Characteristics and gelling properties of gelatin from goat skin as affected by drying methods

Sulaiman Mad-Ali¹ · Soottawat Benjakul¹ · Thummanoon Prodpran² · Sajid Maqsood³

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Abstract Characteristics and gel properties of spray-dried goat skin gelatin (SDGG) and freeze-dried counterpart (FDGG) were determined, in comparison with commercial bovine gelatin (BG). SDGG gel had the similar gel strength to FDGG gel and their gel strengths were higher than that of BG gel. SDGG gel showed slightly higher a^* and b^* values as well as the higher solution turbidity than those of FDGG. Both SDGG and FDGG solutions could set at room temperature (25–28 °C) within 18.52–19.30 min and showed the gelling and melting temperatures of 25.14–25.23 and 34.09–34.18 °C, respectively. Gels from SDGG and FDGG had the denser structure with smaller voids than that from BG. Therefore, drying methods affected the characteristics and gel properties of gelatin from goat skin to some degree.

Keywords Goat skin · Gel strength · Characteristic · Property · Drying

Introduction

Gelatin is the fibrous protein obtained by thermal denaturation or partial hydrolysis of collagenous materials such as bovine and porcine skins as well as demineralized bones (Mad-Ali et al. 2016). Gelatin has many applications in food and non-food industries (Sinthusamran et al. 2014). Generally, the properties of gelatin are governed by several factors, such as raw material and the intrinsic parameters, including chemical composition, molecular weight distribution as well as amino acid composition (Benjakul et al. 2012; Regenstein and Zhou 2007). The global demand of gelatin was 348.9 kilo tons in 2011 and is expected to reach 450.7 kilo tons in 2018 (Sheela 2014). Compared with gelatin from aquatic or marine animals, gelatins from land animals have the better gelling property with superior rheological characteristics (Norland 1990). Although gelatin has a wide range of applications, the pessimism and strong concerns still persist among consumers, mainly due to religious sentiments (Asher 1999). Porcine gelatin cannot be used in Kosher and Halal foods, while bovine gelatin is prohibited for Hindus (Kaewruang et al. 2013). Poultry gelatin has been also concerned, due to avian influenza. Thus, gelatin from alternative land animals, especially by-products from goat slaughtering, e.g. skin or bone, should be taken into account to serve for increasing demand of gelatin in the world market. Goat is one of economically important animals raised in Thailand for their meat and milk, especially for Muslims. When goats are slaughtered, skin generated as by-product accounts for 6.4–11.6% (based on the body weight) (Warmington and Kirton 1990). Goat skin can be used as an alternative raw material for gelatin production, in which the appropriate alkaline pretreatment is required (Mad-Ali et al. 2016).

✉ Soottawat Benjakul
soottawat.b@psu.ac.th

¹ Department of Food Technology, Faculty of Agro-Industry, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand

² Department of Material Product Technology, Faculty of Agro-Industry, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand

³ Department of Food Science, College of Food and Agriculture, United Arab Emirates University, 15551 Al-Ain, United Arab Emirates

Spray drying has been widely applied in the food industry due to good quality and low water activity of powder gained (Ferrari et al. 2012). After gelatin is extracted, drying is one important process to yield the gelatin with the long shelf-life. Compared with spray drying, freeze drying is time-consuming and costly. Freeze-drying process is 4–5 times more expensive than spray drying (Hammami and René 1997). Spray drying can be a means to remove undesirable odor from gelatin (Saeleaw et al. 2016; Sai-Ut et al. 2014). Nevertheless, Saeleaw et al. (2016) reported that drying conditions influenced the properties of gelatin from seabass skin, especially gelling properties. Drying methods can affect the characteristics and gel properties of gelatin from goat skin, however such an information has not been reported. Thus, the present study aimed to characterize and determine the properties of gelatin from goat skin as affected by different drying methods.

Materials and methods

Chemicals/gelatin

All chemicals were of analytical grade. Glutaraldehyde was purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA). Food grade bovine bone gelatin with the bloom strength of 150–250 g was obtained from Halagel (Thailand) Co., Ltd. (Bangkok, Thailand).

Collection and preparation of goat skins

Skins from Anglo-Nubian goats with the age of approximately 2 years were collected from a local slaughter house in Chana district, Songkhla province, Thailand. Seven kilograms of goat skins were randomly taken from three goats, pooled and used as the composite sample. The skins were packed in polyethylene bag, embedded in the insulated box containing ice (a skin/ice ratio of 1:2, w/w) and transported to the Department of Food Technology, Prince of Songkla University, within 2 h. Upon arrival, the skins were cleaned and washed with running water (26–28 °C). Prepared skins were then cut into small pieces ($2.5 \times 2.5 \text{ cm}^2$) using knives, placed in polyethylene bags and stored at -20°C until use. The storage time was not longer than 2 months. Before use, the frozen skins were thawed using a tap water (26–28 °C) for 15 min.

Pretreatment of goat skins

Prepared skins were pretreated with 0.75 M NaOH solution at a ratio of 1:10 (w/v) at room temperature (25–28 °C). The mixture was stirred manually twice a day. Alkaline

solution was removed and replaced by the same volume of freshly prepared solution every day. Pretreatment was carried out for 48 h. The skins were then transferred on the perforated screen to remove the solution.

Alkali-pretreated skins were subsequently mixed with 10 volumes of 0.75 M Na_2SO_4 solution. The mixture was allowed to stand at room temperature for 24 h. Subsequently, the skins were washed with running water until the pH of wash water became neutral or slightly alkaline. After washing, the obtained skins were soaked in 2 M H_2O_2 solution at a ratio of 1:10 (w/v). The mixture was left at 4 °C for 24 h. During soaking, H_2O_2 solution was changed every 12 h. The skin samples were then washed thoroughly three times with 10 volumes of tap water. The obtained skins were subjected to gelatin extraction.

Extraction of gelatins

To extract gelatin, the pretreated skins were placed in distilled water (50 °C) with a skin/water ratio of 1:10 (w/v) in a temperature-controlled water bath (W350, Memmert, Schwabach, Germany) for 2.5 h with a continuous stirring at a speed of 150 rpm using an overhead stirrer equipped with a propeller (RW 20.n, IKA-Werke GmbH & CO.KG, Staufen, Germany). The mixture was then filtered using two layers of cheesecloth. The filtrate was further filtered using a Whatman No. 4 filter paper (Whatman International, Ltd., Maidstone, England) with the aid of JEIO Model VE-11 electric aspirator (JEIO TECH, Seoul, Korea).

To clarify the gelatin, the resulting filtrate was mixed with diatomaceous earth (0.5%, w/v) and stirred using an overhead stirrer at a speed of 100 rpm for 30 min. The mixture was then centrifuged at $8000 \times g$ at 28 °C using a centrifuge model Avanti J-E (Beckman Coulter, Inc., Palo Alto, CA, USA) for 15 min to remove the debris. The supernatant was subsequently mixed with activated carbon (0.3%, w/v). The mixture was stirred at room temperature using an overhead stirrer at a speed of 100 rpm for 30 min. The mixture was then centrifuged at $12,000 \times g$. The supernatant with 1.25% solid content (w/v) was collected and subjected to spray-drying.

Drying of gelatin

Clarified gelatin solution was separated into two portions. The first portion was dried using a spray dryer (LabPlant SD-06 Basic, North Yorkshire, England) equipped with a spray-drying chamber having 500 mm height and 210 mm diameter and a two-liquid-nozzle spray nozzle (0.5 mm in size). A cyclone separator, a hot-air blower, and an exhaust blower were equipped. The gelatin solution was fed by a peristaltic pump at 485 mL/h into the chamber, and

atomized by hot air (air velocity of 2 m/s) from the blower in a downward current flow mode, using an inlet temperature of 160 °C, and an atomizing pressure of 2.8 bars. The second portion was subjected to freeze-drying using a freeze dryer (CoolSafe 55, ScanLaf A/S, Lyngø, Denmark) at −50 °C for 72 h.

The obtained gelatins were transferred into a ziplock bag, placed in a plastic vacuum box and kept at room temperature (25–28 °C) until used for analyses.

Analyses

Gel strength

Gelatin gel was prepared as per the method of Kittiphattanakabawon et al. (2010). Gelatin sample was dissolved in distilled water (60 °C) to obtain a final concentration of 6.67% (w/v). The solution was stirred until gelatin was solubilized completely. Gelatin solution was transferred to a cylindrical mold with 3 cm diameter and 2.5 cm height. The solution was incubated at the refrigerated temperature (4 °C) for 18 h prior to analysis.

Gel strength was determined at 8–10 °C using a texture analyzer (Stable Micro System, Surrey, UK) with a load cell of 5 kg, cross-head speed of 1 mm/s, equipped with a 1.27 cm diameter flat-faced cylindrical Teflon® plunger. The maximum force (grams), taken when the plunger had penetrated 4 mm into the gelatin gels, was recorded.

Color of gel

The color of gelatin gels (6.67% w/v) was measured by a Hunter lab colorimeter (Color Flex, Hunter Lab Inc., Reston, VA, USA). L^* , a^* and b^* values indicating lightness/brightness, redness/greenness and yellowness/blueness, respectively, were recorded. The colorimeter was warmed up for 10 min and calibrated with a white standard. Total difference in color (ΔE^*) was calculated as described by Mad-Ali et al. (2016).

Turbidity of gelatin solution

The turbidity of gelatin solution (6.67%, w/v) was determined according to the method of Fernández-Díaz et al. (2001). The turbidity of gelatin solutions was measured by reading the absorbance at 360 nm using a double-beam spectrophotometer (model UV-1601, Shimadzu, Kyoto, Japan).

Setting time for gel formation

The setting time of gelatin solution was determined at 4 and 25 °C, according to the method of Sinthusamran et al.

(2014). The gelatin solution (6.67%, w/v) was prepared in the same manner as described previously. The solution (2 mL) was transferred to thin wall test tube (diameter of 12 mm and length of 75 mm) (PYREX®, Corning, NY, USA) and preheated at 60 °C for 10 min, followed by incubation in a water bath with temperatures of 4 and 25 °C. An aluminum needle with the diameter and length of 0.1 and 25 cm, respectively, was inserted manually into the gelatin solution and raised every 10 s. The time at which the needle could not detach from the gelatin sample was recorded as the setting time. The setting time was expressed in min.

Gelling and melting temperatures

Gelling and melting temperatures of gelatin samples were measured following the method of Mad-Ali et al. (2016) using a controlled stress rheometer (RheoStress RS 75, HAAKE, Karlsruhe, Germany). Gelatin solution (6.67%, w/v) was preheated at 35 °C for 30 min. The measuring geometry used was 3.5 cm parallel plate with the gap of 1.0 mm. The measurement was performed at a scan rate of 0.5 °C/min, frequency of 1 Hz, oscillating applied stress of 3 Pa during cooling from 50 to 5 °C and heating from 5 to 50 °C. The gelling and melting temperatures were calculated, where $\tan \delta$ became 1 or δ was 45°.

Fourier transform infrared (FTIR) spectroscopic analysis

The spectra of gelatin samples were obtained using a FTIR spectrometer (EQUINOX 55, Bruker, Ettlingen, Germany) equipped with a deuterated L-alanine tri-glycine sulfate (DLATGS) detector. The horizontal attenuated total reflectance (HATR) accessory was mounted into the sample compartment. The internal reflection crystal (Pike Technologies, Madison, WI, USA), made of zinc selenide, had a 45° angle of incidence to the IR beam. Spectra were acquired at a resolution of 4 cm^{−1} and the measurement range was 4000–450 cm^{−1} (mid-IR region) at room temperature. Automatic signals were collected in 32 scans at a resolution of 4 cm^{−1} and were rationed against a background spectrum recorded from the clean empty cell at 25 °C. Deconvolution was performed on the average spectra for the amide-A, amide-B, amide-I and amide II bands using a resolution enhancement factor of 1.8 and full height band width of 13 cm^{−1}. Analysis of spectral data was carried out using the OPUS 3.0 data collection software program (Bruker, Ettlingen, Germany).

Microstructure of gelatin gel

Microstructure of gelatin gel (6.67%, w/v) was visualized using a scanning electron microscopy (SEM). Gelatin gel

having a thickness of 2–3 mm was fixed with 2.5% (v/v) glutaraldehyde in 0.2 M phosphate buffer (pH 7.2) for 12 h. The samples were then rinsed with distilled water for 1 h and dehydrated in ethanol with a serial concentration of 50, 70, 80, 90 and 100% (v/v). The samples were subjected to critical point drying. Dried samples were mounted on a bronze stub and sputter-coated with gold (Sputter coater SPI-Module, West Chester, PA, USA). The specimens were observed with a scanning electron microscope (JEOL JSM-5800 LV, Tokyo, Japan) at an acceleration voltage of 15 kV.

Statistical analysis

Experiments were run in triplicate using three different lots of samples. The data were subjected to analysis of variance (ANOVA). Comparison of means was carried out by the Duncan's multiple range test. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS 11.0 for windows: SPSS Inc., Chicago, IL, USA).

Results and discussion

Gel strength

Gel strength of different samples is presented in Table 1. SDGG, FDGG and BG had the gel strength of 258, 260 and 207 g, respectively. There was no difference in gel strength between SDGG and FDGG ($p > 0.05$). Lower gel strength of BG might be due to lower imino acid content, especially hydroxyproline content (data not shown). Imino acids are considered to be associated with the stability of the triple-helix of collagen and gel structure through hydrogen bonding between free water molecules and the hydroxyl group of the hydroxyproline in gelatin (Fernández-Díaz et al. 2001). Gelatin from bovine skin was reported to contain a lower content of imino acids than that from goat skin (Gómez-Estaca et al. 2009; Mad-Ali et al. 2016). Additionally, the difference in gel strength could be due to

the differences in intrinsic characteristics, such as molecular weight distribution and amino acid composition. Protein degradation fragments may reduce the ability of α -chains to anneal correctly by hindering the growth of the existing nucleation sites (Ledward 1986). Similar protein patterns between SDGG and FDGG were found (Mad-Ali et al. 2017). Pretreatment condition and type of raw material have the influence on chemical compositions of gelatin, which directly affect the functional properties, especially gelation (Benjakul et al. 2012). This was evidenced by the lower gel strength of BG, compared with goat skin gelatin, regardless of drying methods used.

Color of gelatin gel

The color of various gelatin gels expressed as L^* , a^* and b^* is shown in Table 1. Similar L^* -values (lightness) were observed between both SDGG and FDGG gels ($p > 0.05$), while the higher a^* -(redness) and b^* -values (yellowness) were found for SDGG gel, compared with FDGG counterpart ($p < 0.05$). During spray drying, non-enzymatic browning reaction might arise at high temperature (Sae-leaw et al. 2016). This could enhance the yellow color of the gel. However, the markedly lower b^* -values of both gelatins from goat skin were observed, compared with BG. Gels of SDGG and FDGG showed the higher ΔE^* with the lower L^* , than that of BG gel. Thus, type of raw material and process of gelatin extraction, especially drying methods, could impact the color of gelatin gel.

Turbidity of gelatin solution

Solution turbidity of SDGG and FDGG in comparison with BG is shown in Table 1. The turbidity and dark color of gelatin is commonly caused by inorganic, protein and mucosubstance contaminants, which are not removed during the extraction (Zarai et al. 2012). Both SDGG and FDGG solutions showed the higher turbidity than BG solution ($p < 0.05$). Gelatin manufacture generally has a good process to clarify the impurities from the gelatin

Table 1 Gel strength, solution turbidity and gel color of gelatin from goat skin with different drying methods

Samples	Gel strength (g)	Turbidity (A_{360})	Color			
			L^*	a^*	b^*	ΔE^*
SDGG	258 $\pm$ 4.38 ^a	2.01 $\pm$ 0.06 ^a	27.92 $\pm$ 0.47 ^b	−0.15 $\pm$ 0.59 ^a	−1.35 $\pm$ 0.16 ^b	64.95 $\pm$ 0.53 ^a
FDGG	260 $\pm$ 4.57 ^a	1.81 $\pm$ 0.05 ^b	27.39 $\pm$ 0.17 ^b	−0.27 $\pm$ 0.03 ^b	−2.08 $\pm$ 0.15 ^c	65.50 $\pm$ 0.15 ^a
BG	207 $\pm$ 3.37 ^b	0.50 $\pm$ 0.07 ^c	30.55 $\pm$ 2.67 ^a	−0.15 $\pm$ 1.70 ^a	14.05 $\pm$ 1.70 ^a	63.76 $\pm$ 1.98 ^b

Values are presented as mean $\pm$ SD (n = 3)

Different lowercase superscripts in the same column indicate significant difference ($p < 0.05$)

SDGG, FDGG and BG represent spray-dried goat gelatin, freeze-dried goat gelatin and commercial bovine gelatin, respectively

solution, such as chemical clarification and filtration processes. When comparing solution turbidity between SDGG and FDGG, the former exhibited a higher turbidity than the latter ($p < 0.05$). When gelatin was spray-dried at high temperature, gelatin molecules from SDGG might undergo conformation changes, which favored the aggregation to some degree, especially via the exposed hydrophobic reactive groups (Johnson and Zabik 1981). Clarity of gelatin gel is one of essential aesthetic properties and generally determines the quality and acceptability of finished product (Zarai et al. 2012). Therefore, drying methods affected the turbidity of gelatin solution from goat skin.

Setting time for gel formation

The setting times required for the gel formation of different gelatins are presented in Fig. 1a. The setting time of gelatin solutions at 4 °C was in the ranges of 0.40–0.50 min. The setting time at 4 °C of both SDGG and FDGG was shorter than BG ($p < 0.05$). Nevertheless, no difference in setting time at 4 °C between SDGG and FDGG was found ($p > 0.05$). For the setting time at room temperature (25 °C), all gelatin samples were set within 18.52–34.72 min. A similar result was observed, in comparison with setting at 4 °C. However, a longer setting time was required at 25 °C. In general, gelatin with low molecular weight peptides yield a longer setting time (Kittiphattanabawon et al. 2010; Sinthusamran et al. 2014). Amino acid composition, especially imino content was also reported to affect functional properties of gelatin (Benjakul et al. 2009). Shorter setting time was coincidental with higher hydroxyproline content (data not shown) and higher gel strength (Table 1). It was noted that both SDGG and FDGG were able to set at 25 °C and their setting times were twofold shorter than that of BG. The nucleated polypeptides of gelatin from goat skin were more likely generated during gelation. Subsequent network formation could be augmented. When comparing gelatin samples between SDGG and FDGG, no differences in setting times were found for both temperatures tested ($p > 0.05$). The results suggested that drying methods had no effect on the time used for network development of gelatin from goat skin.

Gelling and melting temperature

The changes in the phase angle (δ) of SDGG and FDGG in comparison with BG during cooling (from 50 to 5 °C) and subsequent heating (from 5 to 50 °C) are depicted in Figs. 1b and 1c, respectively. All gelatin samples formed a gel in the temperature range of 22.4–25.2 °C. Sharp decrease and rapid transition in phase angle during cooling were regarded as the increase in amount of energy that is elastically stored in storage modulus (G') (Kasankala et al.

Fig. 1 Setting time (a) and changes in phase angle (δ , °) during cooling (b) and subsequent heating (c) of gelatin solution (6.67%, w/v) from goat skin with different drying methods. SDGG, FDGG and BG represent spray-dried goat skin gelatin, freeze-dried goat skin gelatin and commercial bovine gelatin, respectively. Bars represent the standard deviation ($n = 3$). Different uppercase letters within the same samples indicate significant differences ($p < 0.05$). Different lowercase letters within the same setting temperature indicate significant differences ($p < 0.05$)

2007). SDGG and FDGG showed higher gelling points than BG ($p < 0.05$). However, no difference in gelling point between SDGG and FDGG was found ($p > 0.05$).

Lower gelling point of BG was in agreement with lower hydroxyproline content (data not shown) and poorer gel strength (Table 1) as well as the longer setting time (Fig. 1a). Gelling point is governed mainly by imino acid content, molecular weight distribution and also the ratio of α/β chains in the gelatin (Karim and Bhat 2009). Gelatin from goat skin has a higher content of imino acids than that from bovine skin (Gómez-Estaca et al. 2009; Mad-Ali et al. 2016). Mad-Ali et al. (2016) also reported that pretreatment conditions prior to gelatin extraction had an influence on gelling point of resulting gelatin from goat skin.

Melting points of all gelatins were in the temperature range of 31.7–34.2 °C. Melting points of goat skin gelatin were higher than that of BG. Thermal stability of gelatin gel is directly related with proline-rich regions in gelatin molecules (Gómez-Guillén et al. 2002). Proline plays a crucial role in promoting the formation of polyproline II helix (Ross-Murphy 1992). Apart from imino content, the melting point of gelatin also increases with increasing MW (Jamilah and Harvinder 2002). With higher melting temperature, gel could be retained for a longer time, thereby rendering the better mouth feel when consumed. The gelling and melting temperatures of gelatin depend on species used as raw material, which may have different living environments and habitat temperatures (Gómez-Guillén et al. 2002). Nevertheless, drying methods had no effect on melting point of gelatin from goat skin.

Fourier transform infrared (FTIR) spectra

FTIR spectra of SDGG and FDGG in comparison with BG are depicted in Fig. 2. The amide I band of SDGG, FDGG and BG appeared at 1634.17, 1632.73 and 1629.48 cm^{-1} , respectively, which was in agreement with Yakimets et al. (2005) who stated that the absorption peak at 1633 cm^{-1} was characteristic of the coiled structure of gelatin. The amide I vibration mode is primarily a C=O stretching vibration coupled to contributions from the C–N stretch, C–C–N deformation and in-plane NH bending modes (Bandekar 1992). The spectral differences in amide I of different gelatin samples were largely attributed to different conformation of polypeptide chains as well as hydrogen bonding in protein (Uriarte-Montoya et al. 2011). Generally, the amide I peak of SDGG showed slightly higher wavenumber, compared with that of FDGG. This suggested the loss of triple helix due to the enhanced disruption of inter-chain interaction caused by spray drying at high temperature. Nevertheless, no marked difference in intensity of amide I peak between SDGG and FDGG was found. When comparing the amide I between goat skin gelatin and BG, the latter had a lower wavenumber. Additionally, lower amplitude was also observed in BG, suggesting that the changes in molecular order due to the interaction of

C=O with adjacent chains (Sinthusamran et al. 2014). The decrease in peak intensity and narrowing of peak area might reflect the association of peptide fragments (Prystupa and Donald 1996).

The characteristic absorption bands of SDGG, FDGG and BG in the amide II bands were found at the wavenumbers of 1544.25, 1526.39 and 1531.37 cm^{-1} , respectively. The amide II band resulted from an out-of-phase combination of a C–N stretch and in-plane NH deformation modes of the peptide group (Bandekar 1992). The frequency range of 1550–1520 cm^{-1} is due to amide II with α -helical structure between 1550–1540 cm^{-1} and β -sheets at 1525–1520 cm^{-1} (Hashim et al. 2010). It was noted that the amide II band of FDGG was shifted to the lower wavenumber, compared with SDGG. A shift of the amide II peak to lower wavenumber is associated with the existence of hydrogen bonds (Sinthusamran et al. 2013). During spray drying, hydrogen bonds were destroyed and N–H bonds might be disrupted. Hashim et al. (2010) reported that the amide II vibration is caused by deformation of the N–H bonds. Lower amplitude was found in FDGG, compared to SDGG, indicating that N–H was more involved in bonding with the adjacent α -chains (Ahmad and Benjakul 2011). In the present study, BG showed the lowest amplitude with the lowest wavenumber.

Amide III was detected around the wavenumber of 1237.45, 1238.14, 1237.74, cm^{-1} for SDGG, FDGG and BG, respectively. The amide III represented the combination peaks between C–N stretching vibrations and N–H deformation from amide linkages as well as absorptions arising from wagging vibrations from CH_2 groups from the glycine backbone and proline side-chains (Jackson et al. 1995). No remarkable differences were observed in amide III among all samples.

The amide A band, arising from the stretching vibrations of N–H group, appeared at 3297.05, 3279.66 and 3276.66 cm^{-1} for SDGG, FDGG and BG, respectively. Normally, a free N–H stretching vibration occurs at the wavenumbers of 3400–3440 cm^{-1} . When the N–H group of a peptide is involved in a hydrogen bond, the position is shifted to lower frequencies (Sinthusamran et al. 2014). Lower wavenumber with the slightly lower amplitude was found in FDGG, compared with SDGG. FDGG might form inter-molecular interaction during freeze-drying, particularly via hydrogen bonding. Additionally, the lowest wavenumber with the lowest amplitude was found in BG, compared with the others. Ahmad and Benjakul (2011) reported that the lower amplitude as well as the lower wavenumber at amide A region indicated N–H group of shorter peptide fragments in gelatin sample was involved in hydrogen bonding. The amide B was observed at 3080.38, 3073.26 and 3076.59 cm^{-1} for SDGG, FDGG and BG, respectively, corresponding to asymmetric stretch vibration

Fig. 2 FTIR spectra of gelatin from goat skin with different drying methods. Key: see Fig. 1 caption

Fig. 3 Microstructures of gelatin gel from goat skin with different drying methods. Key: see Fig. 1 caption

of $=C-H$ as well as $-NH_3^+$ (Ahmad and Benjakul 2011). Among all samples, BG showed the lowest wavenumber with the lowest amplitude of amide B peak. FDGG had the lower wavenumber than SDGG, suggesting the higher interaction of $-NH_3^+$ group between peptide chains, occurring during freeze-drying. Therefore, the secondary structure of gelatins was affected by drying methods and condition used. Furthermore, pretreatment process and type

of raw material also had the influence on structure and functional groups of gelatin.

Microstructure of gelatin gels

Gel microstructures of goat skin gelatin prepared by spray and freeze drying methods and BG are illustrated in Fig. 3. All gelatin gels were sponge or coral-like in structure. Both

SDGG and FDGG showed the fine and dense gel network with high connectivity of protein strands. The fine and ordered structure of goat skin gelatin gel was in agreement with high gel strength (Table 1). Spray drying might not show the negative effect on the chain length of protein. On the other hand, the larger strands with bigger voids were found in the gel of BG. The coarser network of the gel might be easier to disrupt by the force applied. The coarser gel structure of BG was coincidental with the lower gel strength (Table 1). It is well known that the distribution of α -, β - and γ -chains is an important factor affecting property of gelatin (Sinthusamran et al. 2014). In addition, hydroxyproline is associated with gel formation via initiation of nucleation zones via hydrogen bonding through its –OH group (Kittiphattanabawon et al. 2010). Coarser gel structure of BG coincided with lower hydroxyproline content, compared with the others (data not shown). The formation of gel network also depended on pretreatment and extraction conditions (Yang et al. 2008) as well as the types of raw material (Benjakul et al. 2012). Therefore, the arrangement and association of molecules in the gel matrix of gelatin from goat skin was not affected by drying methods. However, types of raw material directly contributed to gel network of gelatins.

Conclusion

Both freeze-drying and spray drying methods had an impact on characteristics and gel properties of resulting gelatin. SDGG had the higher turbidity with higher a^* and b^* values than FDGG. Generally, goat skin gelatin had the better characteristics and properties including higher gel strength, shorter setting time as well as higher gelling and melting point than bovine gelatin. Thus, goat skin could be used as an alternative source for gelatin production.

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