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Effect of surimi quality on properties of edible films based on Alaska pollack

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Abstract

Transparent and flexible edible/biodegradable films were successfully made from frozen Alaska pollack surimi. The effects of surimi quality on film formation, tensile strength (TS), elongation at break (EAB), water vapour permeability (WVP), light transmission, transparency, film solubility, protein solubility, and enzyme hydrolysis of surimi films were investigated. Thawed Alaska pollack surimi was incubated at 30 °C for 20 min (slight protein denaturation) and at 30 °C for 5 h (complete protein denaturation) in order to intentionally lower the surimi quality. Slight protein denaturation caused decreased EAB of the films and the complete denaturation gave rise to reduction of TS and EAB. The remaining of film properties were not markedly influenced by the loss of surimi quality. Hydrogen bonds, together with ionic bonds, played an important role in the formation of surimi films, but hydrophobic interactions were more involved when surimi with complete protein denaturation was used for the film preparation.

Keywords: Edible film; Alaska pollack; Frozen surimi; Mechanical property; Water vapour permeability

1. Introduction

Almost three decades ago, when surimi analogue of crab legs was first developed in Japan, many countries became interested in making and using frozen surimi, especially from Alaska pollack, because it provides consumers with novel, nutritious, and convenient foods. However, the production of frozen surimi and the consumption of surimi-based products have been gradually declining in Japan in recent years (Ministry of Agriculture, Forestry & Fisheries, Japan, 2001), partly due to the lack of new product introduction. As a value-added form of surimi, we have successfully developed a procedure to prepare edible/biodegradable films from fish myofibrillar proteins (Shiku, Hamaguchi, & Tanaka, 2003). Transparent and flexible films were obtained from a film-forming solution, based on frozen Alaska pollack surimi in distilled water, together with glycerol.

It is well-established that the quality of frozen surimi is markedly influenced by the freezing rate, frozen storage temperature and time, steadiness of storage conditions, and thawing conditions (Matsumoto & Noguchi, 1992; MacDonald, Lanier, & Carvajal, 2000). As with other frozen products, surimi has longer shelf-life at lower and nonfluctuating temperatures. The storage condition of frozen surimi was recommended to be −23 to −25 °C, with minimum fluctuation, by the Japanese Association of Refrigeration (Matsumoto & Noguchi, 1992). Thawing is another quality-deciding step in surimi processing. For instance, freeze/thaw damage to surimi, due to malfunctions in the freezer cooling system, could occur before the surimi-based products are prepared (Nielsen & Pigott, 1994). Therefore, it is obvious that improper storage and thawing procedures bring about a lowering of frozen surimi

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quality to the extent that it cannot be used for the production of surimi analogues such as crab legs, scallops, and shrimp.

In order to gain an effective utilization of frozen surimi of poor quality, including land-processed surimi, the influence of surimi quality on physicochemical properties of edible/biodegradable surimi films was investigated in this study.

2. Materials and methods

2.1. Materials

Blocks (10 kg each) of ship-processed Alaska pollack (*Theragra chalcogramma*) surimi (SA grade) were purchased from Maruha Co. (Tokyo, Japan) and stored at −35 °C during the study. This surimi contained 4% sorbitol, 4% sucrose, and 0.3% sodium triphosphate with 75% water content.

In order to prepare edible films from surimi, the frozen surimi was first thawed at 4 °C for 16 h. In another study, the thawed surimi was cut into 1 cm thick slices and kept at 30 °C for 20 min and 5 h to intentionally lower the quality. Such surimi with different quality was also used to prepare edible films by the same procedure as described below.

Some synthetic films, low density polyethylene (LDPE), oriented polypropylene (OPP), polyester (PE), and polyvinylidene chloride (PVDC), were purchased from Tokyu Hands Department Store (Tokyo, Japan) and their mechanical properties, water vapour permeability (WVP) and light transmission, were also determined for comparison.

2.2. Determination of surimi quality

2.2.1. General

The quality of frozen Alaska pollack surimi was evaluated by three different methods.

2.2.2. Kamaboko gel texture

NaCl (2.5%) was added as percentage by weight of surimi standardized at 80% water and chopped for 3 min in a National MK-K75 food processor (National Electric Co., Osaka, Japan). After chopping, the meat paste was stuffed into stainless steel tubes (diameter 3 cm × height 3 cm). Kamaboko gels were prepared by heating the stuffed meat pastes at 80 °C for 20 min after the setting treatment at 30 °C for 40 min. The gels formed were subjected to gel strength measurement with a rheometer (Type SD-305, Sun Science Co., Tokyo, Japan; spherical plunger, diameter 0.5 cm). Compression on the sample piece was executed with a table speed of 60 mm min^{-1}. The quality of the gels was assessed by measuring their breaking force (g) and breaking strain (cm). The averages, with standard errors of eight measurements, were calculated.

2.2.3. Protein solubility in 0.6 M KCl

Protein solubility of surimi was determined as described by Benjakul and Bauer (2000). To 2 g sample, 40 ml of 0.6 M KCl were added and the mixture was homogenized for 30 s. The homogenate was then centrifuged at 3900*g* for 20 min at 4 °C. The supernatant was diluted using 0.6 M KCl, prior to the protein determination by a Bio-Rad Protein Assay (Bradford method, Bio-Rad Laboratories, Hercules, CA, USA).

2.2.4. Ca^{2+}-ATPase activity

The extent of denaturation of myofibrillar proteins in Alaska pollack surimi was evaluated by Ca^{2+}-ATPase activity, according to the procedure reported by Hashimoto and Arai (1978).

2.3. Preparation of the film-forming solution

From the results of our preliminary study (Shiku et al., 2003), the protein concentration of the film-forming solution was fixed to 2% and glycerol as a plasticizer was added at 50% (w/w) of protein. After the thawed surimi was stirred in distilled water at a high speed with glycerol for 30 min, pH of the film-forming solution was adjusted to 11 with 1 M NaOH and dispersed thoroughly using a glass homogenizer (Sibata Scientific Technol. Ltd, Tokyo, Japan) for 2 min. Then the solution was treated with a Hybrid Mixer (HM-500, Keyence Co., Tokyo, Japan) to remove air bubbles.

2.4. Film casting and drying

The prepared film-forming solution (4 g) was cast onto a rimmed silicone resin plate (50 × 50 mm) sitting on a level surface and dried in a ventilated oven at 25 ± 0.5 °C and 50 ± 5% relative humidity (RH) for 24 h (Environmental Chamber model H110K-30DM; Seiwa Riko Co., Tokyo, Japan). After the water was evaporated, resulting films were manually peeled off. Transparent and easily-handled films were thus formed.

2.5. Measurement of film thickness

Film thickness was measured using a micrometer (Dial Pipe Gauge, Peacock Co., Tokyo, Japan) to the nearest 0.005 mm at nine random locations of the film. Precision of the thickness measurements was ±5%.

2.6. Measurement of mechanical property

Prior to testing mechanical properties, the films were conditioned for 48 h at 50 ± 5% RH and 25 ± 0.5 °C (Environmental Chamber model H110K-30DM).

Tensile strength (TS) and elongation at break (EAB) were determined using a Texture Analyzer (TA.XT2 Stable Micro Systems, UK) as described in our previous paper (Iwata, Ishizaki, Handa, & Tanaka, 2000). A total of ten samples were tested for each film type.

2.7. Measurement of water vapour permeability (WVP)

WVP values were measured using a modified ASTM method (American Society for Testing & Materials, 1989). The film was sealed on a glass permeation cup containing silica gel (0% RH) with silicone vacuum grease and a rubber band to hold the film in place. The cups were placed, at 30 °C, in a desiccator with distilled water. The cups were weighed at 1 h intervals over a 12 h period and WVP (g m^{-1} s^{-1} Pa^{-1}) of the film was calculated as follows (McHugh, Bustillos, & Krochta, 1993): $WVP = wxA^{-1}t^{-1}(P_2 - P_1)^{-1}$, where w is the weight gain of the cup (g), x is the film thickness (m), A is the area of exposed film (m^2), t is the time of gain (s), and $(P_2 - P_1)^{-1}$ is the vapour pressure differential across the film (Pa). This entire procedure was repeated twice, for a total of eight tests on each film type.

2.8. Light transmission and film transparency

The ultraviolet (UV) and visible light barrier properties of the films were measured at selected wavelengths between 200 and 800 nm, using a UV–Vis Recording Spectrophotometer (model UV-160, Shimadzu Co., Kyoto, Japan) according to the procedure reported by Fang, Tung, Britt, Yada, and Dalgleish (2002). The transparency of the films was calculated by the following equation (Han & Floros, 1997): transparency $= A_{600}/x$ or $-\log T_{600}/x$, where A_{600} is the absorbance at 600 nm, T_{600} is the transmittance at 600 nm, and x is the film thickness (mm).

2.9. Determinations of film solubility and protein solubility

Film solubility was expressed as percentage of film dry matter solubilized after 24 h of immersion in distilled water (Gennadios, Handa, Froning, Weller, & Hanna, 1998). The conditioned film samples (2×2 cm) were weighed and placed in 50 ml flasks containing 10 ml of distilled water with 0.1% (w/v) sodium azide, then stored at 30 °C for 24 h with continuous gentle stirring. Undissolved dry matter was determined by removing the film pieces with centrifugation at 3000*g* for 20 min and drying them at 105 °C for 24 h. The weight of solubilized dry matter was calculated by subtracting the weight of unsolubilized dry matter from the initial weight of dry matter. Following the centrifugation, the protein concentration in the supernatant was determined using a Bio-Rad *DC* Protein Assay (Lowry method, Bio-Rad Laboratories). Protein solubility was expressed as percentage of total protein in the film which was solubilized at 30 °C for 24 h.

2.10. Hydrolysis by protease

Ground film sample (50 mg) was suspended in 50 ml of α-chymotrypsin (Wako Pure Chem. Ind., Tokyo, Japan) solution (40 μg/ml in 40 mM Tris–HCl buffer, pH 7.6). The suspension was then incubated at 37 °C for 2 h. Hydrolysis was terminated by heating at 100 °C for 3 min. After the filtration through Toyo Roshi No. 7C filter paper (Toyo Roshi Co., Tokyo, Japan), the protein concentration of filtrate was measured using the Bio-Rad *DC* Protein Assay. The degree of hydrolysis was calculated as reported by Yildirim and Hettiarachchy (1998).

2.11. SDS–polyacrylamide gel electrophoresis (SDS–PAGE)

SDS–PAGE was performed according to Laemmli (1970). Film-forming solutions and surimi films were dissolved in 2% SDS-8 M urea-20 mM Tris–HCl (pH 8.8) in the presence of 2-mercaptoethanol. 10% separating gels were employed. The gels were stained with 0.05% Coomassie Brilliant Blue R-250 (Sigma Chemical Co., St. Louis, Miss, USA) in isopropyl alcohol/acetic acid/water (25:10:65%, v:v:v) and were destained in isopropyl alcohol/acetic acid/water (10:7:83%, v:v:v). The standard protein mixture (Sigma Chemical Co.) ranged in molecular mass from 20 to 205 kDa.

2.12. Protein solubility in various solvents

Surimi films were solubilized in four different solutions at pH 7 (Perez-Mateos, Lourenco, Montero, & Borderia, 1997): 0.6 M NaCl (S1), 0.6 M NaCl + 1.5 M urea (S2), 0.6 M NaCl + 8 M urea (S3), and 0.6 M NaCl + 8 M urea + 0.5 M 2-mercaptoethanol (S4). Ground film samples were weighed and transferred into glass flasks with four different solutions. The flasks were gently shaken for 24 h at 30 °C using a reciprocating shaker. Following the filtration with Toyo Roshi No. 7C filter paper, the protein concentration in the filtrate was determined using the Bio-Rad Protein Assay.

2.13. Statistical analysis

Statistics, on a completely randomized design, were determined using the General Linear Models procedure in SAS (SAS Institute, 1988). Duncan's multiple-range test ($p \leqslant 0.05$) was used to determine significance of differences between means.

3. Results and discussion

3.1. General

There have been some studies reporting that transparent and flexible edible films can be successfully prepared from myofibrillar proteins of sardine (Cuq, Aymard, Cuq, & Guilbert, 1995), Nile tilapia (Sobral, Monterrey, & Habitante, 2002), and blue marlin (Shiku et al., 2003). However, the effect of protein denaturation on the properties of edible films based on myofibrillar proteins has not been elucidated. In this study, Alaska pollack surimi of different qualities was used to prepare the edible films and their properties were determined.

3.2. Quality of surimi used for film preparation

Alaska pollack surimi of varying quality was prepared by incubating surimi at 30 °C for 20 min and 5 h, and the quality was evaluated by gel-forming ability, solubility in 0.6 M KCl, and Ca^{2+}-ATPase activity. Table 1 shows the quality of surimi used for the preparation of edible films. The breaking strength of kamaboko gels decreased to one half after 20 min incubation at 30 °C. The surimi incubated for 5 h at 30 °C brought about very fragile kamaboko gels (breaking strength = 113.5 g). Protein solubility in 0.6 M KCl and myofibrillar Ca^{2+}-ATPase activity also showed slight denaturation of proteins after 20 min of incubation and complete denaturation after 5 h of incubation. A loss of gel-forming ability is known to be accompanied by loss of myofibrillar Ca^{2+}-ATPase activity (Scott, Porter, Kudo, Miller, & Koury, 1988).

3.3. Mechanical property and water vapour permeability

TS and EAB of surimi films are presented in Table 2, together with some synthetic films. TS of films from surimi with slight protein denaturation was not significantly different ($p > 0.05$) from that of the control film, while the complete denaturation of myofibrillar proteins in surimi caused a marked decrease of TS ($p \leqslant 0.05$). TS of synthetic films tested in this study were much larger than that of surimi films (Table 2). In contrast to TS, even slight denaturation of myofibrillar proteins brought about a significant loss of EAB ($p \leqslant 0.05$), indicating that the flexibility of surimi films can be easily

Table 1
Kamaboko gel texture, protein solubility in 0.6 M KCl, and Ca^{2+}-ATPase activity of Alaska pollack surimi with different qualities[a]

Pretreatment[b]	Breaking strength[c] (g)	Breaking strain[c] (cm)	Protein solubility (%)	Ca^{2+}-ATPase activity (μMPi mg^{-1} $protein^{-1}$ min^{-1})
30 °C				
0 min	465.8 ± 19.2a (100%)[d]	1.2 ± 0.1a (100%)	38.3 ± 1.6a (100%)	0.43 ± 0.08a (100%)
20 min	248.0 ± 6.9b (53.2%)	0.8 ± 0.1b (67%)	31.3 ± 2.1b (81.7%)	0.31 ± 0.06b (72.0%)
5 h	113.5 ± 9.4c (24.4%)	0.9 ± 0.1b (75%)	9.2 ± 0.9c (24.0%)	0.05 ± 0.01c (11.6%)

[a] Means ± standard deviation. Any two means in the same column followed by the same letter are not significantly different ($p > 0.05$).
[b] Thawed Alaska pollack surimi was preheated at 30 °C for 0 min (control), 20 min, and 5 h in order to intentionally reduce the surimi quality.
[c] Breaking strength and strain of kamaboko gels prepared from Alaska pollack surimi by setting at 30 °C for 40 min, then heating at 80 °C for 20 min.
[d] (%) is relative to the control value.

Table 2
Tensile strength (TS), elongation at break (EAB), and water vapour permeability (WVP) of surimi films prepared from Alaska pollack surimi with different qualities and synthetic polymer films[a]

Pretreatment[b]	TS (MPa)	EAB (%)	WVP ($\times 10^{-10}$ g m^{-1} s^{-1} Pa^{-1})
30 °C			
0 min	5.86 ± 0.89a	123.5 ± 16.2a	1.69 ± 0.06a
20 min	5.21 ± 0.73a	56.4 ± 11.3b	1.72 ± 0.10a
5 h	3.09 ± 0.78b	40.3 ± 10.6b	1.71 ± 0.20a
Synthetic films[c]			
LDPE	16.5 ± 0.9	>1000	0.020 ± 0.006
OPP	50.7 ± 8.2	73 ± 27	0.038 ± 0.035
PE	81.6 ± 3.2	19 ± 6	0.198 ± 0.015
PVDC	65.6 ± 10.8	18 ± 5	0.002 ± 0.000

[a] Means ± standard deviation. Any two means in the same column followed by the same letter are not significantly different ($p > 0.05$).
[b] Thawed Alaska pollack surimi was preheated at 30 °C for 0 min (control), 20 min and 5 h in order to intentionally reduce the surimi quality.
[c] LDPE: low density polyethylene, OPP: oriented polypropylene, PE: polyester, PVDC: polyvinylidene chloride.

lost due to the decrease of surimi quality. EAB of surimi films prepared in this study was larger than PE and PVDC films, but much lower than LDPE and OPP films (Table 2).

On the other hand, WVP of surimi films was not affected by the quality of surimi as shown in Table 2. WVP of any surimi film prepared in this study was almost equivalent to that of fish sarcoplasmic protein films (Iwata et al., 2000) and myofibrillar protein films (Shiku et al., 2003). However, the WVP values of surimi films were two or three orders of magnitude greater than those of synthetic polymer films examined in this study (Table 2).

3.4. Light transmission and transparency

Table 3 summarizes the light transmission at selected wavelengths for the surimi films, as influenced by the degree of protein denaturation, in comparison, to some synthetic polymer films. The control film had excellent barrier properties to UV light in the 200–280 nm region, regardless of the quality of surimi, suggesting that surimi films can prevent the lipid oxidation induced by UV light in the food systems. This result is in agreement with other studies on blue marlin myofibrillar protein-based films (Shiku et al., 2003) and whey protein films (Fang et al., 2002). On the other hand, synthetic polymer films did not prevent the passage of UV light above 280 nm, except PE film (Table 3).

The control surimi film had a transparency of 2.19 (Table 3), indicating that the film is fairly transparent. The transparency of surimi films, which was relatively close to that of blue marlin myofibrillar protein-based films (Shiku et al., 2003) and synthetic polymer films (Table 3), slightly decreased with decreasing quality of the surimi. Data obtained in this study seem to indicate that the surimi films are clear enough to be used as see-through packaging or coating materials.

3.5. Film solubility, protein solubility and enzymatic hydrolysis

Film solubility can be viewed as a measure of the water resistance and integrity of a film (Rhim, Gennadios, Handa, Weller, & Hanna, 2000). The film solubility of surimi films was not significantly ($p > 0.05$) affected by the quality of surimi (Table 4). The film solubility of surimi films was similar to that of blue marlin myofibrillar protein films (Shiku et al., 2003), but was larger than that of sarcoplasmic protein films (Iwata et al., 2000). The larger solubility of surimi films is probably ascribable to the weaker structure of the films, as seen by their smaller TS and larger EAB (Table 2).

Table 3
Light transmission (%) and transparency (A_{600}/mm) of surimi films prepared from Alaska pollack surimi with different qualities

Pretreatment[a]	Wavelength (nm)								Transparency
	200	280	350	400	500	600	700	800	
30 °C									
0 min	0.3	0.3	61.4	65.8	68.9	70.8	71.1	71.1	2.19
20 min	0.3	0.3	53.5	69.9	74.1	77.0	79.1	80.1	2.77
5 h	0.3	0.3	62.9	69.4	73.1	74.4	75.4	75.4	3.47
Synthetic films[b]									
LDPE	13.1	67.5	79.9	83.4	85.6	86.9	87.8	83.6	3.05
OPP	4.6	80.0	86.2	87.9	88.8	89.1	89.3	89.6	1.67
PE	0.3	0.3	68.3	73.6	82.1	83.5	84.2	84.9	1.51
PVDC	0.3	79.1	83.8	86.6	87.5	90.0	87.9	84.9	4.58

[a] Thawed Alaska pollack surimi was preheated at 30 °C for 0 min (control), 20 min, and 5 h in order to intentionally reduce the surimi quality.
[b] LDPE: low density polyethylene, OPP: oriented polypropylene, PE: polyester, PVDC: polyvinylidene chloride.

Table 4
Film solubility, protein solubility, and enzymatic hydrolysis of surimi films prepared from Alaska pollack surimi with different qualities[a]

Pretreatment[b]	Film solubility (%)	Protein solubility (%)	Enzymatic hydrolysis[c] (%)
30 °C			
0 min	75.1 ± 1.0a	51.3 ± 1.1a	84.2 ± 2.9a
20 min	76.9 ± 1.1a	50.6 ± 4.8a	81.2 ± 3.5a
5 h	76.9 ± 5.1a	51.4 ± 2.4a	83.4 ± 2.5a

[a] Means ± standard deviation. Any two means in the same column followed by the same letter are not significantly different ($p > 0.05$).
[b] Thawed Alaska pollack surimi was preheated at 30 °C for 0 min (control), 20 min, and 5 h in order to intentionally reduce the surimi quality.
[c] Degree of protein hydrolysis by α-chymotrypsin after 2 h digestion at 37 °C.

The protein solubility of surimi films in distilled water was around 50%, irrespective of the quality of surimi (Table 4), suggesting that the surimi films are formed through weak interactions of myofibrillar proteins. The protein digestibility of surimi films was determined by α-chymotrypsin hydrolysis at 37 °C during 2 h (Table 4). Hydrolysis of the films by α-chymotrypsin increased with time and plateaued out towards the end of the digestion period (data not shown). The protein digestibility of surimi films was between 80 and 85%, and it was apparently not ($p > 0.05$) influenced by the degree of surimi protein denaturation (Table 4). The large hydrolysis degree of surimi films, by the protease, indicated that they were digestible.

3.6. Film-forming mechanism

Fig. 1 depicts SDS-PAGE patterns of the films prepared from surimi with different qualities. It is obvious from this Figure that the myosin heavy chain (MHC) band intensity did not change during the incubation of surimi at 30 °C for up to 5 h, suggesting that surimi used in this study does not contain any proteolytic enzymes active around pH 7. According to the study by Cuq et al. (1995) on the edible films based on sardine myofibrillar proteins, the degradation of MHC took place, mostly, in the acidic pH range, due to cathepsins which are strongly associated with the myofibrillar proteins and are not removed by the washing treatment of surimi production (Young, Torlay, & Reid, 1992). On the other hand, after the films were formed, the MHC band intensity decreased and the components which could not penetrate into 10% separating gels increased with lowering quality of surimi (Fig. 1), suggesting that the mechanism of film formation could be dependent on the quality of surimi.

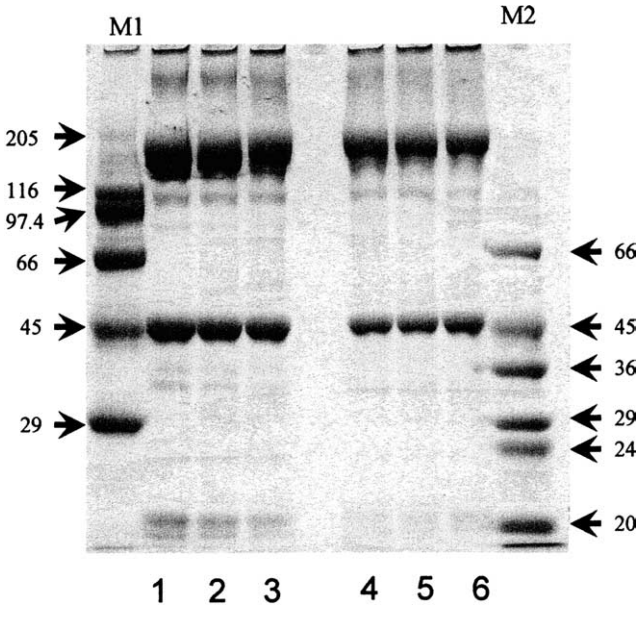

Fig. 1. SDS-PAGE patterns of surimi films. 1: undenatured Alaska pollack surimi, 2: surimi with slight denaturation, 3: surimi with complete denaturation, 4: films from undenatured surimi, 5: films from slightly denatured surimi, 6: films from completely denatured surimi. M1: high molecular mass standard (29–205 kDa), M2: low molecular mass standard (20–66 kDa).

The distribution and extents of inter- and intra-molecular interactions, which give rise to a three-dimensional network structure of the films, should affect their mechanical properties. The main associative forces involved in surimi films may be inter-molecular covalent bonds with secondary hydrophobic and hydrogen interactions, as was pointed out by Choi and Han (2002), Rangavajhyala, Ghorpade, and Hanna (1997), and Rhim et al. (2000). The films prepared from surimi with various qualities were solubilized in four different solutions which can disrupt ionic bonds, hydrogen bonds, hydrophobic interactions, and disulfide bonds. The protein solubilities (percent of total protein content) in four disrupters are listed in Table 5.

As shown in Table 5, approximately 30% of the proteins in surimi films were soluble in S1 (0.6 M NaCl), which can disrupt ionic bonds, regardless of the surimi quality ($p > 0.05$). Protein solubility in S2 (0.6 M NaCl + 1.5 M urea), which can disrupt hydrogen bonds, decreased significantly ($p \leqslant 0.05$) when the films were prepared from the surimi incubated at 30 °C for 5 h. On the other hand, their solubility was markedly increased, to more than 70%, with the addition of 8 M urea (S3), which disrupts hydrophobic interactions. The addition of 2-mercaptoethanol to S3 (S4) did not increase the protein solubility of surimi films, indicating that disulfide bonds were not involved in the formation of surimi films, irrespective of the surimi quality. It is known that MHC molecules contain about 40 sulfhydryl groups with almost no disulfide bonds (Roussel & Cheftel, 1990). Although inter-molecular disulfide bonds can be formed during drying of the protein solution, the presence of S–S bonds was not observed in the surimi films. From the above results, it was elucidated that hydrogen bonds and hydrophobic interactions, together with ionic

Table 5
Protein solubility (%) of surimi films prepared from Alaska pollack surimi in various extraction solutions[a,b]

Solutions	30 °C		
	0 min	20 min	5 h
S1	30.6 ± 3.0a	31.0 ± 2.1a	32.9 ± 3.4a
S2	57.7 ± 5.1a	56.9 ± 5.9a	44.9 ± 4.6b
S3	75.2 ± 4.7a	74.8 ± 5.2a	71.3 ± 4.1a
S4	75.7 ± 5.2a	75.4 ± 6.2a	72.0 ± 5.3a

[a] S1:0.6 M NaCl; S2:0.6 M NaCl + 1.5 M urea; S3:0.6 M NaCl + 8 M urea; S4:0.6 M NaCl + 8 M urea + 0.5 M 2-mercaptoethanol.

[b] Means ± standard deviation. Any two means in the same row followed by the same letter are not significantly different ($p > 0.05$).

bonds, played an important role in the formation of surimi films, and that the film-forming mechanism of the control and 20 min surimi films was quite different from the 5 h-surimi films. The hydrogen bonds were predominant interactions for the former films, whereas the hydrophobic interactions were predominant for the latter films.

4. Conclusion

Transparent and flexible edible films were successfully prepared from frozen Alaska pollack surimi, regardless of surimi quality. The mechanical properties, water vapour permeability, light transmission, transparency, film solubility, protein solubility, and enzymatic digestibility of surimi films were determined. The slight denaturation of proteins in surimi did not cause any changes of these properties, except the reduction of EAB, while the complete denaturation of proteins, brought about decreases of TS and EAB. The remaining properties were not significantly affected. The hydrophobic interactions played more important roles in the formation of films from surimi with complete protein denaturation than films from surimi without or only slight protein denaturation. The result of this study leads to more effective utilization of low quality surimi and land-processed surimi.

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