduction to sensory evaluation. Sensory evaluation practices* (3rd ed., pp. 1–9). Academic Press.
- Tongdeesoonorn, W., Mauer, L. J., Wongruong, S., Sriburi, P., & Rachtanapun, P. (2012). Mechanical and physical properties of cassava starch-gelatin composite films. *International Journal of Polymeric Materials*, 61(10), 778–792. <https://doi.org/10.1080/00914037.2011.610049>
- Wang, L., Auty, M. A., Rau, A., Kerry, J. F., & Kerry, J. P. (2009). Effect of pH and addition of corn oil on the properties of gelatin-based biopolymer films. *Journal of food engineering*, 90(1), 11–19. <https://doi.org/10.1016/j.jfoodeng.2008.04.030>
- Yang, L., & Paulson, A. T. (2000). Effects of lipids on mechanical and moisture barrier properties of edible gellan film. *Food Research International*, 33(7), 571–578. [https://doi.org/10.1016/S0963-9969\(00\)00093-4](https://doi.org/10.1016/S0963-9969(00)00093-4)

How to cite this article: Kalantarmahdavi, M., Salari, A., Pasdar, Z., & Amirousefi, M. R. (2022). Edible hyaluronic acid-rich burger separator discs prepared from slaughterhouse waste. *Food Science & Nutrition*, 10, 3515–3526. <https://doi.org/10.1002/fsn3.2954>