

The development of imitation crab sticks by substituting spent laying hen meat for Alaska pollack

S. K. Jin,* I. C. Hur,* J. Y. Jeong,* Y. J. Choi,† B. D. Choi,† B. G. Kim,‡ and S. J. Hur§¹

**Department of Animal Resources Technology, Jinju National University, Gyeongnam, Jinju, Chilam-dong 150, Republic of Korea; †Division of Marine Bioscience, Gyeongsang National University, Gyeongnam, Tongyeong, Inpyeong-dong 445, Republic of Korea; ‡Hansung Foods Co. Ltd., Chungnam, Dangin-kun, Hapduk-eup 106-25, Republic of Korea; and §Department of Applied Biochemistry, Konkuk University, Chungbuk, Chungju, Danwol-dong 322, Republic of Korea*

ABSTRACT Imitation crab stick (ICS) samples were divided into 5 treatments, a control composed of commercial ICS containing no breast meat from spent laying hens, and treatments 1, 2, 3, and 4, in which 5, 10, 15, and 20% batter from breast meat of whole spent laying hens was substituted for Alaska pollack surimi, respectively. Imitation crab stick samples containing spent laying hen breast meat batter showed significantly ($P < 0.05$) higher moisture levels than the control sample. However, the myoglobin and metmyoglobin levels did not differ significantly ($P > 0.05$) among ICS samples. During storage, whiteness was greater in the control sample than in the ICS samples containing spent laying hen breast meat batter. The saturated and monounsaturated fatty acids increased, whereas the polyunsaturated fatty acids decreased in response to substituting surimi with spent laying hen breast meat

batter. The moisture content and pH were increased as the amount of spent laying hen breast meat batter increased. The lipid oxidation value (TBA-reactive substances) and protein degradation value (volatile basic nitrogen) tended to increase during storage as the amount of spent laying hen breast meat batter increased. None of the sensory evaluation items differed among ICS samples during storage, although the color of the final products, mechanical color (by colorimeter), and textural properties did differ among samples. These results indicate that substituting laying hen breast meat batter for Alaska pollack surimi is a very useful method for the production of ICS because it enables the use of a simple production process that does not require steps, such as washing or pH adjustment, for myofibrillar protein recovery.

Key words: imitation crab stick, spent laying hen, Alaska pollack surimi, textural property

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INTRODUCTION

Surimi is a term that describes highly processed seafood products made by the removal of soluble proteins, lipids, pigments, and odorous compounds from the flesh of fish, which, with the addition of cryoprotectants, can be stored in the frozen state (Hall, 2010). Surimi-based foods, such as imitation crab, are mass-produced, low-cost sources of fish protein designed to imitate high-cost luxury products, including crab, lobster, shrimp, and scallops (Mansfield, 2003). The growth of the surimi-based food industry has been based on Alaska pollack surimi; however, the number of Alaska pollack caught has been decreasing. Subsequently, the production of foods based on Alaska pollack surimi has declined and

is being supplemented by surimi production using species other than Alaska pollack. To date, several studies have been conducted to evaluate the development of surimi-based foods made from beef, pork, mutton, and chicken (Kenney et al., 1992; Yang and Froning, 1992; Park et al., 1996; Srinivasan and Xiong, 1996; Antonomanolaki et al., 1999; Nowsad et al., 2000). The application of surimi technology in the production of surimi-based foods from other species could provide a new approach toward increasing its value and utilization. For example, spent laying hens may be a good source of surimi-based foods because their meat is very cheap or free, and the use of spent laying hens would improve the utilization of this waste resource. Our studies have been related to the development of surimi-based products from chicken. In previous studies, we used myofibrillar protein gel collected from spent laying hen breast meat to make surimi-based foods such as imitation crab sticks (ICS). However, in the present study of ICS, batter made from whole spent laying hen

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¹Corresponding author: hursj@hotmail.com

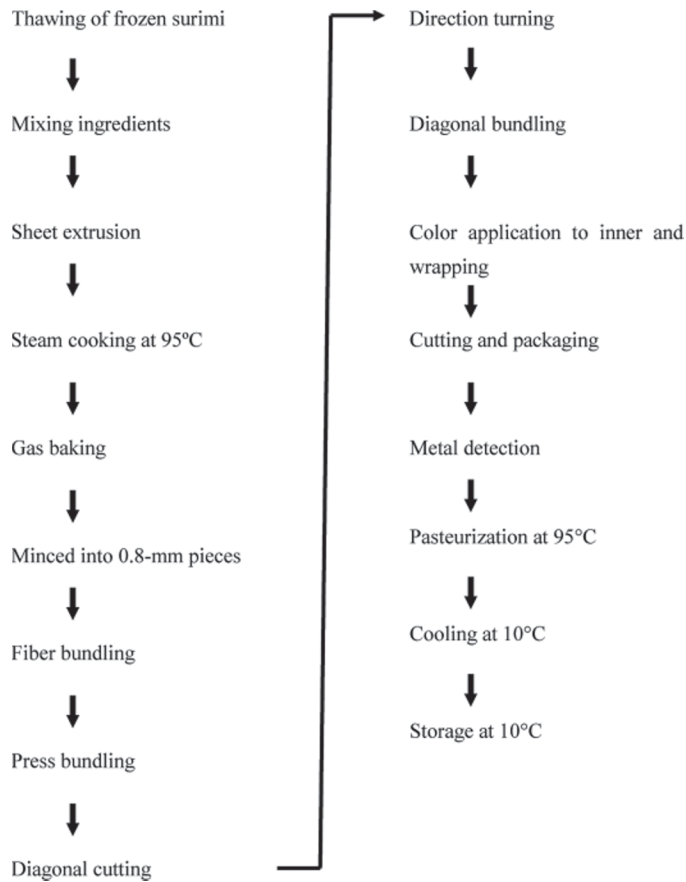


Figure 1. Crab stick manufacturing process.

breast meat was substituted for Alaska pollack surimi. Thus, the purpose of this study was to develop ICS in which spent laying hen breast meat batter was substituted for Alaska pollack surimi and to investigate the effects of substituting Alaska pollack surimi with spent laying hen breast meat on the quality characteristics of ICS during storage.

MATERIALS AND METHODS

Sample Preparation

Alaska pollack was obtained from the Hansung Food Co. Ltd. (Hapduk, Republic of Korea), and spent laying hen breasts were obtained at the same time from a commercial slaughterhouse. Three batches were collected on different days for experimental replication. Imitation crab stick samples were divided into 5 treatments, a control, composed of commercial ICS containing no spent laying hen breast meat, and treatments 1, 2, 3, and 4, in which 5, 10, 15, and 20% whole spent laying hen breast meat batter was substituted for Alaska pollack surimi. Whole spent laying hen breast meat batter was collected by the cutting method. Briefly, spent laying hen breast lean meat was minced into pieces of about 0.8 mm in diameter by using a silent cutter (YNF101-A, Youngnam Machinery Co. Ltd., Busan, Republic of Korea) for 8 min. The batter from whole spent laying hen breast meat was then used for the production of ICS. The formulation of the ICS is presented in Table 1, and a flow diagram of the ICS preparation method is shown in Figure 1. The ICS samples were vacuum packaged and then stored at 0°C for 4 wk.

Measurement of Myofibrillar Protein

The procedure used to determine the myofibrillar proteins was similar to that described by Kuo and Chu (2003). Briefly, myofibrillar proteins were isolated from samples by homogenizing 4 g of minced samples in a Polytron homogenizer (T25-B, IKA Labortechnik, Staufen, Germany) for 10 s in 40 mL of a 2°C isolating medium [containing 100 mM KCl, 20 mM potassium phosphate (pH 7.0), 1 mM EDTA, and 1 mM sodium azide). The homogenate was then sedimented at 1,000

Table 1. Formula for the imitation crab sticks

Ingredient (%)	Control	Treatment			
		1	2	3	4
Alaska pollack surimi	52.78	47.50	42.22	36.95	31.67
Spent laying hen breast meat	—	5.28 (5) ¹	10.56 (10)	15.83 (15)	21.11 (20)
Potato starch	2.64	2.64	2.64	2.64	2.64
Wheat starch	2.64	2.64	2.64	2.64	2.64
Sugar	1.40	1.40	1.40	1.40	1.40
Salt	1.29	1.29	1.29	1.29	1.29
Crab extract	1.17	1.17	1.17	1.17	1.17
Carrageenan	0.59	0.59	0.59	0.59	0.59
Kelp extract	0.40	0.40	0.40	0.40	0.40
Albumen	0.41	0.41	0.41	0.41	0.41
Calcium carbonate	0.66	0.66	0.66	0.66	0.66
Crab flavor	0.29	0.29	0.29	0.29	0.29
Soybean oil	0.33	0.33	0.33	0.33	0.33
Mixture seasoning	0.29	0.29	0.29	0.29	0.29
Phosphate	0.20	0.20	0.20	0.20	0.20
Red colorant	0.03	0.03	0.03	0.03	0.03
Flavorings	1.88	1.88	1.88	1.88	1.88
Distilled water	33.00	33.00	33.00	33.00	33.00
Total	100	100	100	100	100

¹Values in parentheses indicate the 5, 10, 15, and 20% spent laying hen breast meat batter used in treatments 1, 2, 3, and 4, respectively.

$\times g$ for 15 min at $20 \pm 1^\circ\text{C}$, after which the supernatant was decanted. The sediment was then resuspended at $1,000 \times g$ for 15 min at $20 \pm 1^\circ\text{C}$, and the supernatant was decanted. The sediment was again resuspended in 5 vol (vol/wt) of the original isolating medium and passed through a polyethylene strainer (0.1-mm pore size) to remove the connective tissue and debris. Five more volumes, resulting in 10 vol (vol/wt) total of the original isolating medium, were used to further facilitate passage of myofibrillar protein through the strainer. The supernatant was again sedimented at $1,000 \times g$ for 15 min at $20 \pm 1^\circ\text{C}$, after which it was decanted. The sediments were washed 3 more times by suspension in 5 vol (vol/wt) of the original isolating medium, after which they were sedimented at $1,000 \times g$ for 15 min at $20 \pm 1^\circ\text{C}$. Finally, the sedimented myofibrillar proteins were resuspended in 5 vol (vol/wt) of the original isolating medium. The protein concentration was then determined by the biuret procedure described by Clark and Switzer (1977). Briefly, a 0.5-g sample was mixed with 0.5 mL of biuret reagent (541-2, Sigma-Aldrich, St. Louis, MO). After 10 min, the absorbance of the assay mixture was measured at 550 nm using a spectrophotometer calibrated to zero with a reagent blank.

Measurement of Myoglobin and Metmyoglobin

The myoglobin content was determined by direct spectrophotometric measurement as described by Chaijan et al. (2004). Two grams of chopped sample was weighed into a 50-mL polypropylene centrifuge tube, after which 20 mL of 40 mM phosphate buffer (pH 6.8) was added. The mixture was then homogenized at 13,500 rpm for 10 s, followed by centrifugation at $3,000 \times g$ for 30 min at 4°C . Next, the supernatant was filtered through Whatman number 1 filter paper, and 0.2 mL of 1% (wt/vol) sodium dithionite was added to the filtrate to reduce the myoglobin. The myoglobin content was then determined by direct spectrophotometric measurement at 555 nm. The myoglobin content was calculated from the millimolar extinction coefficient of 7.6 and a molecular weight of 16,111 (Gomez-Basauri and Regenstein, 1992) and was expressed as milligrams per gram of ICS sample. The analysis of metmyoglobin content was performed as described by Lee et al. (1999). Five grams of minced sample was placed into a 50-mL polypropylene centrifuge tube, and 25 mL of ice-cold phosphate buffer (pH 6.8, 40 mM) was added. The mixture was homogenized (T25-B, IKA Labortechnik) for 10 s at 13,500 rpm. The homogenized sample was allowed to stand for 1 h at 4°C and centrifuged at 5,000 rpm for 30 min at 4°C . The supernatant was filtered through Whatman number 1 filter paper, and the absorbance (A) was read at 700, 572, and 525 nm by spectrophotometer (Lambda 850, PerkinElmer, Waltham, MA). Percentage of metmyoglobin was calculated using the following equation (Krzywicki, 1982): metmyoglo-

$$\text{bin (\%)} = \{1.395 - [(A_{572} - A_{700}) / (A_{525} - A_{700})]\} \times 100.$$

Measurement of Color

Color [Commission Internationale de l'Éclairage L^* (lightness), a^* (redness), b^* (yellowness)] was measured using a colorimeter (CR-400, Minolta, Tokyo, Japan), with measurements standardized with respect to the white calibration plate. Five readings were made from the surface of samples and whiteness (W) was determined using the following formula: $W = L^* - 3b^*$ (Jin et al., 2006).

Measurement of Textural Properties

Textural properties were determined using a modified version of the method described by Kealy (2006). Samples were equilibrated and evaluated at room temperature. Five pieces 3.5 cm wide and 3 cm thick were tempered at 20°C before measuring. The brittleness, hardness, cohesiveness, springiness, gumminess, chewiness, and adhesiveness were measured using a texture analyzer (EZ-test, Shimadzu, Tokyo, Japan) equipped with a cylindrical plunger (5-mm diameter) and 500-N load cell. The crosshead speed was 66 mm/min.

Measurement of Fatty Acid Composition

Lipids were extracted with chloroform and methanol as described by Folch et al. (1957). The extracted lipids were then concentrated using an evaporator (Turbovap 500, Zymark, Hopkinton, MA). The fatty acid composition was determined using a modified version of the method described by Hur et al. (2004). A 0.1-g quantity of lipid extract was methylated with 1 mL of 3 N HCl in methanol (33050-U, Supelco, Bellefonte, PA) at room temperature for 40 min at 60°C and subsequently cooled at room temperature. Next, water (1 mL) and hexane (5 mL) were added, and the samples were vortexed and centrifuged at $500 \times g$ for 10 min at 4°C . The upper organic solvent layer was used to determine the fatty acid composition. Fatty acid methyl esters were analyzed on a gas chromatograph equipped with an on-column injector port and flame-ionization detector. A capillary column, DB-5 and Carbowax (30 m $\times$ 0.32 mm $\times$ 0.25 μm ; Shimadzu, Tokyo, Japan) was used for the separation of the fatty acid methyl esters. The oven temperature of the gas chromatograph (HP 6890, Agilent, Santa Clara, CA) was 140°C , and this was increased at a rate of $2^\circ\text{C}/\text{min}$ to a final temperature of 230°C . The temperatures of the injector and detector ports were set at 240 and 250°C , respectively. The fatty acid methyl esters (1 μL) were injected into the split injection port (100:1 split ratio). The flow rate for the helium carrier gas was 1 mL/min (30 cm/s). Each fatty acid was detected based on comparison with the

retention time of an analytical standard (1891-1AMP, Sigma-Aldrich).

Measurement of Moisture, Fat, and pH

Moisture was determined according to the method described by AOAC (1990). The moisture content was determined by the oven-drying method at 110°C for 24 h. Moisture was calculated as $[100 - (\text{total protein} + \text{total lipid} + \text{total ash})]$. Fat content was determined by the Soxhlet method. The pH was measured using a digital pH meter (Model 420A, Orion, Beverly, MA). Approximately 5 g of sample was cut into small pieces, after which 45 mL of distilled water was added and a slurry was made using a blender. The pH of the slurry was then recorded.

Measurement of Lipid Oxidation Value

The TBA-reactive substances (TBARS) value as a lipid oxidation value was determined using a modified version of the method described by Buege and Aust (1978). Briefly, 5 g of sample was weighed into a 50-mL test tube and homogenized with 15 mL of deionized, distilled water using a Polytron homogenizer (T25-B, IKA Labortechnik) for 10 s at its highest speed. Next, 1 mL of sample homogenate was transferred to a disposable test tube (13 × 100 mm), after which butylated hydroxyanisole (50 µL, 10%) and TBA-trichloroacetic acid (2 mL) were added. The mixture was then vortexed and incubated in a boiling water bath for 15 min to develop the color. The sample was cooled in cold water for 10 min, vortexed again, and centrifuged at $2,000 \times g$ for 15 min at 4°C. The absorbance of the resulting supernatant solution was determined at 531 nm against a blank containing 1 mL of deionized, distilled water and 2 mL of TBA-trichloroacetic acid solution. The amounts of TBARS were expressed as milligrams of malondialdehyde per 100 g of sample.

Measurement of Protein Degradation

The volatile basic nitrogen (VBN) was measured as a protein degradation value using a modified version of the method described by Pearson (1976). Briefly, 1 g of sample and a few drops of phenolphthalein indicator were placed in a distillation flask, after which 3.5 mL of 20% sodium hydroxide solution were added. The apparatus was then immediately sealed and the end of the steam distillate was collected in a flask containing 20 mL of 4% boric acid and a few drops of Tashiro indicator (methyl red:methylene blue, 2:1). The steam distillation procedure was continued until 250 mL of distillate had been collected. Next, the basic solution obtained was titrated against 0.01 M hydrochloric acid to the end point, which was indicated by a green to gray color change. The VBN content was determined after blank correction that had been determined by the steam distillation of 6% perchloric acid.

Measurement of Sensory Evaluation

Sensory evaluation was performed by a panel of 15 semitrained tasters. The panel consisted of 15 adults (8 males and 7 females) aged 20 to 35 yr. Training the taste panel involved discussing the terminology to be used and agreeing on the interpretation of each term. The individual techniques for determining each characteristic were also discussed in full. A randomized complete block design was used for the sensory evaluation. Before the assessment, a 2-h preliminary panel orientation was carried out so that each panelist could become familiar with all the procedures applied in this session. Panel development was conducted according to the pre-screening, screening, training, and performance evaluation phases proposed by Cross et al. (1987). The panelists evaluated each treatment within each replication in quintuplicate, and the evaluation was performed with the samples at room temperature. Triplicate responses were taken to monitor the inherent texture variability associated with this sample. One slice 0.5 cm thick and 5 cm in diameter was cut into 6 pie-shaped wedges and presented to each panelist. The panelists chose 3 of the most characteristic wedges to avoid a sample containing large pieces of connective tissue. The color, aroma, flavor, tenderness, juiciness, and overall acceptability were then evaluated using a 9-point scale (color: 9 = very good, 1 = very bad; aroma: 9 = very intense, 1 = very weak; flavor: 9 = very good, 1 = very bad; tenderness: 9 = very tender, 1 = very tough; juiciness: 9 = very juicy, 1 = very dry; overall acceptability: 9 = very good, 1 = very bad).

Statistical Analysis

Statistical analyses were conducted for 3 batches of ICS. Data for each batch of ICS collected to describe the myofibrillar protein, myoglobin, metmyoglobin, color, textural properties, fatty acid composition, moisture, pH, TBARS, VBN, and sensory evaluation were analyzed using SAS software (SAS Institute Inc., Cary, NC) by the generalized linear model procedure. The Student-Newman-Keuls multiple-range test was used to compare differences among means. Significant differences ($P < 0.05$) between mean values of 15 samples were determined for the myofibrillar protein, myoglobin, metmyoglobin, color, textural properties, fatty acid composition, moisture, pH, TBARS, and VBN ($n = 15$). Significant differences ($P < 0.05$) between sensory evaluations were determined ($n = 45$).

RESULTS AND DISCUSSION

Myofibrillar Protein, Myoglobin, and Metmyoglobin

Myofibrillar protein, myoglobin, and metmyoglobin are presented in Table 2. The ICS samples containing spent laying hen breast meat batter (treatments 1, 2,

3, and 4) had a significantly ($P < 0.05$) higher moisture content than the control. However, myoglobin and metmyoglobin did not differ significantly ($P > 0.05$) among ICS samples. The functional and textural properties of the ICS depended on many factors, including thermal conditions, the amounts and types of extractable protein, protein solubility, fat, moisture, pH, ionic strength, and salt and phosphate contents. In general, high protein, high myofibrillar protein, high collagen, low crude fat, and adequate water are required to make high-quality surimi-based products (Jin et al., 2007). In this study, the myofibrillar protein contents were significantly ($P < 0.05$) higher in ICS samples containing spent laying hen breast meat batter. Thus, increasing the myofibrillar protein content by substituting surimi with spent laying hen breast meat batter may have improved the physicochemical stability of ICS. In the present study, myoglobin and metmyoglobin did not influence the color of ICS. This may have been because chicken breast contains smaller amounts of myoglobin and metmyoglobin.

Color

Results of the color evaluation are presented in Table 3. After 4 wk of storage, lightness (L^*) was greater in ICS samples containing spent laying hen breast meat batter (treatments 2, 3, and 4); however, whiteness was higher in the control than in the ICS samples containing spent laying hen breast meat batter. Whiteness is one of the most important factors associated with the quality of surimi, and myoglobin plays an essential role in its whiteness (Chen, 2002). Ochiai et al. (2001) suggested that high-quality surimi with greater whiteness can be obtained when as much dark muscle as possible is removed, and that a low myoglobin content is better than a high myoglobin content for surimi quality. Thus, a washing process is necessary for color improvement and gel strengthening of surimi produced from whole muscle (Chaijan et al., 2004). Evaluation of the final products (Figure 2) revealed that treatment 4 was darker than the other ICS samples. This result may have occurred because the treatment 4 sample contained greater amounts of whole chicken breast meat batter than the other ICS samples. Thus, a greater amount of whole chicken breast meat batter in ICS may be the cause of color deterioration, although the color scores of sensory evaluation did not differ significantly ($P > 0.05$) among samples during the storage periods.

Textural Properties

The textural properties are presented in Table 4. Brittleness and hardness were greater in treatment 2 than in the other ICS samples during storage; however, the cohesiveness, springiness, gumminess, chewiness, and adhesiveness did not differ significantly ($P > 0.05$) among ICS samples after 2 wk of storage. High pH, high protein content, and low water content are usually closely related to textural properties. Xing (1992) reported that pH dependence on gel strength was related to altered protein-protein interactions, and Lanier (1986) reported that the gel-forming ability depended on many factors, including pH, ionic strength, protein solubility, and the types and amounts of extractable proteins. However, textural properties were not influenced by pH, protein content, or water content in the present study because these factors did not differ among groups. It is not clear why the brittleness and hardness of treatment 2 were greater than those of the other ICS samples, but we assume that the compositions of Alaska pollack surimi and spent laying hen breast meat batter in treatment 2 were appropriate to improve the textural strength. This may indicate that this mixture produced the best hardness of myofibrillar protein in Alaska pollack surimi and chicken breast meat batter, thereby increasing the binding capacity of the proteins.

Fatty Acid Composition

The fatty acid composition is presented in Table 5. The saturated and monounsaturated fatty acids increased and the polyunsaturated fatty acid decreased in response to substitution with spent laying hen breast meat batter. In the present study, the decrease in the levels of polyunsaturated fatty acids observed in ICS samples containing spent laying hen breast meat batter may have been because the amount of fish muscle was lower in that group than in the control sample. Polyunsaturated fatty acids usually have double-bond molecules and are therefore prone to oxidation, and lipid oxidation is closely related to the changes in color that occur in meat products (Warriss, 2010). However, in the present study, the lipid oxidation value (TBARS) increased with a decrease in polyunsaturated fatty acids in response to substitution with spent laying hen breast meat batter. These findings may have occurred because the crude fat content was lower in the control sample than in the ICS samples containing spent laying

Table 2. Myofibrillar protein, myoglobin, and metmyoglobin contents of imitation crab sticks at 0 d

Treatment	Myofibrillar protein (mg/g)	Myoglobin (mg/g)	Metmyoglobin (%)
Control	7.07 ± 0.18 ^B	0.39 ± 0.00	0.47 ± 0.01
1	7.95 ± 0.28 ^A	0.39 ± 0.00	0.47 ± 0.01
2	7.84 ± 0.38 ^A	0.39 ± 0.00	0.47 ± 0.00
3	7.93 ± 0.36 ^A	0.39 ± 0.01	0.46 ± 0.01
4	8.07 ± 0.54 ^A	0.39 ± 0.00	0.46 ± 0.01

^{A,B}Means in the same column with different superscripts differ significantly ($P < 0.05$).

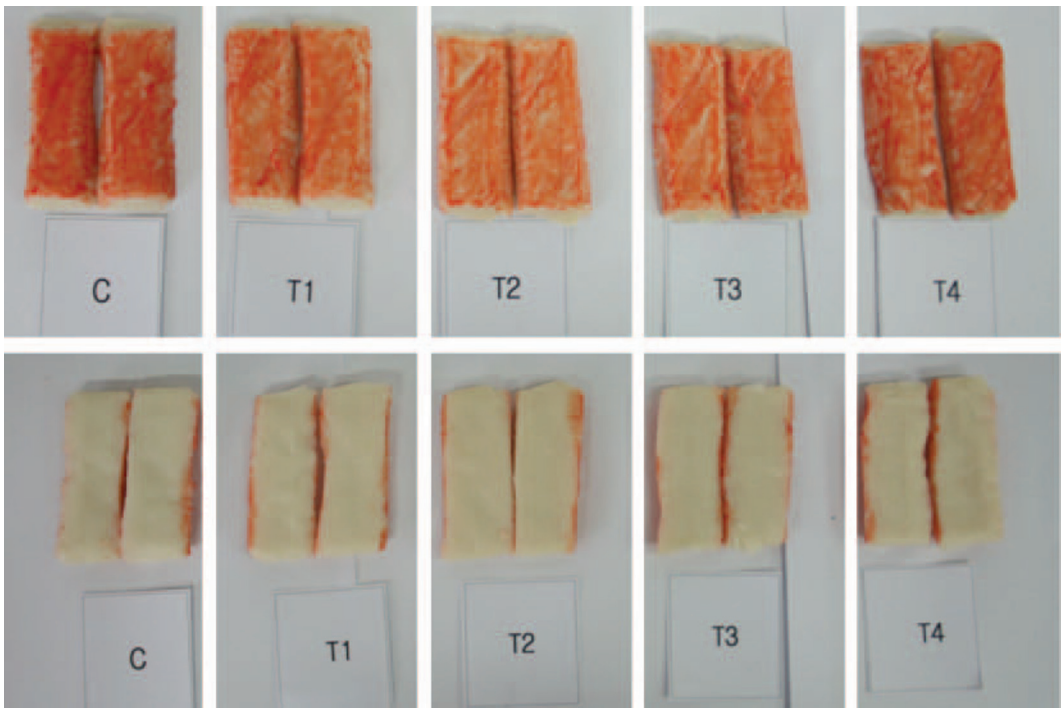


Figure 2. Final products. C = control; T1, T2, T3, T4 = treatments in which 5, 10, 15, and 20% whole spent laying hen breast meat batter was substituted for Alaska pollack surimi. The top row of photos shows the front of the products; the bottom row shows the back. Color version available in the online PDF.

hen breast meat batter. Indeed, in the present study, the spent laying hen breast meat batter contained fat (>2%), whereas the control sample contained only myofibrillar protein.

Moisture, Fat, and pH

The moisture, fat, and pH values are presented in Table 6. The moisture content and pH were significantly

Table 3. Changes in the color of imitation crab sticks during cold storage

Color ¹	Storage (wk)		
	0	2	4
L*			
Control	79.34 ± 0.46	78.97 ± 0.39 ^{CD}	79.14 ± 0.42 ^B
Treatment 1	79.91 ± 0.43 ^a	78.69 ± 0.56 ^{b,D}	79.00 ± 0.40 ^{ab,B}
Treatment 2	79.60 ± 0.16 ^b	79.67 ± 0.33 ^{b,BC}	80.24 ± 0.22 ^{a,A}
Treatment 3	79.98 ± 0.99	80.98 ± 0.26 ^A	80.34 ± 0.87 ^A
Treatment 4	80.21 ± 0.79	80.11 ± 0.66 ^B	81.17 ± 0.64 ^A
a*			
Control	−2.30 ± 0.05 ^b	−1.78 ± 0.14 ^{a,A}	−1.75 ± 0.11 ^a
Treatment 1	−2.36 ± 0.05 ^c	−1.76 ± 0.06 ^{a,A}	−1.86 ± 0.02 ^b
Treatment 2	−2.31 ± 0.08 ^b	−1.79 ± 0.17 ^{a,A}	−1.92 ± 0.03 ^a
Treatment 3	−1.90 ± 0.75	−2.04 ± 0.06 ^B	−1.90 ± 0.09
Treatment 4	−2.43 ± 0.06 ^b	−1.94 ± 0.10 ^{a,AB}	−1.82 ± 0.09 ^a
b*			
Control	8.26 ± 0.05 ^{a,C}	7.58 ± 0.32 ^{b,C}	7.69 ± 0.17 ^{b,D}
Treatment 1	9.55 ± 0.14 ^B	9.57 ± 0.44 ^B	9.37 ± 0.10 ^C
Treatment 2	12.11 ± 0.34 ^{a,A}	11.40 ± 0.34 ^{b,A}	11.42 ± 0.03 ^{b,A}
Treatment 3	11.81 ± 0.38 ^{a,A}	11.31 ± 0.12 ^{b,A}	10.88 ± 0.11 ^{b,B}
Treatment 4	11.90 ± 0.15 ^{a,A}	11.37 ± 0.19 ^{b,A}	11.19 ± 0.24 ^{b,A}
W ²			
Control	54.57 ± 0.59 ^{b,A}	56.24 ± 0.81 ^{b,A}	56.06 ± 0.58 ^{a,A}
Treatment 1	51.27 ± 0.34 ^B	49.97 ± 1.25 ^B	50.88 ± 0.19 ^B
Treatment 2	43.27 ± 1.11 ^{b,C}	45.48 ± 1.02 ^{a,C}	45.98 ± 0.23 ^{a,D}
Treatment 3	44.54 ± 2.10 ^C	47.06 ± 0.48 ^C	47.69 ± 0.77 ^C
Treatment 4	44.52 ± 1.24 ^{b,C}	46.00 ± 0.85 ^{ab,C}	47.60 ± 1.06 ^{a,C}

^{a-c}Means in the same row with different superscripts differ significantly ($P < 0.05$).

^{A-D}Means in the same column with different superscripts differ significantly ($P < 0.05$).

¹L* = lightness; a* = redness; b* = yellowness; W = whiteness.

²W = L* − 3b*.

Table 4. Changes in the textural properties of imitation crab sticks during cold storage

Textural property	Storage (wk)		
	0	2	4
Brittleness (kg)			
Control	0.10 ± 0.01 ^B	0.11 ± 0.03 ^B	0.11 ± 0.01 ^A
Treatment 1	0.09 ± 0.01 ^B	0.09 ± 0.01 ^B	0.08 ± 0.01 ^C
Treatment 2	0.13 ± 0.01 ^{ab,A}	0.13 ± 0.01 ^{a,A}	0.12 ± 0.01 ^{b,A}
Treatment 3	0.10 ± 0.01 ^B	0.10 ± 0.01 ^B	0.10 ± 0.01 ^{AB}
Treatment 4	0.09 ± 0.02 ^B	0.10 ± 0.01 ^B	0.09 ± 0.01 ^{BC}
Hardness (kg)			
Control	0.12 ± 0.01 ^B	0.13 ± 0.01 ^{AB}	0.13 ± 0.01 ^{AB}
Treatment 1	0.11 ± 0.01 ^{BC}	0.10 ± 0.01 ^C	0.09 ± 0.02 ^C
Treatment 2	0.15 ± 0.01 ^A	0.14 ± 0.01 ^A	0.14 ± 0.02 ^A
Treatment 3	0.10 ± 0.01 ^{BC}	0.10 ± 0.01 ^C	0.11 ± 0.01 ^{BC}
Treatment 4	0.09 ± 0.02 ^C	0.12 ± 0.01 ^B	0.11 ± 0.02 ^{BC}
Cohesiveness (%)			
Control	0.52 ± 0.03 ^{a,B}	0.42 ± 0.07 ^b	0.39 ± 0.05 ^b
Treatment 1	0.40 ± 0.02 ^{BC}	0.50 ± 0.20	0.42 ± 0.07
Treatment 2	0.45 ± 0.02 ^{BC}	0.39 ± 0.08	0.32 ± 0.03
Treatment 3	0.33 ± 0.05 ^{b,C}	0.61 ± 0.09 ^a	0.35 ± 0.03 ^b
Treatment 4	0.94 ± 0.20 ^{a,A}	0.39 ± 0.10 ^b	0.34 ± 0.06 ^b
Springiness (mm)			
Control	1.24 ± 0.12 ^B	1.10 ± 0.11	1.08 ± 0.16
Treatment 1	1.09 ± 0.04 ^{BC}	1.20 ± 0.28	1.13 ± 0.24
Treatment 2	1.16 ± 0.05 ^{BC}	1.05 ± 0.09	1.01 ± 0.11
Treatment 3	0.99 ± 0.20 ^{b,C}	1.43 ± 0.09 ^a	1.01 ± 0.12 ^b
Treatment 4	2.10 ± 0.11 ^A	1.05 ± 0.09	0.99 ± 0.15
Gumminess (kg)			
Control	0.06 ± 0.01 ^B	0.06 ± 0.01	0.05 ± 0.01
Treatment 1	0.04 ± 0.00 ^C	0.06 ± 0.02	0.04 ± 0.01
Treatment 2	0.07 ± 0.00 ^B	0.05 ± 0.02	0.05 ± 0.01
Treatment 3	0.03 ± 0.01 ^{b,C}	0.06 ± 0.01 ^a	0.04 ± 0.01 ^b
Treatment 4	0.09 ± 0.02 ^{a,A}	0.05 ± 0.02 ^b	0.04 ± 0.02 ^b
Chewiness (kg × mm)			
Control	0.08 ± 0.01 ^B	0.06 ± 0.02	0.05 ± 0.02
Treatment 1	0.05 ± 0.01 ^{CD}	0.07 ± 0.04	0.05 ± 0.02
Treatment 2	0.08 ± 0.01 ^{BC}	0.06 ± 0.02	0.04 ± 0.01
Treatment 3	0.04 ± 0.01 ^{b,D}	0.09 ± 0.01 ^a	0.04 ± 0.01 ^b
Treatment 4	0.18 ± 0.04 ^{a,A}	0.05 ± 0.02 ^b	0.04 ± 0.02 ^b
Adhesiveness (%)			
Control	0.02 ± 0.01 ^B	0.02 ± 0.01	0.03 ± 0.01
Treatment 1	0.03 ± 0.01 ^{a,B}	0.03 ± 0.00 ^a	0.02 ± 0.01 ^b
Treatment 2	0.05 ± 0.01 ^A	0.04 ± 0.01	0.03 ± 0.01
Treatment 3	0.03 ± 0.01 ^B	0.03 ± 0.01	0.02 ± 0.01
Treatment 4	0.02 ± 0.01 ^B	0.03 ± 0.01	0.03 ± 0.01

^{a,b}Means in the same row with different superscripts differ significantly ($P < 0.05$).

^{A-D}Means in the same column with different superscripts differ significantly ($P < 0.05$).

($P < 0.05$) higher in the control sample than in the ICS samples containing spent laying hen breast meat batter. However, the fat content was higher in ICS samples containing spent laying hen breast meat batter than in the control sample. The moisture content and pH increased as the amount of spent laying hen breast meat batter increased. Water content is a critical factor in surimi products (Uddin et al., 2006), and Uddin et al. (2006) suggested that the standard water content of surimi is 78%. In the present study, the water content was lower in ICS samples containing spent laying hen breast meat batter than in the control sample. These findings may have occurred because the water content differed between Alaska pollack surimi and spent laying hen breast meat batter, whereas the manufacturing process may not have influenced the water content. Honikel (1987) reported that pH had a profound effect on physical properties, such as water-holding capacity, tenderness, and color of the meat. A high pH, high pro-

tein content, and low water content are usually closely related to a high water-holding capacity and shear force in meats (Jin et al., 2007). However, pH was found to have no effect on the textural properties of any of the ICS samples evaluated in the present study. Thus, we assumed that the changes in moisture and pH were influenced by the substitution methods. In general, changes in the pH of meat products are closely related to postmortem glycolysis. However, glycogen can be removed by washing; thus, pH changes may have been less influenced by the physicochemical characteristics of the ICS samples.

TBARS and VBN

The TBARS and VBN values are presented in Table 7. The lipid oxidation value (TBARS) and protein degradation value (VBN) were significantly ($P < 0.05$) lower in the control sample than in the ICS samples contain-

Table 5. Fatty acid composition of imitation crab sticks during cold storage at 0 d

Fatty acid ¹ (%)	Treatment				
	Control	1	2	3	4
Undecanoic acid (C11:0)	0.08 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
Myristic acid (C14:0)	1.13 ± 0.07 ^A	0.79 ± 0.01 ^B	0.78 ± 0.01 ^B	0.77 ± 0.01 ^B	0.74 ± 0.01 ^B
Pentadecanoic acid (C15:0)	0.21 ± 0.01 ^A	0.20 ± 0.00 ^{AB}	0.19 ± 0.01 ^{BC}	0.18 ± 0.01 ^C	0.16 ± 0.01 ^D
Palmitic acid (C16:0)	16.45 ± 0.36 ^B	15.52 ± 0.00 ^C	16.70 ± 0.06 ^B	17.39 ± 0.04 ^A	17.32 ± 0.08 ^A
Palmitoleic acid (C16:1)	1.68 ± 0.15 ^A	1.24 ± 0.03 ^B	1.32 ± 0.01 ^B	1.37 ± 0.01 ^B	1.34 ± 0.03 ^B
Magaric acid (C17:0)	0.33 ± 0.01 ^B	0.34 ± 0.01 ^A	0.34 ± 0.01 ^B	0.33 ± 0.00 ^B	0.30 ± 0.01 ^C
Magaoleic acid (C17:1)	0.25 ± 0.01 ^A	0.20 ± 0.01 ^B	0.19 ± 0.01 ^B	0.17 ± 0.01 ^C	0.15 ± 0.01 ^D
Stearic acid (C18:0)	7.10 ± 0.07 ^A	6.84 ± 0.08 ^B	7.08 ± 0.13 ^A	7.24 ± 0.05 ^A	7.16 ± 0.07 ^A
Oleic acid (C18:1)	20.67 ± 0.81 ^C	20.68 ± 0.10 ^C	23.70 ± 0.18 ^B	24.83 ± 0.04 ^A	25.45 ± 0.14 ^A
Linoleic acid (C18:2)	32.71 ± 1.07 ^D	38.33 ± 0.06 ^A	37.32 ± 0.13 ^{BC}	36.47 ± 0.06 ^C	37.58 ± 0.38 ^{AB}
Linolenic acid (C18:3)	4.08 ± 0.14 ^C	4.64 ± 0.01 ^A	4.26 ± 0.02 ^B	3.97 ± 0.01 ^C	3.99 ± 0.06 ^C
Arachidic acid (C20:0)	0.34 ± 0.01 ^C	0.39 ± 0.00 ^A	0.36 ± 0.00 ^B	0.33 ± 0.00 ^D	0.32 ± 0.00 ^E
Eicosenoic acid (C20:1)	0.41 ± 0.01 ^A	0.33 ± 0.00 ^B	0.31 ± 0.01 ^C	0.30 ± 0.00 ^C	0.29 ± 0.01 ^D
Eicosatrienoic acid (C20:4)	5.26 ± 0.10 ^A	2.94 ± 0.02 ^B	1.90 ± 0.03 ^C	1.74 ± 0.02 ^D	1.37 ± 0.04 ^E
Behenic acid (C22:0)	0.28 ± 0.01 ^C	0.32 ± 0.00 ^A	0.30 ± 0.00 ^B	0.27 ± 0.00 ^D	0.27 ± 0.01 ^D
Docosahexaenoic acid (C22:6)	8.99 ± 0.31 ^A	7.17 ± 0.03 ^B	5.21 ± 0.02 ^C	4.59 ± 0.05 ^D	3.51 ± 0.17 ^E
SFA	25.93 ± 0.47 ^{BC}	24.46 ± 0.09 ^C	25.81 ± 0.17 ^D	26.57 ± 0.10 ^A	26.32 ± 0.11 ^{AB}
MUFA	23.02 ± 0.96 ^C	22.46 ± 0.11 ^C	25.50 ± 0.20 ^B	26.67 ± 0.04 ^A	27.24 ± 0.17 ^A
PUFA	51.04 ± 1.44 ^B	53.08 ± 0.10 ^A	48.69 ± 0.12 ^C	46.76 ± 0.06 ^D	46.44 ± 0.27 ^D
EFA	42.05 ± 1.24 ^C	45.91 ± 0.07 ^A	43.48 ± 0.14 ^B	42.18 ± 0.05 ^C	42.94 ± 0.40 ^{BC}

^{A-E}Means in the same row with different superscripts differ significantly ($P < 0.05$).

¹SFA = saturated fatty acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; EFA = essential fatty acid.

ing spent laying hen breast meat batter. The TBARS and VBN values tended to increase as the amount of spent laying hen breast meat batter increased. Lipid oxidation during frozen storage of meat is an important cause of quality deterioration and reduced consumer acceptance (Øverland et al., 2011). Ahn et al. (1993) reported that the differences in fat content, fatty acid composition, and lipid classes had significant effects on lipid oxidation only when oxygen had free access to the stored meat products. In the present study, the TBARS and VBN values increased as the amount of spent laying hen breast meat batter increased. These findings indicate that the shelf life of the ICS would be influenced by substitution with spent laying hen breast

meat batter. This may be because the crude fat and protein contents were higher in ICS samples containing spent laying hen breast meat batter.

Sensory Evaluation

Results of the sensory evaluation are presented in Table 8. No sensory evaluation items differed significantly ($P < 0.05$) among the ICS samples during storage, although the color of the final products, mechanical color, and textural properties differed among ICS samples. These results indicated that the substitution of laying hen breast meat batter for Alaska pollack surimi is a useful method for producing ICS because it enables the

Table 6. Changes in moisture, fat, and pH of imitation crab sticks during cold storage

Item	Storage (wk)		
	0	2	4
Moisture (%)			
Control	74.35 ± 0.06 ^A	74.31 ± 0.22 ^A	74.43 ± 0.11 ^A
Treatment 1	72.92 ± 0.52 ^A	73.73 ± 0.18 ^B	73.87 ± 0.28 ^A
Treatment 2	71.27 ± 0.26 ^D	72.98 ± 0.16 ^C	72.94 ± 0.13 ^B
Treatment 3	73.75 ± 0.06 ^B	72.49 ± 0.37 ^D	71.03 ± 0.28 ^C
Treatment 4	73.02 ± 0.09 ^C	71.75 ± 0.28 ^E	72.91 ± 0.60 ^B
Fat (%)			
Control	1.09 ± 0.20 ^B	0.97 ± 0.15 ^B	0.99 ± 0.21 ^B
Treatment 1	1.83 ± 0.15 ^A	1.71 ± 0.24 ^A	1.84 ± 0.18 ^A
Treatment 2	1.80 ± 0.18 ^A	1.81 ± 0.13 ^A	1.76 ± 0.09 ^A
Treatment 3	1.73 ± 0.22 ^A	1.85 ± 0.19 ^A	1.71 ± 0.17 ^A
Treatment 4	1.96 ± 0.17 ^A	1.99 ± 0.20 ^A	1.88 ± 0.28 ^A
pH			
Control	7.63 ± 0.07 ^A	7.66 ± 0.01 ^A	7.64 ± 0.02 ^A
Treatment 1	7.48 ± 0.00 ^{a,B}	7.44 ± 0.02 ^{b,B}	7.44 ± 0.01 ^{b,B}
Treatment 2	7.24 ± 0.02 ^{a,C}	7.19 ± 0.01 ^{b,C}	7.04 ± 0.00 ^{c,D}
Treatment 3	7.04 ± 0.01 ^{b,D}	6.97 ± 0.01 ^{c,D}	7.19 ± 0.01 ^{a,C}
Treatment 4	7.00 ± 0.01 ^D	6.96 ± 0.06 ^D	6.99 ± 0.01 ^E

^{a-c}Means in the same row with different superscripts differ significantly ($P < 0.05$).

^{A-E}Means in the same column with different superscripts differ significantly ($P < 0.05$).

Table 7. Changes in TBA-reactive substances (TBARS) and volatile basic nitrogen (VBN) of imitation crab sticks during cold storage

Item	Storage (wk)		
	0	2	4
TBARS (mg of MA/100 g) ¹			
Control	0.36 ± 0.01 ^D	0.35 ± 0.02 ^C	0.34 ± 0.01 ^C
Treatment 1	0.39 ± 0.02 ^{a,C}	0.39 ± 0.00 ^{a,B}	0.36 ± 0.01 ^{b,B}
Treatment 2	0.41 ± 0.01 ^{a,B}	0.42 ± 0.01 ^{a,A}	0.36 ± 0.01 ^{b,B}
Treatment 3	0.43 ± 0.03 ^{a,A}	0.40 ± 0.01 ^{ab,AB}	0.38 ± 0.01 ^{b,A}
Treatment 4	0.38 ± 0.01 ^{CD}	0.38 ± 0.00 ^B	0.37 ± 0.00 ^A
VBN (mg/100 g)			
Control	2.05 ± 0.32 ^C	3.36 ± 0.79 ^D	3.36 ± 0.56 ^B
Treatment 1	2.89 ± 0.16 ^{b,B}	5.13 ± 0.58 ^{a,C}	4.76 ± 0.56 ^{a,A}
Treatment 2	3.73 ± 0.32 ^{c,A}	6.72 ± 0.48 ^{a,B}	5.41 ± 0.16 ^{b,A}
Treatment 3	3.64 ± 0.00 ^{b,A}	5.88 ± 0.79 ^{a,BC}	5.04 ± 0.40 ^{a,A}
Treatment 4	3.83 ± 0.16 ^{c,A}	7.19 ± 0.32 ^{a,A}	5.41 ± 0.32 ^{b,A}

^{a-c}Means in the same row with different superscripts differ significantly ($P < 0.05$).

^{A-D}Means in the same column with different superscripts differ significantly ($P < 0.05$).

¹MA = malondialdehyde.

use of a simple production process that does not require myofibrillar protein recovery steps such as washing or pH adjustments.

In conclusion, in the present study, different amounts of spent laying hen breast meat batter were substituted for Alaska pollack surimi to produce ICS. The

Table 8. Changes in the sensory evaluation of imitation crab sticks during cold storage

Sensory property ¹	Storage (wk)		
	0	2	4
Color			
Control	7.92 ± 0.38	7.25 ± 0.52	7.58 ± 0.58
Treatment 1	7.17 ± 0.52	7.17 ± 0.68	7.00 ± 0.71
Treatment 2	6.92 ± 0.66	7.00 ± 0.71	6.67 ± 0.75
Treatment 3	6.92 ± 0.38	7.00 ± 0.63	6.83 ± 0.41
Treatment 4	7.00 ± 0.71	6.83 ± 0.82	6.92 ± 0.74
Aroma			
Control	7.72 ± 0.66	7.25 ± 0.52	6.83 ± 0.93
Treatment 1	7.58 ± 0.49	7.00 ± 0.77	7.42 ± 0.38
Treatment 2	7.67 ± 0.41	7.17 ± 0.68	7.00 ± 0.55
Treatment 3	7.58 ± 0.8	7.17 ± 0.68	6.92 ± 0.58
Treatment 4	7.50 ± 0.89	7.25 ± 0.69	6.58 ± 0.97
Flavor			
Control	8.17 ± 0.61	7.50 ± 0.63	7.08 ± 1.11
Treatment 1	7.67 ± 0.61	7.33 ± 0.82	7.42 ± 0.92
Treatment 2	7.75 ± 0.69	7.08 ± 0.74	6.83 ± 0.82
Treatment 3	7.42 ± 0.66	7.00 ± 0.89	7.08 ± 0.66
Treatment 4	7.33 ± 1.08	6.83 ± 0.82	6.67 ± 0.68
Tenderness			
Control	7.83 ± 0.88	7.42 ± 0.49	7.25 ± 0.61
Treatment 1	7.25 ± 0.61	7.17 ± 0.82	6.92 ± 0.80
Treatment 2	7.42 ± 0.58	7.31 ± 0.75	7.00 ± 0.84
Treatment 3	7.42 ± 0.86	7.08 ± 0.74	6.83 ± 0.68
Treatment 4	7.25 ± 1.04	7.00 ± 0.89	6.58 ± 0.66
Juiciness			
Control	7.75 ± 0.88	7.50 ± 0.45	7.08 ± 0.80
Treatment 1	7.42 ± 0.74	7.42 ± 0.58	7.08 ± 0.80
Treatment 2	6.92 ± 0.86	7.25 ± 0.69	6.42 ± 0.49
Treatment 3	7.08 ± 1.16	7.08 ± 0.66	6.75 ± 0.61
Treatment 4	6.58 ± 1.02	6.83 ± 0.68	6.50 ± 0.45
Overall acceptability			
Control	8.25 ± 0.52	7.50 ± 0.63	7.08 ± 1.11
Treatment 1	7.67 ± 0.61	7.33 ± 0.75	7.50 ± 0.77
Treatment 2	7.57 ± 0.68	7.37 ± 0.68	6.58 ± 0.58
Treatment 3	7.50 ± 0.89	7.00 ± 0.71	6.83 ± 0.75
Treatment 4	7.08 ± 0.74	6.67 ± 0.75	6.42 ± 0.86

¹Color (9 = very good, 1 = very bad), aroma (9 = very intense, 1 = very weak), flavor (9 = very good, 1 = very bad), tenderness (9 = very tender, 1 = very tough), juiciness (9 = very juicy, 1 = very dry), overall acceptability (9 = very good, 1 = very bad).

results revealed that the quality characteristics were not heavily influenced by substituting the spent laying hen breast meat batter for Alaska pollack surimi. These findings indicate that ICS can be made by substituting spent laying hen breast meat batter. Thus, the substitution of spent laying hen breast meat batter for Alaska pollack surimi would be useful from the point of view of the ICS manufacturing procedure or the reduction of wastewater. Moreover, the substitution of Alaska pollack surimi with spent laying hen breast meat batter could benefit from the development of an efficient and economical technology for processing undervalued meat, such as spent laying hen breast meat, into value-added meat products that are palatable and reasonable in cost.

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REFERENCES

- Ahn, D. U., A. Ajuyah, F. H. Wolef, and J. S. Sim. 1993. Oxygen availability affects prooxidant catalyzed lipid oxidation of cooked turkey patties. *J. Food Sci.* 58:278–291.
- Antonomanolaki, R. E., K. P. Vareltsis, S. A. Georgakis, and E. Kaldrymidou. 1999. Thermal gelation properties of surimi-like material made from sheep meat. *Meat Sci.* 52:429–435.
- AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Washington, DC.
- Buege, J. A., and S. D. Aust. 1978. Microsomal lipid peroxidation. *Methods Enzymol.* 52:302–310.
- Chaijan, M., S. Benjakul, W. Visessanguan, and C. Faustman. 2004. Characteristics and gel properties of muscles from sardine (*Sardinella gibbosa*) and mackerel (*Rastrelliger anagurta*) caught in Thailand. *Food Res. Int.* 37:1021–1030.
- Chen, H. H. 2002. Decoloration and gel-forming ability of horse mackerel mince by air-flotation washing. *J. Food Sci.* 67:2970–2975.
- Clark, J. M., and R. L. Switzer. 1977. Experimental Biochemistry. W. H. Freeman and Company, San Francisco, CA.
- Cross, H. R., R. Leu, and M. F. Miller. 1987. Scope of warmed-over flavor and its importance to the meat industry. Pages 1–18 in *Warmed-Over Flavor of Meat*. A. J. St. Angel and M. E. Bailey, ed. Academic Press, Orlando, FL.
- Folch, J., M. Lees, and G. H. Sloan-Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissue. *J. Biol. Chem.* 226:479–507.
- Gomez-Basauri, J. V., and J. F. Regenstein. 1992. Vacuum packaging, ascorbic acid and frozen storage effect on heme and nonheme iron content of mackerel. *J. Food Sci.* 57:1337–1339.
- Hall, G. M. 2010. Surimi and fish mince products. Pages 98–111 in *Fish Processing: Sustainability and New Opportunities*. G. H. Hall, ed. Wiley-Blackwell, Oxford, UK.
- Honikel, K. O. 1987. The water binding of meat. *Fleischwirtschaft* 67:1098–1102.
- Hur, S. J., B. H. Ye, J. L. Lee, Y. L. Ha, G. B. Park, and S. T. Joo. 2004. Effect of conjugated linoleic acid on color and lipid oxidation of beef patties during cold storage. *Meat Sci.* 66:771–775.
- Jin, S. K., I. S. Kim, S. J. Hur, K. H. Park, J. H. Ha, S. M. Kang, Y. J. Choi, and S. J. Kim. 2006. Effect of pH control and physicochemical characteristics of chicken breast surimi. *Korean J. Food Sci. Anim. Resour.* 26:64–69.
- Jin, S. K., I. S. Kim, S. J. Kim, K. J. Jeong, Y. J. Choi, and S. J. Hur. 2007. Effect of muscle type and washing times on physicochemical characteristics and qualities of surimi. *J. Food Eng.* 81:618–623.
- Kealy, T. 2006. Application of liquid and solid rheological technologies to the textural characterization of semi-solid foods. *Food Res. Int.* 39:265–276.
- Kenney, P. B., C. L. Kastner, and D. H. Kropf. 1992. Muscle washing and raw material source affect quality and physicochemical properties of low-fat, restructured beef. *J. Food Sci.* 57:545–550.
- Krzywicki, K. 1982. The determination of haem pigment in meat. *Meat Sci.* 7:29–35.
- Kuo, C. C., and C. Y. Chu. 2003. Quality characteristics of Chinese sausage made from PSE pork. *Meat Sci.* 64:441–449.
- Lanier, F. C. 1986. Functional properties of surimi. *Food Technol.* 40:107–114.
- Lee, B. J., D. G. Hendricks, and D. P. Cornforth. 1999. A comparison of carnosine and ascorbic acid on color and lipid stability in a ground beef patty model system. *Meat Sci.* 51:245–253.
- Mansfield, B. 2003. 'Imitation crab' and the material culture of commodity production. *Cultur. Geogr.* 10:176–195.
- Newsad, A. A. K. M., S. Kanoh, and E. Niwa. 2000. Thermal gelation characteristics of breast and thigh muscles of spent hen and broiler and their surimi. *Meat Sci.* 54:169–175.
- Ochiai, Y., L. Ochiai, K. Hashimoto, and S. Watabe. 2001. Quantitative estimation of dark muscle content in the mackerel meat paste and its products using antisera against myosin light chains. *J. Food Sci.* 66:1301–1305.
- Øverland, M., G. I. Borge, G. Vogt, H. F. Schøyen, and A. Skrede. 2011. Oxidative stability and sensory quality of meat from broiler chickens fed a bacterial meal produced on natural gas. *Poult. Sci.* 90:201–210.
- Park, S., M. S. Brewer, J. Novakofski, P. J. Bechtel, and F. K. McKelth. 1996. Process and characteristics for a surimi-like material made from beef or pork. *J. Food Sci.* 61:422–427.
- Pearson, D. 1976. *The Chemical Analysis of Foods*. 7th ed. Churchill Livingstone, Oxford, UK.
- SAS Institute. 2001. The SAS Program for Windows. SAS Inst. Inc., Cary, NC.
- Srinivasan, S., and Y. L. Xiong. 1996. Gelation of beef heart surimi as affected by antioxidant. *J. Food Sci.* 61:707–711.
- Uddin, M., E. Okazake, H. Fukushima, S. Turza, Y. Yumiko, and Y. Fukuda. 2006. Nondestructive determination of water and protein in surimi by near-infrared spectroscopy. *Food Chem.* 96:491–495.
- Warriss, P. D. 2010. *Meat Science: An Introductory Text*. 2nd ed. CABI Publishing, Wallingford, Oxfordshire, UK.
- Xing, Y. L. 1992. Thermally induced interactions and gelation of combined myofibrillar protein from white and red broiler muscles. *J. Food Sci.* 57:581–585.
- Yang, T. S., and G. W. Froning. 1992. Selected washing processes affect thermal gelation properties and microstructure of mechanically deboned chicken meat. *J. Food Sci.* 57:325–329.