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돼지 반막양근을 이용한 수리미 유사물질의 겔 특성에 미치는 가열시간과 온도의 영향

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The Effects of Cooking Temperature and Time on Gel Property of Surimi-like Material from Porcine *semimembranosus* Muscle

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Abstract

This study examined the optimal cooking condition for surimi-like material (SLM) derived from porcine *semimembranosus* (SM) muscle and the effects of the various cooking temperatures and the cooking time on the gel properties. The most noticeable change that occurred during the preparation of the SLM from the SM was the reduction in the fat content (about 1%) during the washing procedures. The hardness and gel strength value were increased significantly as the cooking temperature was increased by 75℃ for 20 min (p<0.05). The SLMG cooked above 75℃ had a significantly higher WHC than the SLMG cooked below 75℃ (p<0.05). The gelling property of SLMG was effected for different conditions of cooking time and temperatures by the result of SDS-PAGE. After 20 min cooking, some enzyme bands including phosphorylase disappeared. The loss of these bands (about 46 kDa and 60 kDa) was observed after 20 min of cooking time. The photographs of microscopy showed that the filaments of myofibrils did not disappear after a cooking time of 15 min, and that the gaps between the fibers or filament were close. A significant change in the fibers and filaments occurred from 30 min to 35 min of cooking time, and the gradual coagulation of the structure of the SLM was observed with cooking time increased. These results suggest that a desirable surimi gel could be obtained from pork by cooking at 75℃ for 25 min.

Key words: surimi-like material, cooking temperature, cooking time, sarcoplasmic protein, SDS-PAGE, photography of microscope.

Ⅰ. INTRODUCTION

In recent years, there has been considerable interest in the manufacture of surimi-like materials from the muscle of animal species other than fish. The characteristics of surimi-like material from the meat from poultry, beef, pork, sheep and also from meat by-products, such as, beef or pork hearts, have been studied (Liu & Xiong 1996). Also variety study was repored the physicochemical

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and sensory characteristics of fish paste with yam pouder (Kim & Byun 2009). However, the high fat content of red meat, the higher heme pigment level and the high concentration of collagen, pose several problems when red meat is used to produce surimi-like material (Park et al. 1996).

Surimi-like material from the muscle of other animal species is expected to have similar properties to surimi from fish. However, there is little or no information on the preparation of surimi-like material from beef or pork. Using red meat from domestic animals as a starting material presents different problems to those encountered making fish surimi. The main differences between making fish surimi and surimi-like material from the muscle of other animal species are the cooking temperature and time.

The main phenomena in fish products are gel weakening (Modori) and Suwari (Setting). Modori, occurs in many fish surimi during thermal processing (Morrissey et al. 1993). When minces or surimi from these fish are heated slowly at 60−70℃, a reduction in the gel strength is observed. The primary cause for this temperature-dependent gel weakening is believed to be certain enzymes that hydrolyze the myofibrillar proteins, particularly myosin, into small fragments (Wasson 1992). Modori is a phenomenon of deterioration that takes place at temperatures near 60℃, and has been associated with the presence and activity of endogenous serine and cysteine muscle proteases (Ramierz et al. 2002).

Suwari is the name given to the gelling phenomenon of muscle proteins at temperatures ranging from 0 to 40℃. It has been associated with a calcium dependent muscle endogenous transglutaminase. Transglutaminase catalyses the formation of covalent bonds between the adjacent proteins, and improving the gel structure. However, there is a little information about the modori or suwari from surimi-like material derived from the muscle of other animal species.

A phenomenon like Modori is not present in surimi-like material from the muscle of other animal species. This is believed to originate from the difference in enzyme between fish meat and red meat. This enzyme can differ according to temperature and time, and result in the gelling of fish surimi and red meat. Therefore, in this study, an effort was made to develop a method for making surimi-like material from red meat. The aims of this study were to develop a technique for the production of surimi-like material from the *semimembranosus* (SM) muscle of pork and to determine the effects of the various cooking times and cooking temperature on the surimi-like material gel.

Ⅱ. MATERIALS AND METHODS

1. Raw Pork Meats

The SM of fresh pork was obtained from a commercial abattoir. After removing the external fat, epimysial tissue and heavy connective tissue, the lean muscle was diced into approximately 2 ㎤, rap packed and stored in a cold room (2−4℃) in order toed low for maturation for 3 days. Subsequently, the meat was frozen at −60℃ until needed. All the sample preparation procedures were carried out at 2−5℃.

2. Preparation of Surimi-like Material (SLM) from Porcine *semimembranosus* Muscle

The SLM preparation was determined according to the method described by Park et al. (1996). The lean muscle was communited with 9 ㎜ plate in a chopper (K45SS, Kitchen Aid, USA.) and the

chopped muscle was homogenized in a silent cutter with five volumes of iced water for 4 min. The resulting connective tissue was removed by filtering the washed mince through a metal sieve with a 1 mm mesh. After filtering, the washed mince was again filtered in the same manner through a 500 ㎛ metal mesh. The washed mince was centrifuged at 2,220 × g (3,000 rpm) for 10 min at 4℃ in a centrifuge. After centrifugation, the supernatant discarded and the meat residue was homogenized and centrifuged in the same manner. The washing procedure was repeated a third time. In the third washing, the meat residue homogenized with 2.5 volumes of iced water for 4 min. 4% sorbitol (w/w), 3% NaCl (w/w) and 0.5% tripolyphosphate (w/w) were added to the meat residue. The SLM was packed in polystyrene bags and frozen at −60℃ for 30 days prior to testing.

3. Surimi-like Material Gel (SLMG) Preparation

The gel was prepared using a silent cutter for chopping. The well-chilled SLM was placed in the bowl of a food processor that had been previously chilled to −10℃ and the SLM was chopped at a high speed (the latter speed) for 3 min. During chopping, the temperature of the paste was maintained below 10℃. The resulting pasteng pastimmediately stuffed into cellulosstensings (62 ㎜ diameter × 10 ㎝ height) using a hand sausage stuffer. The endng pastbound with thread and the pasteng pastheated at 65, 70, 75, 80, 8ly for 20 min and at 7ly for 15, 20, 25, 30, 35 min in a water bath. After heating, the pasteng pastremoved, 25, the water bath and cooled in tap water of thetheir internal temperature had reduced to < 10℃. The gels were then removed from the cellulose casings, patted dry with paper toweling and wrapped in PVDC wrap for 30 min storage in a cool area, prior to testing. Fifteen experiments were carried out.

4. Proximate Analyses

Two samples (SM and SLM) were analyzed for moisture, protein (Kjeldahl), fat and ash using the standard procedures of AOAC (1990).

5. pH

The pH of the SM and SLM was measured by the direct insertion of an electrode into the sample. The pH of all the treated (time and temperature) samples was determined using standard methods. 3 g of each sample were blended (Poly-tron homogenizer, T25 basic, IKA, Malaysia) at 14.000 rpm for 30 sec with 27 mL of distilled water. An electrode was placed into the resulting slurry, and the meter was allowed to equilibrate for 20 sec. Duplicate samples were read.

6. Color

Three samples (SM, SLM and SLMG) and all treatments (times and temperatures) were evaluated using a chromameter (CR301, Minolta Co, Japan), which had been standardized to a white color standard (L* = 89.2, a* = 0.921, b* = 0.783) at the beginning of each measurement. The SLM samples were measured using the wrap. The cooked SLM gel (SLMG) samples were sliced into 2 ㎝ thick slices and measured. The color of each sample was measured three times.

7. Moisture Content and Water-holding Capacity

The moisture content of the SM, SLM and SLMG were determined using the AOAC method (1990). The water-holding capacity (WHC) was determined from the difference in the SLM moisture and free

water content. The WHC (%) = [(moisture % − free water %) / moisture %] × 100.

8. Textural Properties

The textural evaluation of the SLMG was performed using a rheometer (CR-100D, Sun scientific, Japan). The SLMG was equilibrated at room temperature (ca. 20℃) for 1 hour prior to analysis. Five cylinder-shaped SLM gel samples, 2 ㎝ in length (diameter 0.5 inch), were prepared. The hardness and gel strength were measured using a texture analyzer equipped with a cylindrical plunger (5 ㎜ diameter). The gel hardness, which was measured by the height of the first compression force curve with a 60% deformation (an approx. 8 ㎜ move), is expressed in grams. The rheometer had a 10 ㎏ compression load cell, a table speed of 120 ㎜/min and a full scale range of 1−10 ㎏. The gel strength of all samples was measured at room temperature.

9. Sensory Attribution

An eight-member professional panel was employed to evaluate the sensory characteristics of the SLMG. The panel evaluated each treatment within each replication in triplicate, and the evaluation was performed with the SLMG at room temperature. Triplicate responses were taken to monitor the inherent texture variability associated with this SLM gel. One slice, 1 ㎝ thick and 6.2 ㎝ in diameter, was cut into six pie-shaped wedges and presented to each panelist. The panelists chose 3 of the most characteristic wedges in order to avoid a sample containing large pieces of connective tissue. The brightness, springiness, and hardness were evaluated using ten-point scales (10; extremely bright, spring, and hard: 1; extremely dark, sticky, and soft).

10. SDS-PAGE

The sample for SDS-PAGE obtained from the first supernatant (S1) and the final pellet (P3) from the SLM preparation. The S1 was used for the sarcoplasmic protein while the P3 was used for the myofibrillar protein sample. SDS-PAGE was performed according to the method reported by Laemmli (1970). The protein solutions were mixed at a 1:1 (v/v) ratio with the SDS-PAGE sample treatment buffer (0.125 M Tris-HCl pH 6.8, 4% SDS, 20% glycerol, 10% 2-mercaptoethanol, 1% bromophenol blue) and heated at 100℃ for 1 min in a heating block (Digi-Block®5402, ®Electrothermal, USA). Each sample (1 mg/mL) was loaded on the gel made from 4% stacking and 15% separating gels and subjected to electrophoresis at a constant current of 10−20 mA per gel using a mini-gel electrophoresis unit (Might Small™ SE 245, Hoefer Scientific Instruments, USA). After electrophoresis, the gels were stained with 0.1% Coomassie brilliant blue R-250 in 40% methanol and 7% acetic acid, and destained with 40% methanol and 7% acetic acid. The molecular weight of the protein band apparent was calculated using a standard marker (062K9280, Sigma, USA; M-0630, Sigma, USA). The density of each band on a gel was measured using a gel documentation analysis system (EDAS 290, J Kodak, Japan).

11. Microscopy

For microscopy, the SLMG samples (−0.1 g) that had been homogenized were placed on slides, covered with 1−3 drops of water, then pressed with a cover slip. The slides were examined and photographed under phase contrast illumination using an OLYMPUS (BX51, Olympus, Japan) microscope.

12. Statistical Analysis

Statistical analysis was performed using a SAS/PC (SAS 2001). The data were subjected to an analysis of the variance. A comparison of means was performed using the Duncan's multiple-range test (Steel and Torrie 1980).

Ⅲ. RESULTS AND DISCUSSION

1. Proximate Composition and pH

〈Table 1〉 presents the proximate composition and pH of the SM and SLM. The level of ash and the pH was higher in the SLM than the SM but moisture and fat was lower (p<0.05). The protein content of the SLM was similar to that of the SM. The most noticeable compositional change that occurred during the preparation of the SLM from SM was the reduction of fat (about 1%) during the washing procedures. Kristinsson & Liang (2006) reported that the solubility of muscle proteins at different pH values is importeant for optimizing protein recoveries using the acid- and alkliaided processes. High solubility of muscle proteins is needed to separate them efficiently from impurities at acidic or alkali pH values, while low solubility of proteins is needed for high recovery of proteins after they are precipitated at the isoelectric point (Kristinsson et al. 2005).

The water content of the SLM was 70.69 ± 0.17%. Antonomanolaki et al. (1999) reported that the water content of washed mince was 82.67 ± 1.7%. The water content measured in this study was lower than that reported by Antonomanolaki et al. (1999) because of the dewatering procedure. A force of 2,220 g (3,000 rpm) was adequate to reduce the water content to the 70% range. However, the results are in agreement with those reported by Park et al. (1996) who showed that commercial surimi contained 75% water, 18% protein, < 0.5% fat, and 6.5% other substances.

The percentage protein content of the SLM was similar (p>0.05) to that of the SM. Antonomanolake et al. (1999) reported that the protein content of the washed mince was similar to that of the unwashed mince. The washing procedures using aqueous NaCl or $NaHCO_3$ solutions were shown to be equally effective in removing both the fat and water-soluble proteins (Bonifer & Froning 1996). The washing procedure in this study resulted in the removal of the fat and water-soluble proteins. The majority of the water-soluble components, including the sarcoplasmic proteins and inorganic salts, were removed during leaching, while the concentration of the myofibrillar proteins increased. These results are in agreement with those reported by Toyoda et al. (1992). McCormick et al. (1993) reported that the sarcoplasmic proteins were removed during the washing of mutton. Lin et al. (1995) suggested that the first washing in surimi production removed mainly the sarcoplasmic proteins, which interfere with the functional properties of the contractile proteins (Lanier 1992).

A low level of fat in SLM was expected because

〈Table 1〉 Proximate composition (%) and pH of *semimembranosus* muscle (SM) and surimi-like material (SLM) from porcine *semimembranosus* muscle

Washing treatment	Moisture	Protein	Fat	Ash	pH
SM	73.27±1.58^{A}	19.79±1.93	7.01±1.34^{A}	0.77±0.12^{A}	5.44±0.22^{A}
SLM	70.69±0.17^{B}	20.27±1.22	1.07±0.98^{B}	1.08±0.23^{B}	6.51±0.00^{B}

^{A,B} Values (mean±standard error) within the same column with different superscripts are significantly different (p<0.05).

external fats were trimmed off from the meat prior to mincing. In addition, repeated water washing, centrifugation and the lower density of the fat allowed the fat to float off and be removed. The fat content was reduced to 1.0% (p<0.01) by washing. Hall & Ahmad (1997) reported that during the washing process, fish proteins, mainly myofibrillar, proteins were concentrated with the concomitant removal of fat, blood as well as other flavoring compounds. As a result, the fat content was quite low. Park et al. (1996) reported that a reduction in fat occurred because the adipose cells were broken up or became loose during chopping or blending, and the released lipid was floated off during centrifugation.

The ash content increased after the washing procedure. Antonomanolaki et al. (1999) reported that the washing procedure significantly reduced the ash content. The majority of the water-soluble components, including the sarcoplasmic proteins and inorganic salts, were removed during leaching, while the concentration of the myofibrillar proteins increased, which is in agreement with the results reported by Toyoda et al. (1992). However, the ash in surimi is possibly inorganic matter, mainly from the phosphate salt that is added to the commercially produced surimi to enhance water-binding capacity as well as to prevent protein denaturation during frozen storage. In this experiment, 4% sorbitol (w/w), 3% NaCl (w/w) and 0.5% tripolyphosphate (w/w) were added to the SLM for the same reasons. Therefore, the ash content was higher. These other substances were probably phosphates, salt or sorbitol.

The pH has been reported to affect the gel forming ability of surimi (Lee et al. 1997). In addition, the pH is increased (p<0.05) through washing. Other studies (Yang & Froning 1992) have shown that a washing solution with an elevated pH resulted in better lipid and pigment reduction. The high pH of the washing solution increases the pH of the meat slurry, making the pigments and blood more soluble and easier to remove, while it may also allow for the easier extraction of myoglobin.

2. Changes in Color Measurements

The color measurements of SM, SLM and SLMG were compared (Table 2). The L* values and Hue values increased (p<0.05) from SM<SLM<SLMG, while the other values decreased (p<0.05). In particular, the SLMG had a negative a* value (−1.72±0.03). The SLMG was much lighter (higher L*value) and less red (lower a* value) than the SM or SLM. This was probably related to the increased transparency as well as to the loss of the water-soluble

<Table 2> Color of *semimembranosus* muscle (SM), surimi-like material (SLM) and cooked SLM gel (SLMG[1]) from porcine *semimembranosus* muscle

Washing treatment	CIE values			Chroma	Hue	pH
	L*	a*	b*			
SM	49.31±1.28^{A}	3.25±0.36^{A}	7.86±0.52^{A}	8.87±0.46^{A}	21.38±0.76^{A}	5.44±0.22^{A}
SLM	64.81±0.81^{B}	2.20±0.12^{B}	6.59±0.31^{B}	6.94±0.33^{B}	71.56±0.65^{B}	6.51±0.00^{B}
SLMG	75.87±0.18^{C}	−1.72±0.03^{C}	5.56±0.04^{C}	5.81±0.04^{C}	107.10±0.37^{C}	6.69±0.01^{C}

$^{A-C}$ Values (mean±standard error) within the same column with different superscripts are significantly different (p<0.05).
[1] SLMG was cooked at 75℃ for 35 min.

pigment fractions. Washing increased the lightness and decreased the redness. The reduced redness and lower saturation indicates that washing cycles removed the pigments including myoglobin and any residual hemoglobin. This is in agreement with the results reported by Antonomanolaki et al. (1999), who showed that the L* and b* values of unwashed mince were significantly lower than those of the washed mince. The moisture content was kept constant in the minces in order to avoid a discrepancy in the L* value. This is because moisture has a linear relationship with lightness. Reppond & Babbitt (1997) reported that the L* value increased linearly with the increased moisture content of pollock (*Theragra chalcogramma*). However, these experiments showed that the moisture content was lower ($p<0.05$) in the SLM than in the SM (Table 1). On the other hand, the L* values increased from SM<SLM<SLMG. The increase in the L* values in the SLM indicates the production of a lighter product. Hernandez et al. (1986) reported that a higher pH of the washing medium for mechanically deboned turkey meat resulted in lighter and less red product. The high pH of tap water and the washing procedures they used caused a dramatic reduction in the a* values from 17.65±1.81 in the unwashed mince to 0.17±0.07 in the washed mince. This was apparently due to the removal of the muscle blood and other pigments. Yang & Froning (1992) also observed a marked increase in lightness and decrease in redness in the mechanically deboned poultry meat washed with 0.1 M NaCl. In these experiments, the meat residue was homogenized with 2.5 volumes of iced water for 4 min in the third washing. 4% sorbitol (w/w), 3% NaCl (w/w) and 0.5% tripolyphosphate (w/w) was added to the meat residue. The increase in the pH of the meat residue (SLM) resulted in an increase in lightness.

〈Table 3 and 4〉 show the CIE color values, chroma and Hue data from the SLMG (various cooking times and temperatures). The lightness, yellowness, chroma and Hue values were increased significantly ($p<0.05$) with increasing cooking temperature, while redness values were decreased significantly ($p<0.05$) (Table 3). In addition lightness, yellowness, chroma and Hue values were increased significantly ($p<0.05$) with increasing cooking time, while redness values were significantly decreased ($p<0.05$) (Table 4). In particular, the SLMG had a negative redness values above 75℃ and after 20 min of cooking. These results show that the color of the SLMG is dependent on the cooking time and temperature.

〈Table 3〉 Effect of cooking temperature on color of surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM)

Cooking temperature	CIE values			Chroma	Hue
	L*	a*	b*		
65℃	63.51±0.13^{A}	1.62±0.03^{A}	6.63±0.05^{B}	6.82±0.05^{B}	76.35±0.24^{A}
70℃	64.21±0.16^{B}	0.94±0.03^{B}	6.29±0.05^{A}	6.35±0.05^{A}	81.56±0.26^{B}
75℃	68.59±0.28^{C}	−0.21±0.06^{C}	7.60±0.09^{C}	7.61±0.09^{C}	91.62±0.45^{C}
80℃	74.30±0.12^{D}	−0.84±0.02^{D}	8.47±0.05^{D}	8.51±0.05^{D}	95.59±0.11^{D}
85℃	75.01±0.10^{E}	−0.91±0.03^{D}	8.92±0.05^{E}	8.97±0.05^{E}	95.74±0.21^{D}

$^{A-E}$ Values (mean±standard error) within the same column with different superscripts are significantly different ($p<0.05$).
[1] SLMG was cooked for 20 min.

〈Table 4〉 Effect of cooking time on color of surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM)

Cooking time	CIE values			Chroma	Hue
	L*	a*	b*		
15 min	63.79±0.66^{A}	0.15±0.09^{A}	2.73±0.14^{A}	2.75±0.14^{A}	91.01±2.23^{A}
20 min	72.32±0.50^{B}	−1.61±0.03^{B}	4.65±0.14^{B}	4.92±0.14^{B}	109.11±0.43^{B}
25 min	74.14±0.31^{C}	−1.76±0.03^{CD}	5.17±0.07^{C}	5.46±0.06^{C}	108.70±0.42^{B}
30 min	74.68±0.24^{C}	−1.80±0.03^{D}	5.23±0.04^{C}	5.52±0.04^{C}	108.92±0.37^{B}
35 min	75.87±0.18^{D}	−1.72±0.03^{C}	5.56±0.04^{D}	5.81±0.04^{D}	107.10±0.37^{B}

$^{A-D}$ Values (mean±standard error) within the same column with different superscripts are significantly different (p<0.05).
[1] SLMG was cooked at 75℃.

3. Changes in Gel Forming Characteristic

The gel forming properties are the most important attribute because surimi is formed and cooked to make products. The gel forming characteristics of fish surimi have been studied extensively (Lanier 1992), and have been compared with various comminuted meats (Montejano et al. 1984). The gel forming ability depends on many factors including pH, ionic strength, protein solubility as well as the amount and type of extractable proteins (Lanier 1992). Many instrumental methods have been used to examine the textural qualities of heat-set meat and meat-like products. Lanier (1992) described two textural properties of surimi gels, strength and cohesiveness. These may be measured as the forcrcrstress) and the deformation rstraintresquired to cause mechanical failure in the gel. However, Lee et al. (1997) reported that compression testing is widely used to characterize the gelation properties of proteins. The application of compression without failure (fracturing) provides information on the strength of the elastic elements or the firmness of the protein gels while the failure compression test measures the degree and strength of the protein cross-linkages and thus, the cohesiveness of the gel.

In this study, the gel forming abilities of the SLMG were measured by determining the gel hardness and gel strength after various heating times and temperature. The samples were heated at 65, 70, 75, 80, 85℃ for 20 min and at 75℃ for 15, 20, 25, 30, 35 min in a water bath. After heating, the SLM pastes were removed from the water bath and cooled in tap water until their internal temperature had dropped to < 10℃.

〈Fig. 1 and 2〉 show the effects of the cooking time and temperature on the gel forming characteristics (hardness and gel strength) of the SLMG. After 20 min cooking time at 75℃, the gel forming characteristic values of the SLMG were unchanged (Fig. 1). This indicates that the proteins in the SLM had completed gel formation at 75℃ within 20 min. Moreover, the hardness and gel strength value increased significantly with further 5℃ increases in cooking temperature for 20 min (p<0.05). After setting, in fish surimi, the elevated temperature during heating results in the further oxidation of the sulfhydryl groups with the accompanied dissulfide bond formation. The α-helix unfolds as a result of the instability of the hydrogen bonds, exposing greater numbers of hydrophobic amino acids, resulting a larger amount of hydrophobic interactions (Niwa 1992). A similar study showbic intethe hardness of the surimi-like beef

and pork increased rapidilarpon heating to endpoint temperatures > 45℃ (Park et al. 1996). In addition, Benjakul & Visessanguan (2003) reported that the breaking force and deformation of suwari and kamaboko gels increased with increasing setting temperature and time. Mckeith et al. (1988) reported that the gel strength of beef and pork surimi was lower at temperatures up to 50℃ and was much higher at 80℃. All these reports along with the present study show that different heating procedures strongly influence the gel strength. This unreliability in determining the water changes in gel hardness was attributed to changes in temperature or to changes in the protein concentration from water loss. It is possible that the heating rate, endpoint temperature, protein level and source are important factors in developing the texture of a SLMG.

4. Changes in Sensory Attributes

The increasing cooking temperature of the SLMG affected all the sensory attributes (Table 5). The springiness and the hardness of the sensory attributes scores of the SLMG increased with increasing of cooking temperature above 75℃ (p<0.05). The panelists indicated that the SLMG cooked above 75℃ was preferable based on the 'hardness and springiness'. However, the panelists found the SLMG to have a sticky and high coefficient of viscosity after 15 min cooking time (data not shown). This indicates that the SLM proteins could not completed the gel formation at 75℃ within 15 min.

The results of the sensory evaluation are well matched with those of the mechanical measurements. This means that the sensory attribute value (springiness and hardness) might be related to the gel forming characteristics (hardness and gel strength) obtained by mechanical test analysis. The gel forming characteristic of the SLM increased with increasing cooking time and cooking temperature (Fig. 1 and 2).

In addition, increasing the cooking temperature of the SLMG significantly affected all the sensory

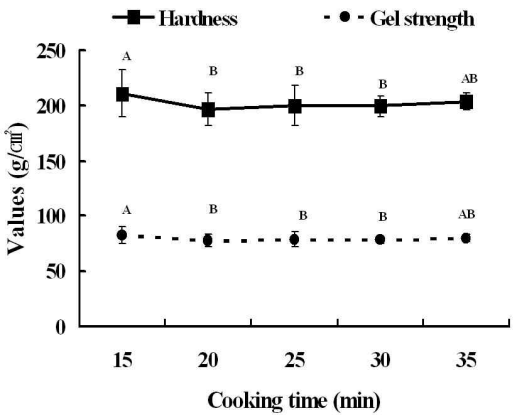
<Table 5> Effect of cooking temperature on the sensory characteristics of surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM)

Cooking temperature	Sensory attributes[2]		
	Brightness	Springiness	Hardness
65℃	3.50±0.53^{A}	3.11±0.56^{A}	3.59±0.50^{A}
70℃	4.76±0.50^{B}	4.28±0.53^{A}	5.33±0.54^{B}
75℃	6.21±0.40^{B}	6.16±0.46^{B}	6.86±0.35^{C}
80℃	7.59±0.23^{C}	6.94±0.43^{B}	7.63±0.42^{C}
85℃	8.76±0.15^{D}	8.39±0.26^{C}	8.90±0.21^{D}

$^{A-D}$ Values (mean±standard error) within the same column with different superscripts are significantly different (p<0.05).

[1] SLMG was cooked for 20 min.

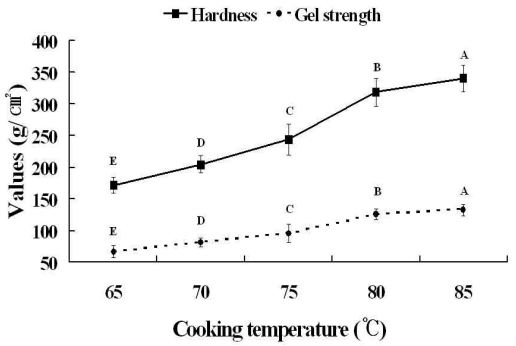
[2] Brightness, springiness, and hardness were evaluated by means of ten-point scales (10: extremely bright, spring and hard, respectively; 1: extremely dark, sticky and soft, respectively).



<Fig. 1> Changes in gel forming strength (hardness and gel strength) of cooked surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM) as increasing of cooking time.

^{A,B} Different letters within a row indicate significant differences between mean values (p<0.05).

[1] SLMG was cooked at 75℃.



〈Fig. 2〉 Changes in gel forming strength (hardness and gel strength) of cooked surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM) as increasing of cooking temperature.

[A-E] Different letters within a row indicate significant differences between mean values ($p<0.05$).

[1] SLMG was cooked for 20 min.

attributes (Table 5). However, there was no significant increase in springiness and hardness between the SLMG cooked at 75℃ and 80℃. The sensory results confirmed the results of the gel forming characteristics (hardness and gel strength). The panelists evaluated the SLMG cooked at 85℃ to be extremely springy and hard gel.

The sensory brightness scores of SLMG increased linearly with increasing cooking temperature significantly ($p<0.05$). The increase in the brightness scores might be related to the pH or water-holding capacity (WHC) of SLMG. Hernandez et al. (1986) reported that a higher pH of the washing medium for mechanically deboned turkey meat resulted in a lighter and less red end-product. The pH of SLM was increased ($p<0.05$) by water-washing (Table 1). As shown in 〈Table 6〉, the cooking temperature affected the pH of the SLMG. In addition, the WHC of the SLMG increased with increasing temperature. The SLMG cooked above 75℃ showed a significantly higher WHC compared with the SLMG cooked below 75℃ ($p<0.05$). Therefore it is possible that the increasing brightness might be due to the increasing WHC as well as the pH of the SLMG.

The WHC of the SLMG was increased significantly at 75℃ ($p<0.05$) (Table 6). However, increasing the cooking time did not affect the moisture content of the SLMG (Table 7). In addition, the pH of the SLMG was increased significantly from 6.62±0.12 to 6.57±0.11 with increasing cooking temperature ($p<0.05$) (Table 6). This suggests that an increased pH as a result of the increasing cooking temperature, along with the high concentration of myofibrillar proteins, enhanced the level of water retention in meat. Furthermore, these results suggest that the increased WHC due to the

〈Table 6〉 Effect of cooking temperature on pH and water-holding capacity (WHC) of surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM)

Cooking temperature	pH	WHC (%)
65℃	6.62±0.12^{A}	74.08±0.07^{A}
70℃	6.63±0.08^{A}	73.95±0.04^{A}
75℃	6.64±0.13^{A}	74.34±0.02^{B}
80℃	6.55±0.08^{B}	74.28±0.10^{B}
85℃	6.57±0.11^{B}	74.32±0.04^{B}

[A,B] Values (mean±standard error) within the same column with different superscripts are significantly different ($p<0.05$).

[1] SLMG was cooked for 20 min.

〈Table 7〉 Effect of cooking time on pH and moisture percent of surimi-like material gel (SLMG[1]) from porcine *semimembranosus* muscle (SM)

Cooking time	pH	Moisture (%)
15 min	6.66±0.04^{A}	79.15±0.39
20 min	6.69±0.02^{B}	79.03±0.54
25 min	6.69±0.07^{B}	79.15±0.55
30 min	6.68±0.04^{B}	79.31±0.50
35 min	6.69±0.06^{B}	79.25±0.22

[A,B] Values (mean±standard error) within the same column with different superscripts are significantly different ($p<0.05$).

[1] SLMG was cooked at 75℃.

increasing pH affected the hardness and springiness of SLMG.

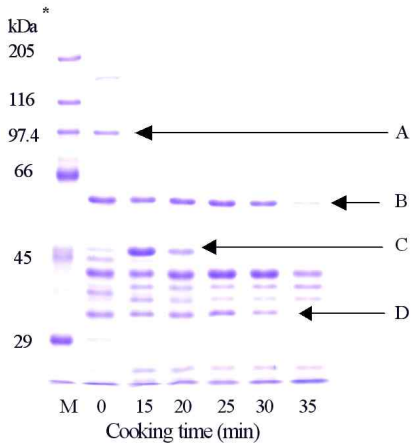
〈Table 7〉 shows the effect of the cooking time on the pH of a SLM gel. The pH of the SLM gel was significantly low at 15 min (p<0.05), and no difference in pH was detected from 20 min to 35 min (p<0.05).

5. Changes in Protein Fractions

The texture of meat is one of the most important quality attributes that has been studied for many years (Bertolar et al. 1994). The main factors considered to affect the meat texture are the myofibrillar proteins, muscle cytoskeleton and intramuscular connective tissue (Silva et al. 2002), in addition to the intrafibre water (Offer et al 1989). The use of SDS-polyacrylamide gel electrophoresis has shown that the proteins of the thick and thin filaments, and the Z disk react differently to cooking in the range of 40−80℃; α-actinin is the most labile and becomes insoluble at 50℃, myosin becomes insoluble at 55℃, actin becomes insoluble between 70 and 80℃, tropomyosin and troponin becomes insoluble at over 80℃ (Cheng & Parrish, Jr 1979), and the sarcoplasmic proteins becomes insoluble at approximately 65℃ (Laakkonen 1973). The denaturation of titin occurs at 73℃ (Fritz et al. 1992) while nebulin survives cooking at 80℃ (Locker 1984).

Meat collagen begins to denature at approximately 65℃ (Laakkonen 1973). Heat-affected changes in various meat components are related to the meat texture. According to Jafarpour and Gorczyca (2009), during the cooking of meat there is first an increase in toughness between 40℃ and 50℃ due to the beginning of denaturation of the myofibrillar proteins, a further increase between 60 and 70℃ because of the shrinkage of intramuscular collagen at 65℃, and a third increase in the range 70−90℃ where the shrinkage and dehydration of the actomyosin occurs. It is generally agreed that heat-induced changes in the connective tissue have a tenderizing effect while the hardening of the myofibrillar proteins during cooking has a toughening effect (Laakkonen 1973). Total cooking losses depend on the temperature as well as the heating rate (Hearne et al. 1978).

〈Fig. 3〉 shows the SDS-PAGE patterns from different SLM gels at various cooking times at the same temperature. Based on several experimental factors (color, instrumental value, WHC and sensory evaluation), the cooking time and temperature had the largest effect on the gelling property of SLMG. This may be associated with the removal of the sarcoplasmic proteins (Fig. 3). In particular, the loss of enzyme increased with increasing cooking time. A band (phosphorylase) was observed after 15 min cooking. However, the band had disappeared after 20 min cooking. In addition, the b



〈Fig. 3〉 Changes in sarcoplasmic protein of surimi-like material gel (SLMG) from porcine *semimembranosus* muscle (SM) by cooking times at 75℃.

* 205 kDa : myosin, 116 kDa : β-galactosidase, 97.4 kDa : phosphorylase, 66 kDa : albumin bovine, 45 kDa : albumin egg, 29 kDa : bovine erythrocytes.

and d band (about 60 kDa) were observed at 30 min cooking time but a small amount of the enzyme was removed after 35 min cooking time. The loss of the c band (about 46 kDa) gradually increased after 20 min cooking time, and the c band was completely lost within 25 min.

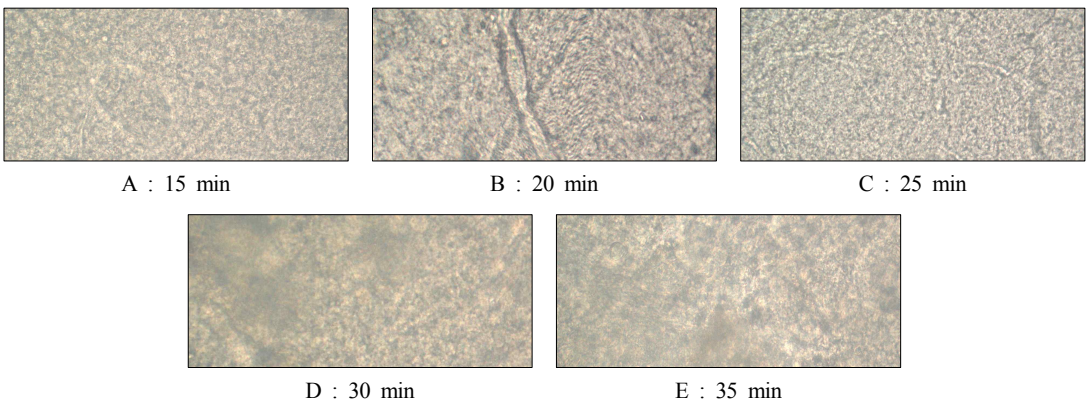
Jafarpour & Gorczyca (2008) reported that these points could be related to aggregation of the myosin tail (36.7℃), the myosin head (56.8℃), and the other protein fractions (83.3℃). There is a significant difference between the sol-gel transition temperatures (Ganesh et al. 2006).

Most of the sarcoplasmic proteins were readily soluble in water and were removed by washing. However, the residual sarcoplasmic proteins, insoluble pigments, structures such as mitochondria, which contain cytochromes, could not be removed from the intact muscle fragments by washing in water. These residual sarcoplasmic proteins adversely affected the forming gel, which as coincident with the increase in the forming strength, color, sensory attributes. This indicates that increasing cooking time and cooking temperature increase the removal or loss of the sarcoplasmic protein, and increase the forming strength (hardness and gel strength), color, sensory attributes (brightness, springiness, hardness).

6. Changes in Microstructure

Microstructure priovides a good picture as to what has happened to the matrix system in relation to the network integrity and the extent of syneresis (Park et al. 2008). Park et al. (2008) reported that, the formation of large water pores in the unheated sol indicates a lack of network formation in which the water had not been immobilized, while relatively small water pores were seen as the gelation progressed (Park et al. 2008).

Physiological changes in the muscle tissue during heating, which were established in previous research (Jones et al. 1977), are as follows: a slight effect up to 50℃, compressing of the myofibrillar proteins at 50℃, coagulation of the thin and thick filaments, further myofibrillar shrinkage, and granulation of sarcolemma at 60℃ myofibrillar fragmentation at the Z disk, completed shrinkage of endomysium at 70℃, more disintegration of thin filaments, gelation of collagen fibers in the peri-



<Fig. 4> Changes in microstructure of surimi-like material gel (SLMG) from porcine *semimembranosus* muscle (SM) by cooking times at 75℃ (photography of microscope × 500, bar length = 1 ㎜).

A filament of myofibrils was found in picture of cooking time 15 min (A), and the gaps between fibers or filament were close.

mysium at 80℃, and the structure becomes amorphous but the principal bounding features of the sarcomeres can be identified at 90℃.

The photographs showed the micro-structural changes of SLM at various cooking times (Fig. 4). A filament of myofibrils was observed at 15 min cooking time (Fig. 4A), and gaps between the fibers or filament were close. With increasing cooking time, the structure of SLM became almost compact from 20 min to 25 min (Fig. 4B and C). A significant change in the fibers and filaments was observed from 30 min to 35 min of cooking time, and a gradual coagulation of the SLM structure was observed with further increases in cooking time (Fig. 4D and E). The same observations were also reported by Yang & Froning (1992) who examined washed chicken meat gels by scanning electron microscopy. Moreover, the diffused small clear spaces within the fibrous network had a greater water holding capacity. This also explains the low expressible fluid values of the gel in the washed mince.

Ⅳ. CONCLUSIONS

The effects of cooking time and temperature on the gel properties of surimi-like material were investigated in order to develop a technique for producing surimi-like material (SLM) from the *semimembranosus*muscle of porks. The color measurements, gel forming characteristics and sensory evaluation of the cooked SLM were affected by the cooking time and temperature. The lightness, yellowness, chroma and Hue values increased significantly with increasing cooking temperature and time, while the redness values decreased significantly. The proteins in the SLM completed gel formation within 20 min at 75℃. The hardness and gel strength value increased significantly with increasing temperature and cooking time. In addition, all the sensory attributes were affected by the cooking temperature and time. These changes were related to the increased pH and water-holding capacity (WHC), which resulted in a high moisture % in the cooked SLM gel. The pH and WHC of the gel increased with increasing cooking temperature and time. A loss of sarcoplasmic enzymes with increasing cooking time was observed. Moreover, the changes in the microstructure of the SLM as a result of the cooking conditions were observed by SEM. The results suggest that a desirable surimi gel can be obtained from pork under the optimal cooking conditions of 75℃ for 25 min.

한글초록

본 연구는 돼지 반막양근(*semimembranosus* muscle, SM)으로부터 획득된 수리미 유사물의 최적의 가열조건을 모색하고자 겔 특성에 미치는 다양한 가열온도와 가열시간의 효과를 조사하였다. 가장 현저한 변화는 수세과정에서 SM으로부터 SLM 처리하는 과정중 지방함량(약 1%)의 감소가 발생하였다. 겔의 강도와 인장강도는 가열온도 75℃에서 20분간 가열했을 때 현저히 증가하였다(p<0.05). SLMG의 겔 특성은 SDS-PAGE의 결과로 살펴보면 가열시간과 온도에 의해 영향을 받은 것으로 나타났다. 가열 20분 후 phosphorylase를 포함한 몇몇의 효소들이 밴드가 사라지기 시작했는데, 46 kDa과 60kDa의 밴드의 소멸은 20분 가열시간 후 관찰되었다. 현미경 사진을 통해 관찰한 결과 가열 15분까지는 섬유 또는 필라멘트들 사이 공간이 밀접하게 나타났으며, 근섬유의 필라멘트들이 사라지지 않고 존재하는 것으로 나타났다. 가열시간 30분에서 35분 사이에 근섬유와 필라멘트 사이 현저한 변화가 발생하였으며, 가열시간이 증가할수록 SLM의 구조적으로 서

로 엉겨 붙는 것이 관찰되었다. 이러한 결과는 가열온도 75℃와 가열시간 25분에서 가장 우수한 젤을 형성하는 것으로 나타났다.

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