Antimicrobial activity of gelatin films based on duck feet containing cinnamon leaf oil and their applications in packaging of cherry tomatoes

So-Young Yang¹ · Ka-Yeon Lee¹ · Song-Ee Beak¹ · Hyeri Kim¹ · Kyung Bin Song¹

Received: 6 March 2017 / Revised: 29 May 2017 / Accepted: 12 June 2017 / Published online: 18 August 2017
© The Korean Society of Food Science and Technology and Springer Science+Business Media B.V. 2017

Abstract Duck feet gelatin (DFG) films were prepared and applied to the packaging of cherry tomatoes. Cinnamon leaf oil (CLO) was incorporated into the DFG films at concentrations of 0.5, 1.0, and 1.5% to provide antimicrobial activity. The DFG films with 1.0% CLO incorporation exhibited the most desirable tensile strength (41.6 MPa) and elongation at break (18.5%). Regarding the antimicrobial activity, the DFG films containing CLO significantly inhibited the growth of foodborne pathogens. In addition, the DFG film with 1.0% CLO was employed in the coating and wrapping of cherry tomatoes inoculated with *Salmonella typhimurium*. The DFG film with 1.0% CLO incorporation reduced the population of the bacteria to below the detection limit. Moreover, the DFG film with CLO delayed the color change on cherry tomatoes. Overall, the DFG film with CLO enhanced the shelf life of cherry tomatoes and can be used as an antimicrobial packaging.

Keywords Antimicrobial activity · Cherry tomato · Cinnamon leaf oil · Duck feet gelatin

Introduction

Petroleum-based film materials are widely used, but they are not biodegradable. With increasing need for eco-friendly packaging materials, biodegradable films have been developed to replace conventional plastic packaging materials. To prepare the biodegradable films, various film

sources have been investigated with different strategies, such as using food processing by-products to overcome high cost [1]. In particular, edible films and coatings have been applied in food systems [2].

Gelatin is a major protein resource for edible films and is obtained from hydrolysis of collagen originating from skins and tendons of vertebrates and invertebrates [3]. Although a considerable amount of gelatin is supplied from porcine skin and bovine hides, poultry feet are also a collagen-rich material and can be used as a gelatin source [4]. Recently, chicken feet gelatin has been used for an edible film [5].

Duck meats are widely consumed in smoked, boiled, or roasted form and their processing generates by-products, such as duck feet. Thus, duck feet gelatin has been extracted to utilize the waste and its physiochemical properties have been reported [6], although duck feet gelatin films for food packaging have never been studied.

Essential oils have been incorporated into gelatin films and coatings to provide antimicrobial and antioxidant activities [7]. However, the addition of essential oils into gelatin films can alter the physical properties of the films because of the interactions between gelatin molecules and oils [8]. Among essential oils, cinnamon leaf oil has shown strong antibacterial activities against foodborne pathogens [9]. This activity is observed because the oil contains up to 95% eugenol followed by trans-cinnamaldehyde [10]. Compared to cinnamon bark oil, cinnamon leaf oil has been scarcely used in antimicrobial films for active packaging. It was reported that the chitosan-based films containing cinnamon leaf oil were prepared and applied to the coating of strawberries [11].

Center for Disease Control and Prevention (CDC) reports indicate that *Salmonella typhimurium* is one of the most frequently occurring pathogens in various foods [12].

✉ Kyung Bin Song
kbsong@cnu.ac.kr

¹ Department of Food Science and Technology,
Chungnam National University, Daejeon 34134, Korea

Thus, control of *S. typhimurium* using essential oils has been studied for the preservation of meat, milk, fruit, and vegetables [13]. Cinnamon bark essential oil has been used to treat tomatoes inoculated with *S. typhimurium*, resulting in significant reduction of the pathogenic bacteria [14]. Recently, it was reported that zein coating with cinnamon oil effectively eliminated *S. typhimurium* from inoculated cherry tomatoes [15].

Till date, there have been no reports on duck feet gelatin (DFG) films or coating containing cinnamon leaf oil (CLO) applied to cherry tomatoes. Therefore, the present study aims to develop a DFG film containing CLO, characterize its physical properties, and evaluate antimicrobial activity in the packaging of cherry tomatoes. The results from this study could promote the possibility that DFG films with CLO could be used as a food packaging material.

Materials and methods

Materials

Duck feet and cherry tomatoes were obtained locally. CLO was obtained from Gooworl Co. (Daegu, Korea). The strains of *Staphylococcus aureus* (ATCC 10537 and KCTC 1621), *Listeria monocytogenes* (ATCC 19111 and ATCC 19115), *S. typhimurium* (ATCC 14028 and KCTC 2421), and *Escherichia coli* O157:H7 (ATCC 43889 and NCTC 12079) were used as major pathogenic bacteria in this study.

Extraction of DFG

Duck feet were washed with tap water. Visible fat and non-collagenous proteins in the duck feet were manually separated, packed in a polyethylene bag, and kept at -20°C until further use. Duck feet gelatin was prepared following the process of Park et al. [16] with minor modifications. Duck feet were soaked in 0.1 N hydrochloric acid (1:10, w/v) at 18°C for 18 h, and then washed with tap water for 2 h. The swollen duck feet were homogenized in water (1:5, w/v) with a blender, and heat-treated at 95°C for 2 h to extract the gelatin. After filtering the extracted gelatin with six-layered gauze, the filtrate was cooled at 20°C for 30 min followed by removal of the fat layer. The extracted gelatin was kept at 18°C for 5 h after which the fat layer was removed again. The gelatin solution was then frozen at -70°C and freeze-dried. The yield of gelatin was approximately 15%. The powdered gelatin was kept at 4°C prior to use.

SDS-PAGE analysis

Duck feet gelatin was dissolved in 5% SDS solution and mixed with sample buffer (2% SDS, 2% β -mercaptoethanol,

65.8 mM Tris-HCl, and 0.01% bromophenol blue). The sample was loaded and separated on a stacking gel (5%) and separating gel (7.5%). After electrophoresis, the gel was stained and then de-stained. Protein molecular weight markers (Bio-Rad Laboratories, Hercules, CA, USA) ranging from 20 to 250 kDa were used to estimate the molecular weight.

Analysis of the amino acid composition of DFG

The amino acids of DFG were analysed using liquid chromatography with Waters 510 pumps, a Waters 2487 UV detector, and a Waters 717 automatic sampler (Waters, Milford, MA, USA), with a Pico-Tag column (Waters). Each amino acid was identified and quantified by comparing retention time and peak area with an authentic standard mixture using Empower 2 software (Waters).

Preparation of DFG films

DFG (3 g, w/v), CLO (0.5, 1.0, and 1.5 g, w/v), and Tween-80 (25% of CLO, w/w) were dissolved in distilled water (100 mL) at 50°C for 30 min. Amount of the CLO was 16.7, 33.3, and 50.0% relative to DFG (w/w), respectively. Homogenization of the mixture was achieved using a homogenizer (Ultra-Turrax T25, IKA, Staufen, Germany) at $10,000\times g$ for 5 min followed by sonication for 8 min (Sonics and Materials, Inc., Newtown, CT, USA). After filtering the solution with six-layered gauze, the filtrate was kept at 60°C for 30 min. Fructose as a plasticizer (1.2 g, w/v) was added into the film-forming solution. The DFG film was prepared by pouring the film-forming solution onto a Teflon-coated plate. After drying at 20°C for 18 h, the film was preconditioned in a humidity chamber at 25°C and 50% relative humidity (RH) to determine the film properties.

Determination of DFG film properties

The rectangular DFG films were prepared and the average of five thickness values taken at random locations was calculated using a micrometer (Mitutoyo, Tokyo, Japan). The mechanical properties of the DFG films were determined using a Testometric machine (M250-2.5 CT, Testometric Company Ltd., Lancashire, UK) equipped with a load cell of 100 N. Tensile strength (TS) and elongation at break (E) of the film samples (2.54×10 cm) were measured under the conditions of 5 cm of initial grip distance with 50 mm/min of cross-head speed. Five replicates were used for each film. The water vapor permeability (WVP) of the DFG films was evaluated using poly (methyl acrylate) cups with 18 mL distilled water [17]. The color of the DFG films are represented by L^* , a^* , b^* , and

total color difference (ΔE^*) values using a colorimeter (CR-400, Minolta, Tokyo, Japan). For the opacity of DFG films, the films were cut into 10×25 mm and the absorbance at 600 nm was determined using a spectrophotometer (UV-2450, Shimadzu Corporation, Kyoto, Japan).

Antimicrobial activity measurement of the DFG films

To assess the antimicrobial activity of the DFG films, disc agar diffusion tests were performed. *E. coli* O157:H7 (ATCC 43889 and NCTC 12079) and *S. typhimurium* (ATCC 14028 and KCTC 2421) were used as Gram-negative bacteria and cultured in Tryptic Soy Broth (TSB, Bacto/Difco, Becton–Dickinson, Sparks, MD, USA) at 37 °C for 18 h. *Staphylococcus aureus* (ATCC 10537 and KCTC 1621) and *L. monocytogenes* (ATCC 19111 and ATCC 19115) used as Gram-positive bacteria were cultured in Brain Heart Infusion broth (Bacto/Difco). The cocktail of each strain was streaked on Mueller–Hinton agar (Bacto/Difco). The solution of the DFG film containing CLO was prepared by dissolving the film in distilled water (0.25 g/mL). Dissolved film was then poured onto the discs (8 mm, diameter) and dried on a clean bench for 30 min. The dried disc was placed onto the inoculated medium and subsequently incubated at 37 °C for 18 h. Inhibition zone (diameter, mm) was determined with a Digimatic calliper (Mitutoyo Corp., Kawasaki, Japan).

Application of the DFG films to packaging of cherry tomatoes

Solutions of DFG and DFG containing 1.0% CLO (DFG–CLO) were prepared to study the coating of cherry tomatoes while DFG films were prepared to examine wrapping of cherry tomatoes. Cherry tomatoes (15 ± 1 g) uniform in size and maturity were prepared and stored at 4 ± 1 °C. *Salmonella* strains (ATCC 14028 and KCTC 2421) were cultured in 25 mL of TSB at 37 °C for 18 h with shaking (150 rpm) until reaching 7 log CFU/mL. The cocktail of strains was inoculated on cherry tomatoes by the dipping method and the tomatoes were dried at 20 °C for 30 min. The cherry tomatoes were then coated with the solution of DFG or DFG–CLO and left to dry on a clean bench for 1 h. For wrapping cherry tomatoes, the films with or without CLO were prepared one day prior to the experiment and heat-sealed in a pouch form. Three cherry tomatoes were wrapped in a pouch with the dimension ($3.5 \times 3.5 \times 12$ cm) and kept them in PET container at RH $70 \pm 10\%$ and 4 ± 1 °C for 10 days. For the microbial analysis, cherry tomatoes (15 g) were immersed in peptone water (135 mL) and shaken for 3 min. The homogenized samples were serially diluted, and 0.1 mL of the solution was spread on xylose lysine

deoxycholate agar (Bacto/Difco) and incubated at 37 °C. After 24 h, colonies were counted as CFU/g.

To evaluate the quality changes in the cherry tomatoes during storage, the weight loss of the cherry tomatoes was measured by comparing with initial weight. In addition, the color change of the cherry tomatoes was measured. Ten fruits were used for color measurement. In particular, the effects of coating and wrapping with the DFG or DFG–CLO films were evaluated by a/b value.

Statistical analysis

One-way analysis of variance was performed to analyse the experimental data using SAS (SAS Institute Inc., Cary, NC, USA) with Duncan's multiple range test. All experiments were repeated three times, except the physical properties of the films ($n = 5$). $p < 0.05$ was considered to be statistically significance.

Results and discussion

Molecular properties of DFG

The molecular weight profile of DFG was visualized on a SDS–PAGE gel (Fig. 1). DFG was mainly comprised of two different α -chains (α_1 , 120 kDa and α_2 , 140 kDa), β -chains (dimers of the α -chains; 230 kDa), and γ -chains (trimers of the α -chains; 280 kDa). The profile indicates a typical type I collagen, which consists of α -, β -, and γ -chains. However, Park et al. [16] identified the molecular weight profile of DFG extracted under different temperature and pressure conditions as having 120–130 kDa (α_1 and α_2) and 200 kDa (β -chain), which differs from our results. This difference might be explained by the fact that the molecular weight profile of gelatin is affected by the extraction conditions.

The major amino acids of collagen are glycine, alanine, proline, and hydroxyproline, regardless of gelatin sources. The amino acid composition of DFG is represented in Table 1. The glycine content in the DFG was 32.8%, almost one-third of total amino acid contents, and glycine is known to play an important role in the tight helix structure of collagen [18]. The glycine content of DFG is similar to those of chicken feet gelatin (33.6%) and tilapia scale gelatin (34.9%) [4, 19]. In addition, tryptophan was not detected in the DFG, which is in good agreement with the reports of chicken feet gelatin [20] and tilapia scale gelatin [19].

Physical and optical properties of DFG films

The physical properties of DFG films with and without added CLO are shown in Table 2. The prepared DFG film

Fig. 1 Molecular weight profile of DFG on a SDS–PAGE. Lane (1) Prestained molecular marker, (2) DFG

Table 1 Amino acid composition of DFG

Amino acid	%
Aspartic acid	4.60
Glutamic acid	7.29
Threonine	2.01
Serine	2.87
Glycine	32.84
Alanine	11.06
Cysteine	0.06
Valine	1.75
Methionine	0.87
Isoleucine	1.18
Leucine	2.53
Phenylalanine	1.65
Tyrosine	0.47
Lysine	3.04
Histidine	1.18
Arginine	4.86
Proline	12.09
Hydroxyproline	9.65
Total	100

was brittle without a plasticizer. When fructose was used in the DFG film, TS (52.3 MPa) and E (15.5%) were obtained (Table 2). The thickness of DFG films was ranged from 69

to 90 μm and increased a little by the addition of CLO. Lee et al. (2016) [17] also found an increase in film thickness of skate skin gelatin films by the incorporation of thyme essential oil. The hydrophobic interactions between gelatin molecules and essential oils might cause rearrangement of gelatin molecules, consequently affecting film thickness.

The TS of DFG films varied from 37.3 to 52.3 MPa. The control film had the highest TS value (52.3 MPa), whereas TS of DFG films incorporated with CLO were lower. In most cases, the addition of essential oils to gelatin films has been reported to cause decreases in TS. Wu et al. [21] reported the decrease of TS in the gelatin film incorporated with cinnamon oil nanoliposome. Martucci et al. [22] also suggested that the TS of gelatin film containing lavender oil decreased with increasing concentration of the oil. The reason for this trend might be explained by the change in the molecular interactions among gelatin molecules in the film being affected by the addition of essential oil, resulting in a decrease of TS in the films containing essential oil [23].

The DFG films incorporated with 0.5 and 1.0% CLO had higher E values than the control film, whereas the DFG films with 1.5% CLO had a lower E value (Table 2). Similarly, Ahmad et al. [24] reported that the E value in the gelatin film containing bergamot oil increased up to a specific concentration of oil and thereafter decreased. These results suggest that the compatibility between gelatin and essential oil is important with regard to the physical properties of the films, and addition of an excessive amount of oil can cause a heterogeneous film structure, affecting the E value.

The WVP value was the lowest for the DFG film with 0.5% CLO, $2.08 \times 10^{-9} \text{ g/m s Pa}$ (Table 2). However, there was no significant difference between the DFG films and DFG films with CLO, except the film with 1.5% CLO, which has the highest WVP, $2.95 \times 10^{-9} \text{ g/m s Pa}$. Teixeira et al. [25] found that the WVP values of the gelatin films incorporated with garlic or organum oil were not statistically different from the control films. Martucci et al. [22] also found that the WVP of gelatin films incorporated with oregano oil was not changed. Similar results for the gelatin films incorporated with bergamot oil were obtained by Ahmad et al. [24]. In general, the hydrophobicity of films is increased by the addition of essential oil, and the incorporation of hydrophobic oils into hydrophilic gelatin molecules usually decreases WVP [26]. However, this trend was not observed in this study.

The optical properties of the DFG films are shown in Table 3. The addition of CLO to DFG films caused increases in the yellowness (b^*) and the total color value (ΔE^*) of the films and decrease in the redness (a^*). The opacity values were decreased by the incorporation of CLO. In particular, the DFG film with 1.0% CLO had the lowest value. Thus, the DFG films with 1% CLO can be used as a see-through packaging material. Lee et al. [5] also

Table 2 Physical properties of the DFG films containing CLO

CLO (%)	Thickness (μm)	Tensile strength (MPa)	Elongation (%)	WVP ($\times 10^{-9}$ g/m s Pa)
0	69.20 $\pm$ 2.68 ^{d,1)}	52.31 $\pm$ 1.47 ^a	15.52 $\pm$ 0.64 ^c	2.14 $\pm$ 0.01 ^b
0.5	76.20 $\pm$ 1.30 ^c	42.11 $\pm$ 0.54 ^b	24.70 $\pm$ 0.90 ^a	2.08 $\pm$ 0.09 ^b
1.0	85.40 $\pm$ 2.61 ^b	41.56 $\pm$ 0.35 ^b	18.47 $\pm$ 0.03 ^b	2.15 $\pm$ 0.02 ^b
1.5	90.40 $\pm$ 3.65 ^a	37.28 $\pm$ 0.32 ^c	12.88 $\pm$ 1.03 ^d	2.95 $\pm$ 0.09 ^a

¹⁾ Values are mean $\pm$ SD ($n = 5$). Any means in the same column followed by different letters are significantly ($p < 0.05$) different by Duncan's multiple range test

Table 3 Optical properties of the DFG films containing CLO

CLO (%)	L*	a*	b*	ΔE^*	Opacity
0	96.24 $\pm$ 0.01 ^{b,1)}	-1.28 $\pm$ 0.02 ^a	7.60 $\pm$ 0.01 ^d	—	2.86 $\pm$ 0.07 ^a
0.5	96.37 $\pm$ 0.02 ^a	-1.93 $\pm$ 0.03 ^b	9.23 $\pm$ 0.01 ^c	1.76 $\pm$ 0.01 ^c	1.66 $\pm$ 0.04 ^b
1.0	96.26 $\pm$ 0.03 ^b	-2.92 $\pm$ 0.01 ^c	10.84 $\pm$ 0.02 ^b	3.62 $\pm$ 0.01 ^b	0.37 $\pm$ 0.04 ^d
1.5	96.13 $\pm$ 0.06 ^c	-3.62 $\pm$ 0.02 ^d	12.93 $\pm$ 0.03 ^a	5.81 $\pm$ 0.01 ^a	0.50 $\pm$ 0.02 ^c

¹⁾ Values are mean $\pm$ SD ($n = 5$). Any means in the same column followed by different letters are significantly ($p < 0.05$) different by Duncan's multiple range test

Table 4 Antimicrobial activities of the DFG films against pathogenic bacteria

CLO (%)	Inhibition zone (mm)			
	<i>E. coli</i> O157:H7	<i>S. typhimurium</i>	<i>S. aureus</i>	<i>L. monocytogenes</i>
0	0	0	0	0
0.5	12.64 $\pm$ 0.37 ^{c,1)}	11.36 $\pm$ 0.98 ^c	15.91 $\pm$ 0.26 ^c	23.07 $\pm$ 0.25 ^c
1.0	22.75 $\pm$ 1.15 ^b	21.01 $\pm$ 0.93 ^b	28.18 $\pm$ 0.34 ^b	27.36 $\pm$ 2.25 ^b
1.5	28.60 $\pm$ 0.30 ^a	26.70 $\pm$ 1.70 ^a	37.39 $\pm$ 2.93 ^a	33.68 $\pm$ 1.98 ^a

¹⁾ Values are mean $\pm$ SD ($n = 5$). Any means in the same column followed by different letters are significantly ($p < 0.05$) different by Duncan's multiple range test

reported that the opacity of chicken gelatin film was lowered with the addition of 1.0% clove oil. Based on the mechanical and optical properties of DFG films with CLO, the DFG film with 1.0% CLO was used for the packaging of cherry tomatoes.

Antimicrobial activity of the DFG films

The antimicrobial activities of the DFG films were tested against *S. typhimurium*, *E. coli* O157:H7, *L. monocytogenes*, and *S. aureus* by the agar diffusion method (Table 4). The DFG film without CLO did not inhibit the growth of bacterial pathogens, whereas the inhibition zone increased proportionally to the increase of CLO concentration. In addition, the antimicrobial activities were more effective against *S. aureus* and *L. monocytogenes* than *S. typhimurium* and *E. coli* O157:H7 due to extra lipopolysaccharide in outer membrane of Gram-negative bacteria. The antimicrobial activity of CLO is attributed to eugenol, which disrupts the membrane structure of *S. typhimurium* [27]. CLO also contains *trans*-cinnamaldehyde that inhibits ATPase, resulting in the

inhibition of APT synthesis thus killing the bacteria [28]. Recently, it was reported that zein films with eugenol incorporated had antimicrobial activity against *Bacillus cereus* and *Salmonella enterica* [29]. Based on these results, the DFG films with CLO can be used as an active packaging with antimicrobial activity.

Application of the DFG films to packaging of cherry tomatoes

The DFG film with 1.0% CLO incorporated (DFG-CLO) was used for both the coating and wrapping of cherry tomatoes. The microbial analysis of the cherry tomatoes coated and wrapped with the DFG film and DFG-CLO was evaluated during storage (Fig. 2). The initial population of *S. typhimurium* on the samples was 5.28 log CFU/g right after inoculation. The population of *S. typhimurium* in the control samples reached 2.5 log CFU/g on the 5th day, and it was 2.2 log CFU/g on the 10th day of storage. Similarly, the populations of *S. typhimurium* in the cherry tomatoes coated and wrapped with the DFG film were 2.1 and 1.8 log CFU/g on the 5th and 10th days, respectively. In

Fig. 2 Changes in the population of *Salmonella typhimurium* on the cherry tomatoes coated and wrapped with DFG films during storage. Filled circle control, open circle coating with DFG, inverted triangle coating with DFG containing CLO, triangle wrapping with DFG film, square wrapping with DFG film containing CLO

contrast, the populations of *S. typhimurium* in the cherry tomatoes coated and wrapped with DFG–CLO had decreased to below the detection limit (1.0 log CFU/g) on the 3rd day of storage. These results clearly indicate that DFG–CLO effectively reduced the population of *S. typhimurium* inoculated on the samples. Similar to our results, Yun et al. [15] reported a decrease in the population of *S. typhimurium* on cherry tomatoes using zein coating incorporated with cinnamon bark oil.

The weight loss in the cherry tomatoes showed a gradual increase during 10 days of storage. The weight losses of the cherry tomatoes coated and wrapped with the DFG and DFG–CLO films were slightly lower than those of the control samples. However, there were no significant differences between the DFG film and the DFG–CLO. These results are similar with the report of Yun et al. [15], where there was no improvement in weight loss by zein coating with cinnamon oil or mustard oil.

Regarding the color change of cherry tomatoes during storage, the cherry tomatoes wrapped with the DFG–CLO had a higher *L* value than other samples (data not shown). The color change of the cherry tomatoes during storage can be compared as *a/b* value. An *a/b* value in the range of 0.95–1.2 is accepted as a ripe fruit. In this study, the color *a/b* values of the cherry tomatoes coated with the DFG films were not different from those of the control (0.9–1.1). In contrast, the color *a/b* value of the cherry tomatoes wrapped with the DFG–CLO had a lower value of 0.8, which indicates a significant difference from other treatments. These color *a/b* values suggest that the wrapping of the cherry tomatoes with the DFG film with CLO can

retard ripening during storage. Similarly, it was reported that zein coating of tomatoes and cherry tomatoes also retards ripening [15, 30].

In conclusion, the DFG film containing CLO effectively inhibited the growth of *S. typhimurium* inoculated on cherry tomatoes during storage compared to the control. In addition, the DFG film containing CLO reduced the color change on cherry tomatoes. Therefore, the DFG film incorporated with CLO developed in this study can be used as a new packaging material to enhance the microbial safety of cherry tomatoes.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

- Vieira MGA, da Silva MA, dos Santos LO, Beppu MM. Natural-based plasticizers and biopolymer films: a review. *Eur. Polym. J.* 47: 254–263 (2011)
- Silva-Weiss A, Ihl M, Sobral PJA, Gomez-Guillen MC, Bifani V. Natural additives in bioactive edible films and coatings: functionality and applications in foods. *Food Eng. Rev.* 5: 200–216 (2013)
- Ogur S, Erkan N. The physicochemical properties of edible protein films. *Ital. J. Food Sci.* 27: 1 (2015)
- Zhou CS, Li YH, Yu XJ, Yang H, Ma HL, Yagoub AEA, Cheng Y, Hu JL, Otu PNY. Extraction and characterization of chicken feet soluble collagen. *LWT-Food Sci. Technol.* 74: 145–153 (2016)
- Lee JH, Lee J, Song KB. Development of a chicken feet protein film containing essential oils. *Food Hydrocoll.* 46: 208–215 (2015)
- Kuan YH, Nafchi AM, Huda N, Ariffin F, Karim AA. Effects of sugars on the gelation kinetics and texture of duck feet gelatin. *Food Hydrocolloids.* 58: 267–275 (2016)
- Pires C, Ramos C, Teixeira G, Batista I, Mendes R, Nunes L, Marques A. Characterization of biodegradable films prepared with hake proteins and thyme oil. *J. Food Eng.* 105: 422–428 (2011)
- Tongnuanchan P, Benjakul S, Prodpran T. Properties and antioxidant activity of fish skin gelatin film incorporated with citrus essential oils. *Food Chem.* 134: 1571–1579 (2012)
- Singh G, Maurya S, deLampasona MP, Catalan CAN. A comparison of chemical, antioxidant and antimicrobial studies of cinnamon leaf and bark volatile oils, oleoresins and their constituents. *Food Chem. Toxicol.* 45: 1650–1661 (2007)
- Wang R, Wang RJ, Yang B. Extraction of essential oils from five cinnamon leaves and identification of their volatile compound compositions. *Innov. Food Sci. Emerg. Technol.* 10: 289–292 (2009)
- Perdones A, Vargas M, Atares L, Chiralt A. Physical, antioxidant and antimicrobial properties of chitosan-cinnamon leaf oil films as affected by oleic acid. *Food Hydrocoll.* 36: 256–264 (2014)
- Harvey RR, Zakhour CM, Gould LH. Foodborne disease outbreaks associated with organic foods in the United States. *J. Food Prot.* 79: 1953–1958 (2016)
- Bajpai VK, Baek KH, Kang SC. Control of *Salmonella* in foods by using essential oils: a review. *Food Res. Int.* 45: 722–734 (2012)

14. Mattson TE, Johny AK, Amalaradjou MAR, More K, Schreiber DT, Patel J, Venkitanarayanan K. Inactivation of *Salmonella* spp. on tomatoes by plant molecules. *Int. J. Food Microbiol.* 144: 464–468 (2011)
15. Yun J, Fan XT, Li XH, Jin TZ, Jia XY, Mattheis JP. Natural surface coating to inactivate *Salmonella enterica* serovar Typhimurium and maintain quality of cherry tomatoes. *Int. J. Food Microbiol.* 193: 59–67 (2015)
16. Park JH, Choe JH, Kim HW, Hwang KE, Song DH, Yeo EJ, Kim HY, Choi YS, Lee SH, Kim CJ. Effects of various extraction methods on quality characteristics of duck feet gelatin. *Korean J. Food Sci. Anim. Resour.* 33: 162–169 (2013)
17. Lee KY, Lee JH, Yang HJ, Song KB. Production and characterisation of skate skin gelatin films incorporated with thyme essential oil and their application in chicken tenderloin packaging. *Int. J. Food Sci. Technol.* 51: 1465–1472 (2016)
18. Wangtueai S, Nookhorm A. Processing optimization and characterization of gelatin from lizardfish (*Saurida* spp.) scales. *LWT-Food Sci. Technol.* 42: 825–834 (2009)
19. Weng WY, Zheng HB, Su WJ. Characterization of edible films based on tilapia (*Tilapia zillii*) scale gelatin with different extraction pH. *Food Hydrocolloid.* 41: 19–26 (2014)
20. Liu DC, Lin YK, Chen MT. Optimum condition of extracting collagen from chicken feet and its characteristics. *Asian-Australas. J. Anim. Sci.* 14: 1638–1644 (2001)
21. Wu JL, Liu H, Ge SY, Wang S, Qin ZQ, Chen L, Zheng QH, Liu QY, Zhang QQ. The preparation, characterization, antimicrobial stability and in vitro release evaluation of fish gelatin films incorporated with cinnamon essential oil nanoliposomes. *Food Hydrocoll.* 43: 427–435 (2015)
22. Martucci JF, Gende LB, Neira LM, Ruseckaite RA. Oregano and lavender essential oils as antioxidant and antimicrobial additives of biogenic gelatin films. *Ind. Crops Prod.* 71: 205–213 (2015)
23. Tongnuanchan P, Benjakul S, Prodpran T. Characteristics and antioxidant activity of leaf essential oil-incorporated fish gelatin films as affected by surfactants. *Int. J. Food Sci. Tech.* 48: 2143–2149 (2013)
24. Ahmad M, Benjakul S, Prodpran T, Agustini TW. Physico-mechanical and antimicrobial properties of gelatin film from the skin of unicorn leatherjacket incorporated with essential oils. *Food Hydrocoll.* 28: 189–199 (2012)
25. Teixeira B, Marques A, Pires C, Ramos C, Batista I, Saraiva JA, Nunes ML. Characterization of fish protein films incorporated with essential oils of clove, garlic and origanum: physical, antioxidant and antibacterial properties. *LWT-Food Sci. Tech.* 59: 533–539 (2014)
26. Hosseini SF, Rezaei M, Zandi M, Farahmandghavi F. Bio-based composite edible films containing *Origanum vulgare* L. essential oil. *Ind. Crops Prod.* 67: 403–413 (2015)
27. Cetin-Karaca H, Newman MC. Antimicrobial efficacy of plant phenolic compounds against *Salmonella* and *Escherichia Coli*. *Food Biosci.* 11: 8–16 (2015)
28. Gill AO, Holley RA. Disruption of *Escherichia coli*, *Listeria monocytogenes* and *Lactobacillus sakei* cellular membranes by plant oil aromatics. *Int. J. Food Microbiol.* 108: 1–9 (2006)
29. Khalil AA, Deraz SF, Abd Elrahman S, El-Fawal G. Enhancement of mechanical properties, microstructure, and antimicrobial activities of zein films cross-linked using succinic anhydride, eugenol, and citric Acid. *Prep. Biochem. Biotechnol.* 45: 551–567 (2015)
30. Zapata PJ, Guillen F, Martinez-Romero D, Castillo S, Valero D, Serrano M. Use of alginate or zein as edible coatings to delay postharvest ripening process and to maintain tomato (*Solanum lycopersicon* Mill) quality. *J. Sci. Food Agric.* 88: 1287–1293 (2008)