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ARTICLE

Interactions between Chicken Salt-soluble Meat Proteins and *Makgeolli* Lees Fiber in Heat-induced Gels

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Abstract

The technological effects of *Makgeolli* lees fiber (0, 0.5, 1.0, 2.0, and 4.0%) on chicken salt-soluble breast meat proteins in a model system on proximate composition, physicochemical properties, and textural properties were investigated. *Makgeolli* lees fiber was obtained from *Makgeolli* brew processing, and the by-products showed good dietary fiber. The moisture and ash contents, water holding capacity, redness, yellowness, hardness, and apparent viscosity of chicken salt-soluble meat protein heat-induced gel systems with *Makgeolli* lees fiber were all higher than the control without *Makgeolli* lees fiber. However, protein solubility and electrophoretic patterns did not differ among the control and treatments with *Makgeolli* lees fiber samples. The chicken salt-soluble protein heat-induced gel systems incorporating *Makgeolli* lees fiber had improved water holding capacity, textural properties, and viscosity due to *Makgeolli* lees fiber addition. These results suggest that the addition of 4.0% *Makgeolli* lees fiber to gel is helpful to improve the physical properties of heat-induced gels.

Key words: heat-induced gel, *Makgeolli* lees fiber, model system, salt-soluble meat protein

Introduction

The gel formation property implies partial denaturation of protein followed by irreversible aggregation, which results in a three-dimensional network (Choi *et al*., 2011; Lanier *et al*., 2004). The heat-induced gelling properties of chicken salt-soluble muscle proteins are the most important functional properties in processed meat products (Smith *et al*., 1998). The meat proteins remain soluble until heated to 60-70°C, when heat-set protein gelation occurs (Choi *et al*., 2011). The gelation of salt-soluble proteins during the heating process is primarily responsible for water and fat stabilization (McCord *et al*., 1998). In general, muscle proteins can be separated to three groups based on solubility: sarcoplasmatic (water-soluble), myofibrillar (salt-soluble), and stromal (insoluble) proteins (Xiong, 1997). The total muscle protein is composed of approximately 60% salt-soluble myofibrillar proteins (Koohmaraie *et al*., 1984). The addition of salt-soluble myofibrillar proteins results in gel formation (Choi *et al*., 2011; Wang *et al*., 1990) and are most important during meat processing due to their ability to produce three-dimensional gels upon heating (Verbeken *et al*., 2005). Choi *et al*. (2011) investigated the effect of rice bran fiber on the gelation of mixed pork salt-soluble myofibrillar proteins and reported that mixed protein samples displayed improved gel characteristics after rice bran fiber treatments. DeFreitas *et al*. (1997) demonstrated the influence of added carrageenan on the gelling characteristics of pork salt-soluble meat proteins in model systems. The physical properties of gel systems are also affected, and can be improved, by the concentration of edible seaweeds that is used (Cofrades *et al*., 2008). The three-dimensional gels greatly influence the yield and textural properties of processed meat products. The gelling forms a three-dimensional structure related to a polymerization reaction between the protein molecules. Reduced-fat or low-fat meat products may be partly substituted by water and isolated soy protein, carrageenan, maltodextrins, chitosan, and dietary fiber, which helps improve emulsion stability and textural properties (Chin *et al*., 1999; Choi *et*

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al., 2010a; García-García and Totosaus, 2008; Park *et al*., 2004).

Makgeolli lees fiber has so far been of limited use in the food industry as a fiber source (Choi *et al*., 2010b). A great deal of *Makgeolli* lees is produced annually in Korea, and the by-products of *Makgeolli* brew processing are commonly used as animal feeds or fertilizers (Blandino *et al*., 2003; Choi *et al*., 2010b, Lee *et al*., 1996). *Makgeolli* lees provide dietary fiber, proteins, minerals, vitamins, alcohol, and organic acids that are recognized and increasingly sought for improved human health (Jeong and Park, 2006). However, dietary fiber sources such as *Makgeolli* lees are not only desirable for their nutritional properties but also for their functional and technological properties. Also, the influence of *Makgeolli* lees fiber on the functional properties of chicken salt-soluble meat proteins is not clearly understood. It is not known whether the *Makgeolli* lees fiber interacts directly or indirectly with the chicken salt-soluble meat proteins during gel network formation (Choi *et al*., 2011; McCord *et al*., 1998).

The objective of this study was to investigate the gelling properties of chicken salt-soluble proteins as affected by various levels of *Makgeolli* lees fiber, and to contribute to the developments of a salt-soluble chicken protein model system.

Materials and Methods

Preparation and processing of *Makgeolli* lees fiber extract

Dietary fiber was extracted using the modified AOAC enzymatic-gravimetric method (AOAC, 1995; Choi *et al*., 2009). *Makgeolli* lees was obtained from Seoul Takju Map Association, Seoul, Korea, alcoholic components were removed by triple washing with four volumes of water (25°C), and the residue was dried (55°C) overnight in an air oven and then cooled. The *Makgeolli* lees was gelatinized with 0.6% termamyl (heat stable alpha-amylase) at 95°C for 1 h to remove starch, followed by filtration. The residue was then washed three times with four volumes of heated water (100°C) and allowed to equilibrate to room temperature (20°C) over 6 h. The residue was then washed with 99.9% ethanol preheated to 60°C, followed by filtration. The residue was dried (55°C) overnight in an air oven and then cooled. The *Makgeolli* lees fiber (moisture content: 3.42±0.14%; fat content: 5.98±0.28%; protein content: 15.51±0.78%; ash content: 0.60±0.06%; dietary fiber content: 60.39±3.81%; CIE L^*-value: 67.35 ±1.02; CIE a^*-value: 4.62±0.45; CIE b^*-value: 16.09±0.85; pH: 4.76±0.24) was then placed in polyethylene bags, vacuum packaged using a model FJ-500XL vacuum packaging system (Fujee Tech, Korea) and stored at 4°C until used for product manufacture (Choi *et al*., 2010b).

Protein extraction

Fresh chicken breast meat (*M. pectoralis major*) was purchased from a local processor. Chicken breast meats were initially ground through an 8-mm plate and then ground through a 3-mm plate. The ground tissue was then placed in polyethylene bags, vacuum packaged using a vacuum packaging system (FJ-500XL, Fujee Tech, Korea) and stored at 0°C until required for salt-soluble protein manufacture. The samples were allowed to equilibrate at 2°C and the meat pH was determined with a pH meter (Model 340, Mettler-Toledo GmbH, Switzerland) after mixing 10 g of ground muscle with 90 mL deionized-distilled water for 1 min. One part meat and two parts 0.58 M saline (0.49 M NaCl, 17.8 mM $Na_5P_3O_{10}$ and 1 mM NaN_3, pH 8.3, 2°C) solution of the same ionic strength and pH were blended for 30 s in a blender. The slurry was kept at 2°C for 1 h and then centrifuged (12,000 g, 2°C) for 1 h in a Supra 25 K high speed refrigerated centrifuge (Hanil Science Industrial, Korea). The protein extract was strained through three layers of cheesecloth (Camou *et al*., 1989). Protein concentrations of the meat solids and supernatant were determined using a Kjeltec® 2300 nitrogen analyzer (Foss Tecator AB, Sweden). Nitrogen was converted to protein by multiplying by 6.25. Moisture and fat determinations were performed by AOAC (1995) methods.

Gel preparation

Chicken salt-soluble meat protein solutions were diluted to 5% protein with a saline solution of the same pH (6.0) as the protein extract, transferred to glass gelling tubes, and various amounts of *Makgeolli* lees fiber were added. The sealed tubes were centrifuged at 800 g for 15 min at 4°C to remove air bubbles. Samples were equilibrated at 20°C for 10 min in a water bath, heated to 90°C at 1.75°C/min and held at 90°C for 20 min. After heating, the tubes were immersed in water overnight at 4°C (McCord *et al*., 1998).

pH

The pH values of sample were determined with a pH meter (Model 340, Mettler-Toledo GmbH, Switzerland). The pH of the gel was measured after blending 5 g of

sample with 20 mL of distilled water for 60 s in homogenizer (Ultra-Turrax SK15, Janke & Kunkel, Germany). All determinations were performed in triplicate.

Proximate composition

Compositional properties of the samples were determined using AOAC procedures (1995). Moisture content (950.46B, oven air-drying method) was determined by weight loss after 12 h of drying at 105ºC in a SW-90D drying oven (Sang Woo Scientific, Korea). Fat content (960.69, ether extractable component) was determined by the Soxhlet method with a Soxtec® Avanti 2050 auto solvent extraction system (Foss Tecator AB, UK), and protein content (981.10) was determined by the aforementioned Kjeldahl method. Ash content was determined according to AOAC method 920.153 (muffle furnace).

Water holding capacity (WHC)

WHC was measured gravimetrically (Kocher and Foegeding, 1993) using heat-induced gels prepared from five formulations (0 (control), 0.5, 1.0, 2.0, and 4.0% *Makgeolli* lees fiber). Before thermal processing, the sealed tubes were centrifuged at 800 g expressed using the following formula:

$$WHC\ (\%) = [1 - (ML/CG)] \times 100$$

where ML is the weight of the moisture loss from the gel after centrifugation and CG is the weight of the cooked gel.

Data represent the mean values from three replicates. One replicate consisted of three observations per treatment.

Color evaluation

The color of each gel was determined using a Minolta Chroma meter CR-210 colorimeter (Minolta, Japan; illuminate C, calibrated with a white plate, CIE L*=+97.83, CIE a*=-0.43, and CIE b*=+1.98). Six measurements for each of five replicates were taken.

Apparent viscosity

Each gel viscosity was measured in triplicate with a Hakke Viscotester®500 rotational viscometer (Thermo Electron, Germany) set at 10 rpm. The standard cylinder sensor (SV-E) was positioned in a 50 mL plastic cup filled with gel and allowed to rotate under a constant rate at s^{-1} for 30 s before each reading was taken. Apparent viscosity values in centipoises were obtained. The temperature (18ºC) of each sample at the time of viscosity testing was also recorded (Park *et al.*, 2004).

Texture profile analysis (TPA)

The textural properties of chicken salt-soluble meat protein samples during thermal gelation were measured with a TA-XT2*i*, texture analyzer (Stable Micro Systems, UK) with 25 kg load cell. The centre core of heat-induced gel samples were cut (20 mm in diameter, 15 mm in height) and compressed twice to 30% of their original height at a constant cross-head speed of 2.0 mm/s. The conditions of texture analysis were as follows: pre-test speed 2.0 mm/s, post-test speed 5.0 mm/s, maximum load 2 kg, head speed 2.0 mm/s, distance 8.0 mm, force 10 g. TPA parameters were hardness [peak force on first compression (kg)], springiness [ratio of the sample recovered after the first compression], cohesiveness [ratio of the active work done under the second force-displacement curve to that done under the first compression curve], gumminess [hardness × cohesiveness (kg)], and chewiness [hardness × cohesiveness × springiness (kg)] (Bourne, 1982).

Protein solubility

Protein solubility was utilized as an indicator of protein denaturation (Joo *et al*., 1999). Sarcoplasmic protein solubility was determined by dissolving 2 g of muscle powder in 20 mL of ice-cold 25 mM potassium phosphate buffer (pH 7.2). The heat-induced gel samples concentrations of the supernatants were determined using the Biuret method (Gornall *et al*., 1949). Total protein solubility was determined by homogenizing 2 g of muscle powder in 20 mL of ice-cold 1.1 mol/L potassium iodide in a 100 mol/L phn concentrations of the supernatants were determined using the Biuret method (Gornall *et al*., 1949). Total protein solubility was determined by homogenizing 2 g of muscle powder in 20 mL of ice-cold 1.1 mol/L potassium iodide in a 100 mol/L phosphate buffer (pH 7.2). The procedures for homogenization, shaking, centrifugation, and protein determination are described above. Myofibrillar protein solubility was obtained by determining the difference between the total and sarcoplasmic protein solubilities.

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE)

SDS-PAGE was performed according to the procedure of Laemmli (1970). SDS-PAGE samples were prepared by adjusting the protein concentration to 6.4 mg/mL. Each diluted sample was combined with 0.5 volumes of

sample buffer/SDS gel loading buffer (50 mM Tris-Cl pH 6.8, 100 mM dithiothreitol, 2%(w/v) SDS, 0.1% bromophenol blue, 10%(w/v) glycerol) and loaded into the separate wells of a Mini-Protean 3 cell (Bio-Rad Laboratories, USA). Ten percent polyacrylamide separating gels contained 30% acrylamide mix (29:1 acrylamide: bisacrylamide), 0.375 M Tris–HCl, pH 8.8, 0.1%(w/v) sodium dodecyl sulfate (SDS), 0.1%(w/v) ammonium persulfate, and 0.04%(v/v) N,N,N',N'-tetramethylenediamine (TEMED). The 5% stacking gel contained 30% acrylamide mix (29:1 acrylamide:bisacrylamide), 0.1 M Tris–HCl, pH 6.8, 0.1%(w/v) SDS, 0.1%(v/v) TEMED, and 0.1% ammonium persulfate. Gels were run at 100 V for approximately 40 min at room temperature, using Tris-glycine electrophoresis buffer (25 mM Tris, 250 mM glycine pH 8.3, 0.1%(w/v) SDS as the running buffer. Gels were stained with 0.25%(w/v) Coomassie Brilliant Blue R-250, 50%(v/v) methanol, and 10%(v/v) acetic acid for 12 h and de-stained in the same solution without Coomassie Brilliant Blue R-250 (Weber and Osborn, 1969). Molecular weights were determined relative to high and low molecular weight standard mixtures (Sigma-Aldrich, USA).

Statistical analysis

The experiment was replicated three times, each with a new batch of salt-soluble meat protein and the data were analyzed using the general linear model (GLM) procedure of the SAS statistical package (2008). Main factors included *Makgeolli* lees fiber level (0, 0.5, 1.0, 2.0, and 4.0%). When an interaction between factors was found to be significant ($p<0.05$), means were separated out by treatment groups. If the interaction was not significant, data were pooled to test the main effect using Duncan's multiple range test.

Results and Discussion

Proximate compositions of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The proximate compositions of the heat-induced gel samples containing *Makgeolli* lees fiber are shown in Table 1. The moisture contents of heat-induced gels samples containing *Makgeolli* lees fiber were higher than that of the control samples without *Makgeolli* lees fiber ($p<0.05$). Increasing levels of *Makgeolli* lees fiber significantly increased the moisture content of chicken salt-soluble protein heat-induced gel systems ($p<0.05$), because higher moisture content gives increased water binding capacity to heat-induced gels. These results agree with those reported by Choi *et al*. (2011), in which the moisture content significantly increased with the addition of rice bran fiber to pork salt-soluble protein heat-induced gels. Similar results were obtained by Osburn and Keeton (2004) for a konjac gel matrix prepared with low-fat sausage emulsions. Increasing levels of konjac increased the moisture content because the addition of konjac was related with higher water holding capacities of the hydrocolloid gel. The protein and fat contents did not significantly differ between control and treatments with *Makgeolli* lees fiber ($p>0.05$). The ash contents of chicken heat-induced gels were higher in formulations containing *Makgeolli* lees fiber than in the control ($p<0.05$), consistent with the influence of minerals and vitamins in the *Makgeolli* lees fiber on the heated-mediated induction of gel formation. Choi *et al*. (2010a) reported similar results for the addition of rice bran fiber to reduced-fat frankfurters, which likely reflected the minerals in the rice bran fiber. These results agree with the result of Cofrades *et al*. (2008), who that the ash content significantly increased with the level of edible seaweeds added to gel meat systems. The ash levels of gel meat systems were higher to the edible seaweeds added, because the edible seaweed

Table 1. Proximate composition of chicken salt-soluble protein heat-induced gel systems formulated with *Makgeolli* lees fiber

Parameters	Control	T1	T2	T3	T4
Moisture (%)	83.03±0.27^{e}	85.21±0.15^{d}	86.17±0.23^{c}	87.04±0.22^{b}	87.40±0.35^{a}
Protein (%)	10.14±0.35	10.12±0.34	9.97±0.24	9.82±0.28	9.74±0.31
Fat (%)	0.62±0.21	0.74±0.28	0.75±0.17	0.78±0.34	0.89±0.32
Ash (%)	2.78±0.08^{c}	2.82±0.04^{b}	2.82±0.08^{b}	2.83±0.04^{ab}	2.86±0.07^{a}

All values are the mean±SD of three replicates.

$^{a-e}$Means within a row with different letters are significantly different ($p<0.05$).

Control, no addition of *Makgeolli* lees fiber; T1, 0.5% *Makgeolli* lees fiber; T2, 1.0% *Makgeolli* lees fiber; T3, 2.0% *Makgeolli* lees fiber; T4, 4.0% *Makgeolli* lees fiber.

treatment sample has containing dietary fiber and mineral.

pH and color of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

Table 2 provides data concerning pH, lightness (CIE L*-value), redness (CIE a*-value), and yellowness (CIE b*-value) values for chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber levels. Uncooked and cooked control had the highest pH values ($p<0.05$). Increasing levels of *Makgeolli* lees fiber were related with lower pH of the chicken salt-soluble protein heat-induced gels ($p<0.05$), probably due to effect of the *Makgeolli* lees fiber (pH, 4.76). These results agree with those reported by Choi *et al*. (2010b), in which the pH significantly decreased with the addition of *Makgeolli* lees fiber to meat emulsion model systems. For this reason, *Makgeolli* lees fiber contained organic acids and lactic acid bacteria. Similarly, Jeong and Park (2006) reported that added *Makgeolli* powder decreased the pH values of food due to the influence of organic acids, saccharides, and lactic acid bacteria contained in the added *Makgeolli*.

The differences in lightness, redness, and yellowness values of chicken salt-soluble protein heat-induced gels containing *Makgeolli* lees fiber were significantly difference ($p<0.05$) (Table 3). The lightness of uncooked and cooked controls were higher than the treatments with *Makgeolli* lees fiber, as increasing levels of *Makgeolli* lees fiber decreased lightness ($p<0.05$). The redness and yellowness values of uncooked and cooked gels was significantly increased with increasing *Makgeolli* lees fiber levels ($p<0.05$), because the gel affected by the *Makgeolli* lees fiber color (CIE L*-value: 67.35±1.02; CIE a*-value: 4.62±0.45; CIE b*-value: 16.09±0.85). Similar results were obtained by Choi *et al*. (2011) for heat-induced gel prepared with pork salt-soluble meat protein in model systems with added rice bran fiber. These results obtained the lightness and redness values of gels decreased and the yellowness values of gels increased with increasing levels of rice bran fiber. Choi *et al*. (2010b) observed that color evaluations of meat emulsion systems with added *Makgeolli* lees fiber show decreased lightness and redness values, and increased yellowness values. The color values of meat products are influenced to the addition of colored dietary fiber from natural sources (Choi *et al*., 2008, 2011; Cofrades *et al*., 2008; Eim *et al*., 2008; Lee *et al*., 2008).

Table 2. pH and color parameters of chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber

	Parameters	Control	T1	T2	T3	T4
Uncooked	pH	6.70±0.02^{a}	6.67±0.02^{ab}	6.66±0.03^{b}	6.63±0.02^{c}	6.58±0.03^{d}
	CIE L*-value	62.30±0.32^{a}	58.52±0.56^{b}	57.56±0.95^{b}	57.39±0.42^{b}	56.66±0.78^{c}
	CIE a*-value	-0.85±0.32^{e}	-0.49±0.18^{d}	0.16±0.44^{c}	1.44±0.48^{b}	3.82±0.79^{a}
	CIE b*-value	5.60±1.16^{d}	5.87±0.72^{d}	9.03±0.77^{c}	12.92±0.85^{b}	19.07±0.87^{a}
Cooked	pH	6.73±0.02^{a}	6.70±0.02^{b}	6.68±0.03^{c}	6.66±0.02^{cd}	6.62±0.03^{d}
	CIE L*-value	82.97±1.11^{a}	80.86±0.87^{b}	78.47±1.33^{c}	75.22±1.17^{d}	71.14±0.97^{e}
	CIE a*-value	-0.63±0.09^{e}	-0.05±0.19^{d}	0.31±0.22^{c}	0.68±0.19^{b}	1.26±0.58^{a}
	CIE b*-value	5.22±0.60^{d}	6.15±0.60^{c}	6.90±0.48^{c}	9.19±0.55^{b}	11.48±0.87^{a}

All values are the mean±SD of three replicates.
$^{a-e}$Means within a row with different letters are significantly different ($p<0.05$).
Control, no addition of *Makgeolli* lees fiber; T1, 0.5% *Makgeolli* lees fiber; T2, 1.0% *Makgeolli* lees fiber; T3, 2.0% *Makgeolli* lees fiber; T4, 4.0% *Makgeolli* lees fiber.

Table 3. Texture profile analysis of chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber

Parameters	Control	T1	T2	T3	T4
Hardness (kg)	0.55±0.08^{e}	0.60±0.08^{bc}	0.63±0.07^{b}	0.66±0.06^{b}	0.90±0.10^{a}
Springiness	0.86±0.03^{d}	0.98±0.01^{a}	0.96±0.02^{ab}	0.94±0.03^{b}	0.92±0.02^{c}
Cohesiveness	0.35±0.04^{c}	0.43±0.04^{b}	0.47±0.05^{b}	0.51±0.05^{a}	0.52±0.04^{a}
Gumminess (kg)	0.19±0.04^{d}	0.26±0.04^{c}	0.30±0.06^{bc}	0.34±0.05^{b}	0.45±0.05^{a}
Chewiness (kg)	0.17±0.05^{d}	0.28±0.04^{c}	0.33±0.05^{b}	0.35±0.06^{b}	0.44±0.04^{a}

All values are the mean±SD of three replicates.
$^{a-e}$Means within a row with different letters are significantly different ($p<0.05$).
Control, no addition of *Makgeolli* lees fiber; T1, 0.5% *Makgeolli* lees fiber; T2, 1.0% *Makgeolli* lees fiber; T3, 2.0% *Makgeolli* lees fiber; T4, 4.0% *Makgeolli* lees fiber.

Water holding capacity of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The water holding capacity of chicken salt-soluble protein heat-induced gel systems are depicted in Fig. 1. The water holding capacity of pure chicken salt-soluble protein in the control was 80.45%, whereas the heat-induced gels with added *Makgeolli* lees fiber had greater water holding capacities than the control (p<0.05). These results are in agreement with a study that reported that heat-induced gel prepared with pork salt-soluble proteins in model systems are affected by rice bran fiber (Choi *et al*., 2011). The pork salt-soluble proteins in model systems with added rice bran fiber had greater water holding capacity than the control. Furthermore, McCord *et al*. (1998) reported that heat-induced gelation characteristics of salt-soluble proteins are influenced by whey protein isolate. DeFreitas *et al*. (1997) observed that the salt-soluble meat protein gels with added carrageenan increased water retention, because higher water holding capacity gives improving binding capacity between the meat protein and water to salt-soluble meat protein gels. The water holding capacity of a hydrocolloid gel can be attributed to increasing moisture content with increasing levels of konjac (Osburn and Keeton, 2004). In general, the increased water holding capacity can be largely attributed to the total amount of solubilized myosin, since myosin is largely responsible (Choi *et al*., 2011; Nakayama and Sato, 1971), and heat-induced gel requires the association of myosin and actin chains, which produces a continuous three-dimensional network in which water is captured (Liu *et al*., 2008).

Protein solubility of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The protein solubility of sarcoplasmic, myofibrillar, and total proteins in the chicken salt-soluble protein heat-induced gel systems formulated with different levels of *Makgeolli* lees fiber are presented in Fig. 2. The sarcoplasmic, myofibrillar, and total protein solubilities in the chicken salt-soluble protein heat-induced gel systems were not significantly different between the control and the *Makgeolli* lees fiber treatments samples (p>0.05), due to same salt and phosphate concentration in the samples treatments added. It is for this reason that protein solubility of meat products is influenced by water holding capacity of meat, but salt or phosphate concentrations in the sample are the major factor to affect the protein solubility in meat products. Dietary fiber from *Makgeolli* lees is useful due to its ability to enhance water holding capacity in meat products, but protein solubilities did not affected. Farouk *et al*. (2002) reported that protein solubility during cooking can influence textural and rheological properties. The protein solubility of salted cooked batters is higher in salt-soluble protein solubility than unsalted meat batters (Farouk and Swan, 1997). Sayre and Briskey (1963) reported that protein solubility in meat of important different qualities characteristics is influenced by careful control of the conditions, and that protein solubility appears to provide a better indication of meat product quality. Thus, gels formation in chicken salt-soluble protein heat-induced gel systems can be affected by the concentration and contents of myofibrillar protein, the

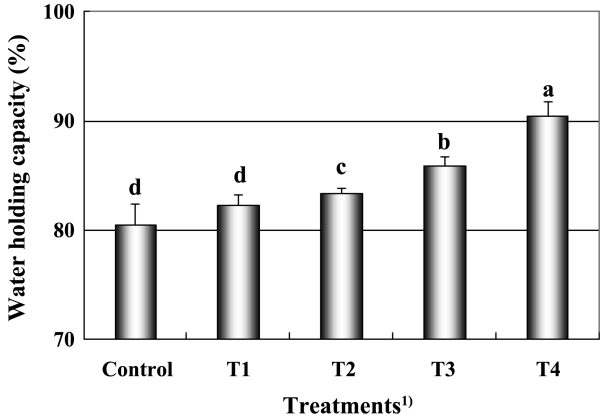

Fig. 1. Water holding capacity of chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber. [a-d]Means in the treatments with different letters are significantly different (p <0.05). Control, no addition of *Makgeolli* lees fiber; T1, 0.5% *Makgeolli* lees fiber; T2, 1.0% *Makgeolli* lees fiber; T3, 2.0% *Makgeolli* lees fiber; T4, 4.0% *Makgeolli* lees fiber.

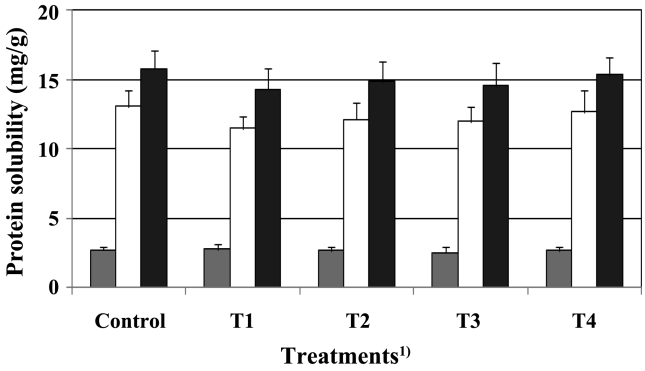

Fig. 2. Protein solubility of chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber. [a-d]Means in the treatments with different letters are significantly different (p <0.05). Control, no addition of *Makgeolli* lees fiber; T1, 0.5% *Makgeolli* lees fiber; T2, 1.0% *Makgeolli* lees fiber; T3, 2.0% *Makgeolli* lees fiber; T4, 4.0% *Makgeolli* lees fiber.

type and concentration of salts and phosphates, water holding capacity, pH, processing time, and temperature, and additives that form self-complexes or complexes with other components (Choi *et al*., 2011; Lanier, 1991).

Apparent viscosity of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The *Makgeolli* lees fiber concentration significantly affected the apparent viscosity of chicken salt-soluble protein unheated gels (Fig. 3). In general, apparent viscosity is related to the textural properties and water holding capacity in model systems. The control and all the treatments with added *Makgeolli* lees fiber samples displayed thixotropic behavior with apparent viscosity values that decreased with increasing rotation time. Similar results were found by Choi *et al*. (2011) who observed that addition of rice bran fiber to pork salt-soluble protein gels results in decreased viscosity with increasing rotation time. The control gel samples had the lowest maximum viscosity, while samples with increasing *Makgeolli* lees fiber concentration had progressively higher maximum viscosity values due to the fiber to high binding capacity between salt-soluble protein and water. The significant changes in apparent viscosity observed for unheated chicken salt-soluble protein gels were due to higher dietary fiber. These results agree with the observation of Choi *et al*. (2010b) that the addition of *Makgeolli* lees fiber to emulsion systems samples resulted in significantly increased apparent viscosity as the content of *Makgeolli* lees fiber increased, as higher viscosity imparted increased elasticity to the emulsion systems. Moreover, Park *et al*. (2004) observed that heat-induced gel prepared from pork salt-soluble protein with added combined water soluble chitooligosaccharide and chitosan samples significantly increases viscosity with increased addition. Increasing viscosity is related with improved emulsion stability, and high viscosity are not easily broken emulsion in model systems (Aktas and Genccelep, 2006; Choi *et al*., 2011).

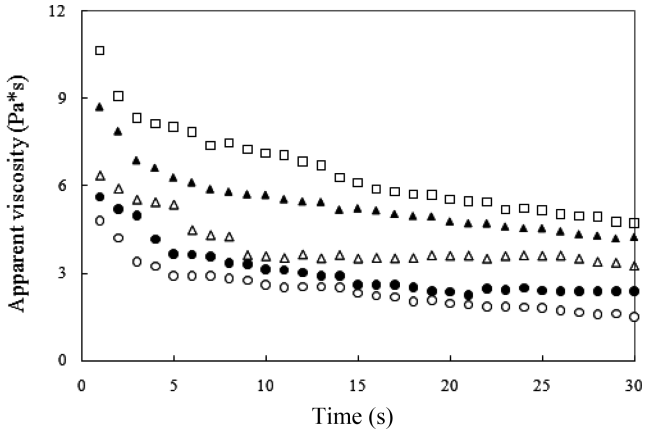

Fig. 3. Apparent viscosity of chicken salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber. (○) Control, no addition of rice bran fiber; (●) T1, 0.5% *Makgeolli* lees fiber; (△) T2, 1.0% *Makgeolli* lees fiber; (▲) T3, 2.0% *Makgeolli* lees fiber; (□) T4, 4.0% *Makgeolli* lees fiber

TPA of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The textural properties of chicken salt-soluble protein heat-induced gel systems with different added *Makgeolli* lees fiber concentration are given in Table 3. The hardness, cohesiveness, gumminess, and chewiness values of heat-induced gels were significantly higher in gels with added *Makgeolli* lees fiber than the control, as increasing *Makgeolli* lees fiber levels increased hardness, cohesiveness, gumminess, and chewiness, perhaps due to the ability of *Makgeolli* lees fiber to create a stronger binding three-dimensional network. These results are agree with reported that meat emulsion systems with rice bran fiber display increased emulsion system hardness, cohesiveness, gumminess, and chewiness values (Choi *et al*., 2009). Chin (2000) reported that heat-induced gels prepared with salt soluble protein with added konjac flour and carrageenan treatments displayed higher gel hardness than salt soluble protein gel without the added ingredients. Improvement of the textural properties of the heated-induced gel with the addition of konjac flour and carrageenan was primarily due to the physical entrapment of protein and water by the ingredients, resulting in higher gel hardness. According to Westphalen *et al*. (2006), the hardness of heat-induced gels concerns relationships between viscoelastic properties and the water holding capacity of myofibrillar protein gels. The springiness of heat-induced gels amended with *Makgeolli* lees fiber was lower than control; the highest springiness in heat-induced gels was obtained with 0.5% *Makgeolli* lees fiber (T1). In this study, all parameters of textural profile analysis for chicken salt-soluble protein heat-induced gel systems had higher values with added *Makgeolli* lees fiber relative to the control without *Makgeolli* lees fiber. Similar results were obtained by Cofrades *et al*. (2008) regarding the effect of added edible seaweed on the characteristics of gel/emulsion meat systems, and by Chin (2000) concerning the influence of added konjac and carrageenan on heat-induced gels prepared with pork salt soluble protein. For these reason, the texture of cooked meat products is affected by the gelling capacity of myofibrillar proteins

and water retention. Nuckles *et al*. (1991) indicated that protein gelation is one of the major functional properties in emulsified meat products, as it provides desirable textural properties.

Electrophoretic banding pattern of protein extracts of chicken salt-soluble protein heat-induced gel systems with *Makgeolli* lees fiber

The electrophoretic pattern of the total soluble proteins is shown in Fig. 4 for chicken salt-soluble protein heat-induced gels with added *Makgeolli* lees fiber. There was no apparent change in salt-soluble protein heat-induced gels lacking *Makgeolli* lees fiber. The main alterations of heat-induced gels were the absence of protein bands at 69 kDa (band A, likely albumin), 37 kDa (band B, likely tropomyosin bbb), and 33 kDa (band C, likely tropomysin β) (Choi *et al*., 2011; DeFreitas *et al*., 1997). The chicken salt-soluble protein heat-induced gel proteins contained low intensity bands at approximately 205 kDa (likely myosin heavy chain) and 45 kDa (likely actin). Thus, the electrophoretic banding pattern of protein extracts of chicken salt-soluble protein heat-induced gel systems was not influenced by the addition of *Makgeolli* lees fiber. In general, myosin heavy chain is the major protein removed by expelled water following during heating (DeFreitas *et al*., 1997), and light chains dissociate and solubilize when myosin heavy chains aggregate and gel during heating (Samejima *et al*., 1984). Similar results were obtained by Choi *et al*. (2011), who reported that actin and myosin heavy chain band from gels mostly disappeared during the high temperature heating. Hofmann (1977) indicated that the presence of sodium chloride has a distinct negative effect on the intensity of the stained myosin band, while actin exhibits less sensitive behavior.

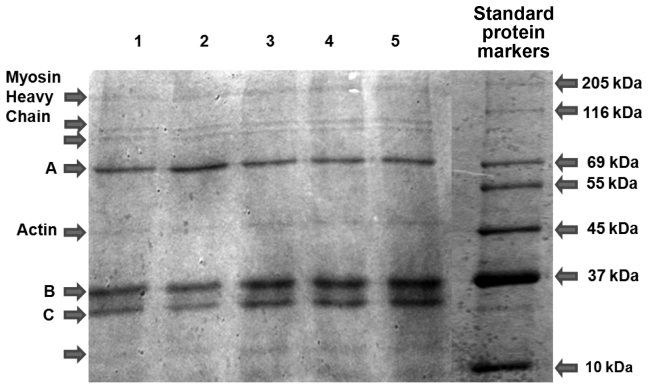

Fig. 4. SDS-PAGE patterns of salt-soluble protein heat-induced gels formulated with *Makgeolli* lees fiber. Lane 1, control (no addition of *Makgeolli* lees fiber); Lane 2, T1 (0.5% *Makgeolli* lees fiber); Lane 3, T2 (1.0% *Makgeolli* lees fiber); Lane 4, T3 (2.0% *Makgeolli* lees fiber); Lane 5, T4 (4.0% *Makgeolli* lees fiber)

The technological and functional effects of *Makgeolli* lees fiber on chicken salt-soluble meat proteins in a model system were investigated. The increased water holding capacity of chicken salt-soluble protein heat-induced gels upon the addition of *Makgeolli* lees fiber were probably due to the molecular interactions of hydrocolloids among proteins, water, and *Makgeolli* lees fiber. This study demonstrates that protein mixtures such as sarcoplasmic and myofibrillar protein can be controlled in terms of hardness characteristics by adding *Makgeolli* lees fiber during gel formation. These results indicate that the functional properties of *Makgeolli* lees fiber under various conditions in low-fat and reduced-fat meat products involve meat proteins due to the *Makgeolli* lees fiber alone, with no obvious molecular interactions.

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