Effect of Setting Temperatures and Time on the Gelation Properties (Suwari and Modori Phenomena) of Surimi from Mechanically Deboned Chicken Meat*

Sung Ki Lee** **and Byung Jin Min**[1]

Department of Food Science and Technology in Animal Resources, Kangwon National University, Chunchon 200-701, Korea

ABSTRACT : This study was carried out to investigate gel forming and degradation properties (suwari and modori phenomena) of chicken surimi from mechanically deboned chicken meat (MDCM) at various setting temperatures and time. Chicken surimi was manufactured by a continuous process including chopping of MDCM, washing with 5% NaCl solution or pure water, standing, straining and centrifuging etc. Total process of washing for the MDCM from chopping to centrifuging was repeated over 3 cycles. Gel from prepared surimi were formed at 90°C for 30 min after various setting treatments. The textural properties of gels were measured at the temperature ranges of low (10°C), medium (25°C and 30°C) and high (45 to 70°C). The compressive force (CF), hardness and fracturability of surimi gel at 10°C increased as setting time increased, and showed the highest value at 30 h of setting time. The CF and hardness of chicken surimi gel at 25°C and 30°C showed the highest values at 10 h of setting time. Most of gel strengths including CF, and texture profile analysis (TPA) values showed the highest levels in the range 47.5 to 52.5°C ($p<0.05$). The gel strength at 60°C increased slightly at 30 min, but then continued to decrease with longer setting times. There was no increase of gel strength at 70°C, but only a continuous decrease over setting time. In conclusion, suwari (gel setting) and modori (gel degradation) phenomena occur during the gel formation of surimi from MDCM. The temperature range in chicken surimi was 47.5 to 52.5°C for suwari and 60 to 70°C for modori. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 12 : 1758-1763)***

Key Words : Surimi, Mechanically Deboned Chicken Meat (MDCM), Suwari, Modori, Setting Temperature, Setting Time

INTRODUCTION

Suwari (setting) is the Japanese term for the gelation effect of heat-induced transition of myofibrillar proteins which unfold and interact with one another to form a network, resulting in improved elasticity and firmness (Mackie, 1992). It is known that this "suwari" process in surimi (a Japanese commercial name for minced meat) forms more elastic gels in fish paste which has been cooked after a setting stage of fixed time duration than in fish paste processed without such a setting stage (Lanier and Lee, 1992). Opposing this setting process, "modori" (gel degradation) phenomenon weakens the gel formed with heating. Although extensively studied by many researchers, the mechanism of the suwari and modori phenomena have not yet been explained precisely. Suwari is attributed to improvement of protein hydrolyzation by addition of salt ion, protein denaturation or change of structure and formation of network structure between protein molecules (Niwa, 1992). Furthermore, this setting effect occurs in a range of uncooked temperatures and even at temperatures less than room temperature (Lee, 1984).

Generally, a single myosin well forms gelation in myofibrillar, even though thermal gelation properties are influenced by myosin and actin rate (Lan et al., 1995). Cooked muscle products arise in heat-induced gelation and became continuous, crosslinked, three dimensional structures (Foegeding, 1987; Foegeding et al., 1991).

In fish meat, many cases of heat induced heat gelation properties including suwari and modori phenomena have already been reported (Lanier and Lee, 1992). However few such reports have investigated chicken surimi from mechanically deboned chicken meat (MDCM). Gelation properties are very important factors to improve the quality of processed meat product by using chicken surimi. Therefore, the present study was conducted to understand gelation properties of chicken surimi. Especially, the optimal temperature and setting time to improve the texture of chicken surimi gel were investigated.

MATERIALS AND METHODS

Preparation of chicken surimi

Mechanically deboned chicken meat (MDCM) from broilers at 1 day postmortem, produced using a deboner (Beehive deboner, RSTP06 LE Separator, USA), was obtained from a local manufacturer. The MDCM was kept in a deep freezer (-80°C) and used for experiments within 1

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** Corresponding Author: S. K. Lee. Tel: +82-33-250-8646, Fax: +82-33-244-2198, E-mail: skilee@kangwon.ac.kr

[1] Department of Food Science and Human Nutrition, Clemson University, South Carolina, 29634, USA.

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Table 1. Textural properties of chicken surimi gel[1] set at 10°C

Textural properties	Setting time (h)					
	0	5	10	15	20	30
Compressive						
Force (g·cm)	670.4^{d}	697.6^{d}	$1,135^{c}$	$1,224.6^{b}$	$1,253.7^{ab}$	$1,278.5^{a}$
Hardness (g)	135.9^{c}	148.7^{bc}	153.1^{b}	162.9^{ab}	160.7^{ab}	171.4^{a}
Fracturability (g)	130.9^{c}	134.3^{c}	138.4^{c}	156.0^{b}	158.3^{ab}	169.4^{a}
Adhesiveness (g·s)	-248.7^{b}	-292.7^{b}	-297.7^{b}	-300.3^{ab}	-304.3^{ab}	-307.7^{ab}

[a, b, c, d] Means within row with different superscripts are significantly different ($p<0.05$).

[1] For gel preparation, the mixed surimi containing 2% NaCl was cooked at 90°C for 30 min.

month. All chemicals used in this experiment were of special reagent grade.

The frozen MDCM at -80°C was thawed in air at 4°C for 18 h and chopped with 4 times its weight of washing solution using a silent cutter (Seiki Co Ltd, OSK 10600 Type A, Japan) for 2 min 30 sec. and then blended using a Kitchen Aid (Kitchen Aid Inc, USA) for 10 min. Total process of washing for the MDCM from chopping to centrifuging was repeated over 3 cycles. In the washing process, the first and the second washing solutions used 0.5% NaCl, but the third washing was with distilled water. The blended slurry was allowed to stand for 10 min. The blended slurry was then strained by different cycles using three size meshes in the order of 2 mm, 1 mm and 0.6 mm. The slurry was centrifuged (Beckman J2-21, Germany) at 1,028×g for 15 min and the supernatant was discarded. Finally, the residual precipitate (washed MDCM) after the third washing procedure was used as experimental materials. Moisture, crude fat, crude protein and crude ash of the washed MDCM processed by different cycles were determined by standard AOAC method (1990). The final moisture content of washed MDCM (chicken surimi) was adjusted to 90% with distilled water. All surimi processing was performed at 4°C.

Gel formation of chicken surimi at various temperatures

The ground chicken surimi was mixed with 2% NaCl using a Kitchen Aid (Kitchen Aid Inc., USA) at speed 6 for 5 min, stuffed into glass tubes (a cylindrical form with 15 mm diameter and 100 mm length) and centrifuged at 707×g for 10 min to remove air bubbles in the tube. The following three different temperature ranges and standing times were applied: i) low temperature set at 10°C, for 5, 10, 15, 20 or 30 h, ii) medium temperature set at 25°C or 30°C, for 1, 2, 3, 4 or 5 h, and iii) high temperature set at 45, 47.5, 50, 52.5, 55, 60 or 70°C, for 1, 2, 3, 4 or 5 h. All prepared samples were cooked at 90°C for 30 min in the water batch after standing for various ranges of temperature and time. The cooked chicken surimi gels were directly cooled in ice water for 10 min and refrigerated at 4°C for 12 h. Finally, the gels were removed from glass tubes and prepared for the tests on textural properties.

Compression and texture profile analysis (TPA) of gels

Compressive force (CF) and texture profile analysis (TPA) of chicken surimi gel were measured by a Texture analyzer (TA-XT2i, Stable Micro Systems Ltd, UK) with a 5 kg load cell. A 35 mm diameter cylinder probe (SMS P/35) was used for samples (20 mm height, 15 mm diameter). The CF was expressed as the force (g) which was multiplied at the first breaking point of gel by moved distance at breaking time (Min and Lee, 2004). Test conditions were as follows: mode, measure force in compress; option, return to start; pretest speed, 5 mm/s; test speed, 0.5 mm/s; post test speed, 5 mm/s; distance, 80%; trigger type, auto; trigger force, 5 g.

Texture profile analysis (TPA) test for heat-induced gel strength also used a Texture analyzer (TA-XT2i, Stable Micro Systems Ltd, UK). The globular gel (20 mm height, 15 mm diameter) was measured using a cylindrical, stainless-steel, spherical probe (diameter 5 mm) attached to a 5 kg load cell on the Texture analyzer. All parameters were calculated by texture analyzer software (version 1.12) from MHK Trading Co. (UK). Test conditions were as follows: mode, TPA; pretest speed, 5 mm/s; test speed, 2 mm/s; posttest speed, 5 mm/s; distance, 15 mm; trigger type, auto; trigger force, 5 g.

Scanning electron microscopy (SEM)

To observe cut sections of the gels, the samples were treated by the methods of Alvarez et al. (1999). Cooked gels were cut into square sections (5×5×1 mm) and rinsed with 0.07 M phosphate buffer (pH 6.8). The samples were fixed in 2% glutaraldehyde for 1 hr. After rinsing with the buffer, the samples were post-fixed with 2% osmium tetroxide (OsO_4) for 50 min and rinsed with 60% ethanol. The rinsed samples were then dehydrated in a graded series of ethanol (60, 70, 80, 90, 95, 99, 99.9 and 100%) for 10 min each and finally replaced with tert-butyl alcohol. The prepared samples were dried in a freezing dryer, mounted on specimen holders, sputter-coated with gold and examined on a SEM 3500 (Hitachi, Japan) operating at up to 15 kV. Replications were performed at five hundred times magnifications (×500).

Statistical analysis

All experiments were conducted on 6 replicate samples.

Table 2. Textural properties of chicken surimi gel[1] set at 25 and 30°C

Temp. (°C)	Setting time (h)						
	0	1	2	3	4	5	10
				Compressive force (g·cm)			
25	690.4[c]	866.2[c]	1,039.3[bc]	1,068.1[bc]	1,356.1[b]	1,361.2[b]	1,732.3[a]
30	690.4[d]	988.0[cd]	1,158.3[bc]	1,223.0[bc]	1,345.5[b]	1,354.4[b]	2,036.6[a]
				Hardness (g)			
25	140.9[b]	135.6[b]	141.6[b]	145.1[b]	146.2[b]	151.8[b]	176.6[a]
30	140.9[b]	137.5[b]	141.3[b]	144.2[b]	149.4[b]	150.8[b]	198.7[a]
				Fracturability (g)			
25	137.2[b]	133.5[b]	135.4[b]	141.6[ab]	145.0[ab]	146.2[ab]	166.2[a]
30	137.2[b]	136.0[b]	138.3[b]	144.2[b]	145.0[b]	149.4[b]	193.3[a]
				Adhesiveness (g·s)			
25	-248.0[a]	-248.9[a]	-259.6[a]	-264.0[a]	-270.0[a]	-281.8[a]	-285.0[a]
30	-248.0[b]	-238.9[b]	-266.5[ab]	-267.3[ab]	-272.1[ab]	-314.7[ab]	-343.2[a]

[a, b, c, d] Means within row with different superscripts are significantly different ($p<0.05$).

[1] For gel preparation, the mixed surimi containing 2% NaCl was cooked at 90°C for 30 min.

The statistical analysis system (SAS Institute, Inc., 1993) was used to determine means, standard deviations, and analyses of variance. Data were analyzed by ANOVA and Duncan's Multiple Range Test (mean comparison) using the General Linear Model procedure of the SAS program.

RESULTS AND DISCUSSION

Textural properties of gels set at low temperature (10°C)

The compressive force (CF) of chicken surimi gel which was set at 10°C increased as setting time increased (Table 1). Until 10 h, CF showed a remarkable increase and after then, little change. The CF of surimi for 30 h was significantly higher than that of control (non-set surimi) ($p<0.05$). The hardness and fracturability of gels increased slightly over the range of setting times. However, there was a significant difference compared to control. The adhesiveness of gels increased from 0 to 10 h of setting time and then tended to maintain steady levels until 30 h. The setting condition for maximum adhesiveness was at 10°C for 30 h. In case of Herring surimi which was set at 10°C for 0 to 24 h, then heated at 90°C for 30 min, the rigidity, shear stress and shear strain at failure increased with holding time at 10°C (Chan et al., 1995).

Our results suggest that heat-induced gel strength for surimi preparation can be increased with time by setting at 10°C and that the suwari phenomenon occurs at 10°C with increasing of setting times.

Textural properties of gels set at medium temperature range (25°C and 30°C)

Table 2 shows the CF and TPA of chicken surimi gels which were formed in gel set at 25°C and 30°C for 1, 2, 3, 4, 5 and 10 h, respectively, and then cooked at 90°C for 30 min. As setting time increased, the CF of gels set at both 25°C and 30°C increased, and the highest CF occurred at 10 hrs of setting time. This result is similar to that of Kim et al. (1993), who noted that an Alaska Pollock surimi showed an optimum setting effect at 25°C during setting time between 25°C and 50°C, and that the shear stress of the surimi gel increased proportionally with longer preincubation at 25°C.

Hardness at 25°C and 30°C also tended to increase as setting time increased. However, there was no significant difference until 5 h. At 10 h of setting time, hardness showed the highest value at both 25°C and 30°C. The change of fracturability of gel was similar to the result for hardness. There was a significant difference of fracturability at 10 h of setting time ($p<0.05$). Adhesiveness set at 25°C and 30°C tended to increase at setting time of 10 h, with no difference between the results at the two temperatures. Maximum adhesiveness was attained in surimi gels set at 30°C for 10 h. According to Park et al. (1994), the strong gels were formed at 25°C setting for 3 h followed by heating at 90°C for 15 min in Pacific whiting surimi.

Cooking temperature is another factor affecting gel strength in surimi. Chicken surimi from mechanically separated chicken meat was equilibrated at 20°C for 10 min in a water bath and heated from 40 to 80°C. The surimi gel strength increased with increasing temperature from 40°C to 80°C at 1.75°C/min (Smyth and O'Neill, 1997).

Textural properties of gels set at high temperature (45-70°C)

The change of compressive force (CF) : CF of surimi gels in the range 45-70°C for 5 h is shown in Figure 1. At 45°C, CF continuously increased until 3 hrs, after which it reduced slightly. At 47.5°C, CF started to increase suddenly until 1 h, maintained a higher level until 4 h, after which it decreased sharply. The CF at 50°C showed the highest level at 1 h of setting time and then tended to decrease. At the setting temperatures of 52.5°C and 55°C, CF was highest at 1 h ($p<0.05$). At 60°C, CF tended to increase slightly and

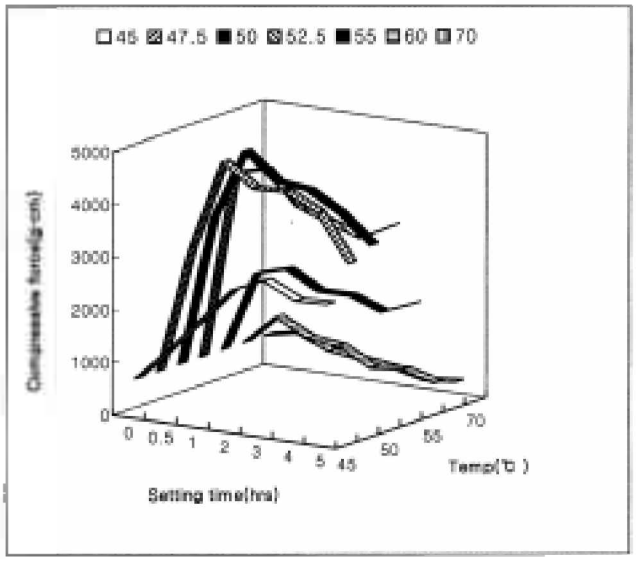

Figure 1. The effect of setting time and temperature on compressive force (g·cm) of chicken surimi gel. For gel preparation, the mixed surimi containing 2% NaCl was set from 45°C to 70°C and then cooked at 90°C for 30 min.

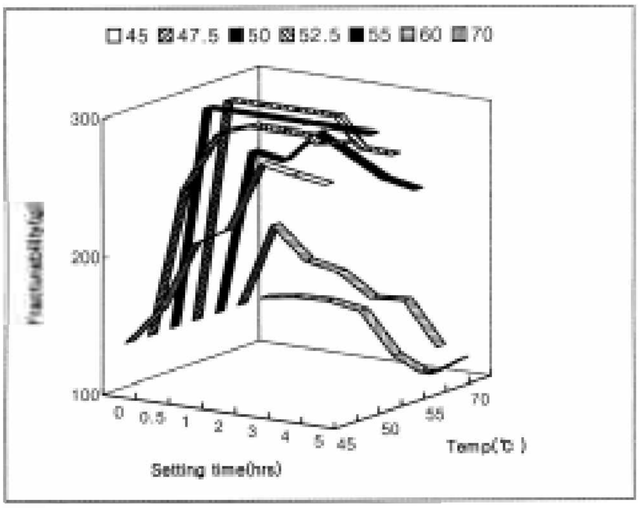

Figure 2. The effect of setting time and temperature on hardness (g) of chicken surimi gel. For gel preparation, the mixed surimi containing 2% NaCl was set from 45°C to 70°C and then cooked at 90°C for 30 min.

attained a maximum value within 30 min of setting time.

The conditions of setting temperature and time for maximum CF were at 45°C for 2-5 h, 47.5-50°C for 1-3 h, 52.5°C for 0.5-2 h, 55°C for 0.5-3 h and 60-70°C for 0.5 h. In the range 45-70°C, the maximum CF of surimi gel was attained in relatively short time periods as the setting temperature increased (Figure 1). The level of maximum CF set at 60-70°C was comparatively lower than that set at 47.5-52.5°C. Therefore, gel intensity set at 60-70°C was decreased sharply after 30 min of setting time, and appeared gel broken phenomenon.

The change of hardness : Figure 2 presents the hardness

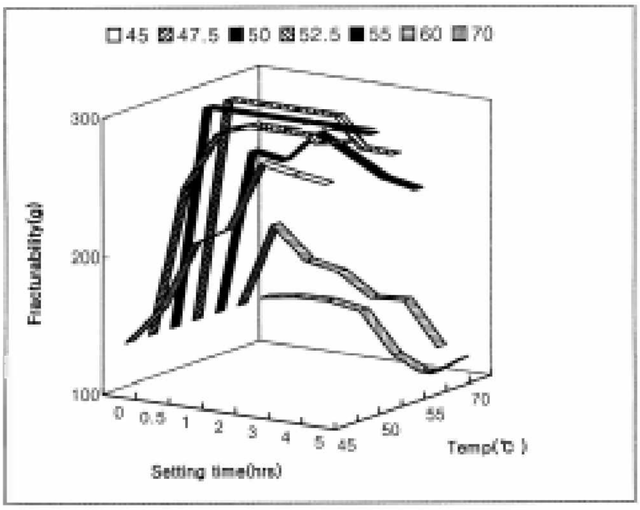

Figure 3. The effect of setting time and temperature on fracturability (g) of chicken surimi gel. For gel preparation, the mixed surimi containing 2% NaCl was set from 45°C to 70°C and then cooked at 90°C for 30 min.

(g) of surimi gel at different setting temperatures and times. The hardness of surimi gel set at 45-55°C tended to increase for 5 h of setting time. The maximum hardness occurred at 45°C for 1-5 h, 47.5°C for 2-5 h, and 50-55°C for 0.5-5 h. It can be recommended that the optimum setting temperature and time for the greatest hardness was 45-55°C for 2-4 h. In the range of the above temperature, salt soluble protein seems to be formed across network structure. O'Neill et al. (1993) also reported that transitions occurring within muscle systems between 50°C and 60°C were most critical in gel network formation.

In the high temperature range of 60 and 70°C, the maximum hardness was attained at 30 min, and then decreased at greater setting times. At 70°C, the greatest hardness set at 30 min was low compared with those of other temperatures and the level of hardness at all setting times was lower than that of other temperatures.

The change of fracturability : The fracturability of gels by setting time and temperature is presented in Figure 3. As setting time increased, the fracturability of gels set in the range of 45-55°C tended to increase. The conditions of temperature and time for maximum fracturability were set at 45-47.5°C for 1-5 h, 50-55°C for 0.5-5 h, and 60°C for 0.5-2 h. At 70°C, the fracturability of gels set at between 0 and 2 h of setting time didn't show significant difference, but then decreased continuously until a setting time of 5 h. From the fracturability results, it is apparent that gel degradation occurred in chicken surimi prepared for setting at 70°C.

Alvarez et al. (1999) reported that sardine surimi gels set, or set and cooked (50°C, or 60°C and 90°C) for different times were studied in order to evaluate modori (thermal gel degradation). When heat-set (50°C or 60°C)

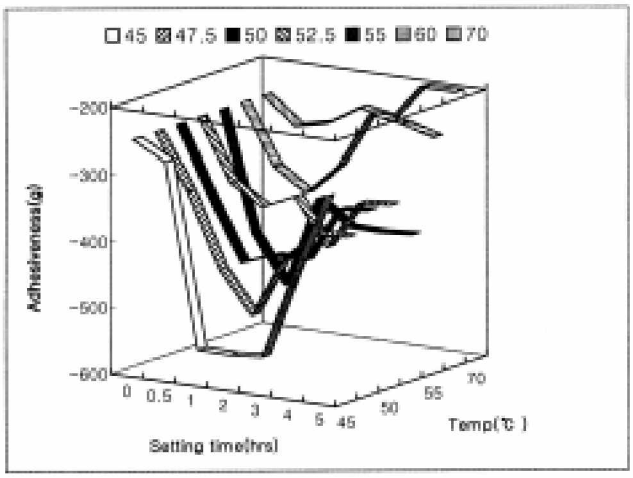

Figure 4. The effect of setting time and temperature on adhesiveness (g·s) of chicken surimi gel. For gel preparation, the mixed surimi containing 2% NaCl was set from 45°C to 70°C and then cooked at 90°C for 30 min.

gels for 30 min or 60 min were cooked at 90°C for 30 min or 60 min, they scored 1 in the FT (folding test) irrespective of setting time and temperature or cooking time, which indicates that modori had occurred. Reports of the optimum temperature range for maximum or minimum gel strengths in some fish surimi are different from our results. Gelation properties of paddlefish surimi were investigated with different heating procedures. Pre-incubation at 40°C caused myosin degradation and reduced gel strength by 55% compared to the control. Pre-incubation at 70°C followed by cooking at 90°C produced gels with maximum strength (Lou et al., 2000). However, for many fish species, extended incubation at certain temperature (generally below 40°C) can enhance the gelation of surimi ("suwari"), whereas for other species, extended incubation around 60°C may weaken the surimi gel ("modori") (Shimizu, 1990). It has been suggested that the "Suwari" phenomenon may be explained by the enhanced formation of gel-networks from fish myosin at relatively low temperatures (Montejano et al., 1984).

The change of adhesiveness : The adhesiveness of gels by setting time and temperature is shown in Figure 4. In the TPA system, adhesiveness is defined as the negative force area of the first bite representing the work necessary to pull the compressing plunger away from the gel sample. The texture must be sticky and viscous if the surimi gel has higher adhesiveness. The conditions of setting temperature and time for optimal adhesiveness were 45-50°C for 1-3 h, 52.5°C for 0.5-5 h, 55°C for 0.5-1 h, and 60°C for 0.5-2 h.

Required setting time for maximum adhesiveness was reduced as setting temperature increased in the range 45-60°C, although the intensity of adhesiveness was comparatively lower with increasing temperature. At 70°C, adhesiveness did not change at settings from 0 to 3 h, after which it decreased until 5 h ($p<0.05$). From these gel adhesiveness results, the modori phenomenon occurred in chicken surimi during the setting processing.

In conclusion, those results of gel strengths by compressive force and TPA test showed that suwari occurs at a setting temperature of 47.5-52.5°C, and that modori occurs at 60-70°C. It can be suggested that the optimal setting conditions for surimi gel preparation from MDCM was setting at 47.5°C-52.5°C for 1-3 h followed by cooking at 90°C for 30 min. It is also important that the temperature range between 60°C and 70°C during cooking is passed as quickly as possible to improve the textural properties of chicken surimi gel.

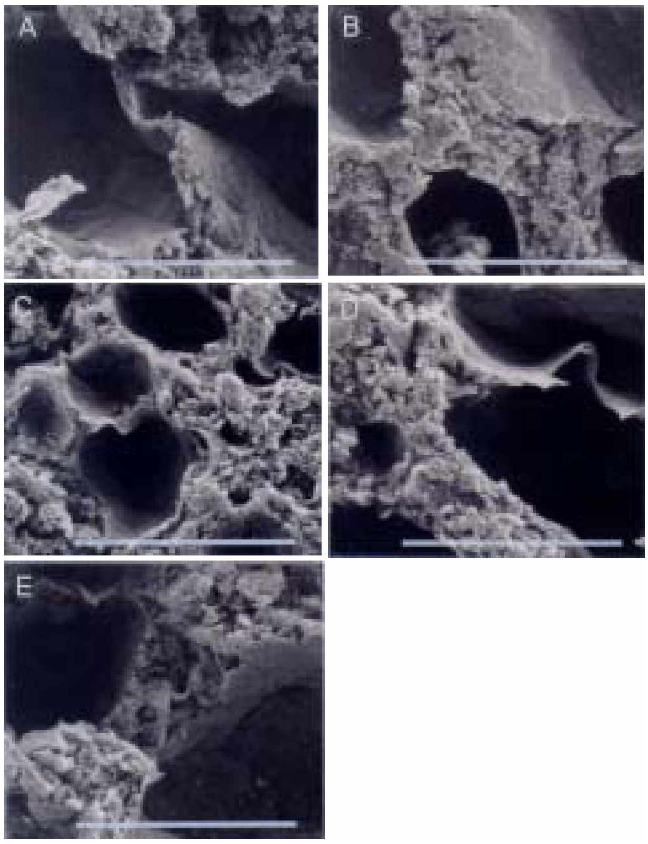

Figure 5. Scanning electron micrographs of chicken surimi gel set at different temperatures. A: Control (non-setting treatment), B: 40°C for 1 h, C: 50°C for 1 h, D: 60°C for 1 h, E: 70°C for 1 h. After these treatments, all samples were cooked at 90°C for 30 min. Bar=200 μm.

The observation of the gel section by SEM

SEM (×500) was used to observe the cutting sections of the gels made at different setting temperatures (Figure 5). The cutting section of the control cooked directly at 90°C for 30 min without setting indicated a large cavity, which was formed from insufficient gelation. The cutting section of gels set at 40°C for 1 h showed a slightly smaller cavity than that of control. However, the cutting section of gels set at 50°C for 1 h was well formed by gelation. Compared to other treatments, the cavities of 50°C setting were smaller sizes, greater number of cavities and more homogeneous phase. At 60°C and 70°C setting, the shape of the large cavities in the cutting sections were similar to those of control. Therefore, these SEM results confirmed the presence of suwari and modori phenomenon of chicken surimi according to different setting times and temperatures.

Therefore, the formations of heat induced gelation of chicken surimi from MDCM were changed according to temperature and setting time like those of fish surimi. The suwari and modori phenomena exist in chicken surimi from MDCM, and do occur during the gel formation. The optimum temperature range in chicken surimi was 47.5°C-52.5°C for suwari and 60°C-70°C for modori.

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