Effect of blend ratio and pH on the physical properties of edible composite films prepared from silver carp surimi and skin gelatin

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Revised: 22 September 2013 / Accepted: 30 September 2013 / Published online: 10 October 2013
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Abstract The effect of blend ratio and pH on the physical properties of surimi-gelatin composite films was investigated. Tensile strength (TS), film water solubility and soluble proteins of composite films increased with the increasing proportion of gelatin, while elongation at break (EAB) decreased. The TS of neutral films with the same ratio of surimi and gelatin were lowest, while increased at acidic or alkaline conditions. Similar tendency was also found in protein solubility and surface hydrophobicity of the film-forming solutions. On the other hand, the film water solubility and soluble proteins of neutral composite films were higher than those of acidic and alkaline films. Furthermore, it was revealed that the dissolved surimi and gelatin proteins could form strong composite films, which were insoluble in water. These results suggested that dissolved proteins were mainly involved in the formation of surimi-gelatin composite films.

Keywords Composite films · Edible films · Surimi · Skin gelatin · Silver carp

Introduction

Application of edible films to replace synthetic polymer films have been recently received increasing attention due to the environmental problems caused by massive use of synthetic packagings (Limpan et al. 2010; Ramos et al. 2012). Application of edible films is a novel choice for food packaging with the purpose of improving food quality and shelf life by controlling moisture, gas, aroma, and lipid diffusion. Edible films can be prepared from polysaccharides, proteins and lipids. Among these agricultural macromolecules, proteins have been empirically used as packaging materials mainly due to their abundance, biodegradability, film-forming ability and nutritional qualities (Park et al. 2002).

The freshwater fish production in China has been continuously increasing over the past decades and it reached 20.6 million tons in the year 2010, including 3.6 million tons of silver carp which is one of the main freshwater fish species cultured in China (Anonymous 2011). A large amount of raw materials are wasted during processing procedures, especially in the preparation of fish steaks, fillets and surimi. During fish processing, approximately 50 % of total weight of raw materials are considered to be underused byproducts, including skins, frames and trims which contain lots of fish meat, and are discarded directly or used as animal feeds. On the other hand, fisheries production appears to be close to the maximum ecosystem productivity. It cannot be increased substantially in the future and may decline because of mismanagement. Therefore, it is an urgent need to shift emphasis from increased production to effective utilization.

Recent studies have revealed that edible films could be prepared from fish sarcoplasmic proteins, myofibrillar proteins, surimi (Chinabark et al. 2007; Shiku et al. 2003; Tanaka et al. 2001) and fish skin gelatin (Jongjareonrak

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et al. 2006). A series of studies on the development of edible films from fish proteins have been intensively conducted, and a simple and easy way to prepare edible films from fish muscle or surimi was found (Tanaka et al. 2001; Shiku et al. 2003; Hamaguchi et al. 2007; Weng et al. 2007). Based on the results of these studies, strong fish protein films can be prepared from surimi by heating film-forming solutions (pH 3) at 70 °C, and the surimi films are formed mainly through hydrophobic interactions. On the other hand, gelatin has also been widely used as a source of edible films, because it is cheap, easy to extract and reduces the ecological problem (Bigi et al. 2001; Choi and Regenstein 2000). Compared with gelatin films, surimi films are better in resistant to water while having lower mechanical properties. Moreover, gelatin films exhibit higher water solubility mainly due to weak interactions involved in film matrix such as hydrogen bonds (Hoque et al. 2010). There are a little researches have been carried out to improve the properties of gelatin edible films, including thermal treatment (Hoque et al. 2010), chemical or enzyme treatment (de Carvalho and Grosso 2004), and blend technique (Cao et al. 2007). From these attempts, it was revealed that blend technique is a cheaper and effective approach and each component provides a determined property (Dong et al. 2006; Limpan et al. 2010; Pérez-Mateos et al. 2009). The physical properties prepared from soybean protein isolate or mungbean protein could be improved by incorporating fish skin gelatin (Denavi et al. 2009; Hoque et al. 2011). However, edible composite films based on fish surimi and gelatin have rarely been reported.

In this study, the preparation of edible composite films based on surimi and skin gelatin from silver carp was investigated, and the effect of blend ratio (10:0, 8:2, 6:4, 5:5, 4:6, 2:8 and 0:10) and pH (3, 7 and 10) on the physical properties of composite films was also examined.

Material and methods

Materials

Blocks (10 kg each) of frozen silver carp surimi (grade A) were obtained from Xiamen Huashun Minsheng Food Co. Ltd. (Fujian, China) and stored at −35 °C during the study. This surimi contained 14.8 % protein, 4 % sorbitol, 4 % sucrose and 77.0 % water. Silver carp skin gelatin powder prepared in our laboratory contained 85.8 % protein and 12.7 % water.

Preparation of the film-forming solutions and film coating

Surimi protein solutions were prepared according to the method described in our previous study (Weng et al. 2007) with minor modifications. The thawed surimi was homogenized on

ice using a high speed homogenizer (Fluko FA25; Shanghai, China) for 90 s to disperse completely. The pH of surimi solution was adjusted to 3.0 with 1 M HCl and heated in a water bath at 70 °C for 30 min. Following heat treatment, surimi solution was cooled in an ice bath and centrifuged at 6,000×g, 4 °C for 15 min. The protein content of the supernatant was determined by the Lowry method (Lowry et al. 1951) and final protein concentration was adjusted to 2 % (w/v) using distilled water. Plasticizer was not added since sorbitol and sucrose in the frozen surimi work as plasticizers to give enough flexibility for the surimi films. On the other hand, the gelatin powders were dissolved in distilled water at 60 °C for 30 min. After the concentration of gelatin solutions was also adjusted to 2 % (w/v), glycerol was added as a plasticizer at the concentration of 20 % (w/w) of protein.

Film-forming solutions were prepared from a blend solution of surimi solution with gelatin solution in different ratios (10:0, 8:2, 6:4, 5:5, 4:6, 2:8 and 0:10). Air bubbles of film-forming solutions were removed by a Hybrid Mixer (UM-113; Unix Co., Tokyo, Japan). The prepared film-forming solutions (4 g) were cast onto a rimmed silicone resin plate (50×50 mm²) setting on a level surface and dried at 25 °C and 50 % relative humidity (RH) for 24 h in an environmental chamber (PSX-330H; Laifu Technology Co., Ltd., Ningbo, China). After evaporation, resulted films were manually peeled off.

Additionally, the ratio of surimi:gelatin at 5:5 was chosen to estimate the influences of pH level. The pH of film-forming solutions was adjusted to 3, 7 and 10 using 1 M HCl or 1 M NaOH prior to the removal of air bubbles.

Film testing

Conditioning

Film samples were conditioned for 48 h before testing in the environment chamber at 25±0.5 °C and 50±5 % RH.

Film thickness

Five readings of each film sample were taken randomly using a micrometer (Thickness Gauge; Ozaki MFG Co., Tokyo, Japan). The final thickness of each film sample was calculated as an average of these reading values.

Mechanical properties

Tensile strength (TS) and elongation at break (EAB) were measured on a texture analyzer (TMS-PRO, Food Technology Co., America) with 100 N load cell according to the method of Shiku et al. (2003) with a minor modification. Three rectangular specimens (width, 15 mm; length, 45 mm) were cut from each film. The initial grip separation was set at 30 mm and cross-head speed was set at 60 mm/min. TS (N)

and EAB (%) were expressed by the maximum load (N) and elongation at the moment of rupture, respectively. A total of ten samples were tested for each film type.

Protein solubility in the film-forming solutions

Film-forming solutions of different pH (3, 7 and 10) were centrifuged (5,000×g, 20 °C) for 20 min, and the protein concentration of supernatant was measured by the Lowry method (Lowry et al. 1951). Protein solubility was calculated as a percentage of total protein in the film-forming solutions. All determinations were carried out at least in quintuplicate.

Surface hydrophobicity

Surface hydrophobicity of the film-forming solutions was determined as reported in our previous study (Weng et al. 2007) with a minor modification. The protein concentration of film-forming solutions was adjusted to 0.001 % (w/v) using distilled water, and a 40 µL of ANS solution (0.04 % in phosphate buffer, pH 7.0) was added to 4 mL of the dilute film-forming solutions. After incubation at 4 °C for 10 min, the mixture was put at ambient temperature (25 °C) for 15 min. The fluorescence intensities of the mixture were measured using a Fluorescence Spectrophotometer (FP-6200; JASCO Co., Tokyo, Japan) at wavelengths (λ_{ex} , λ_{em}) of 365 nm and 470 nm, respectively. Surface hydrophobicity was expressed as the fluorescence intensity relative to that of the film-forming solutions at pH 7.0.

Film water solubility and soluble proteins of films

Film water solubility and soluble proteins of films was measured using a method as described by Gennadios et al. (1998) with a slight modification. The conditioned film sample (5×5 cm) was weighed and immersed into 10 mL of distilled water in 50 mL conical flask containing 0.1 % (w/v) sodium azide to inhibit microbial growth. The conical flasks were covered and then shaken gently at 30 °C for 24 h. Undissolved film matter was dried at 105 °C for 24 h. The weight of solubilized dry matter was calculated by subtracting the weight of insolubilized dry matter from the initial weight of dry matter. The protein concentration was measured by the Lowry method (Lowry et al. 1951), and the soluble proteins were expressed as a percentage of total protein in the film.

Additionally, the protein compositions of composite films dissolved in the water were analyzed using SDS-PAGE.

SDS-PAGE

SDS-PAGE was performed according to the method of Laemmli (1970) using 4 % stacking gel and 8 % separating gel. Electrophoresis samples of soluble protein in film-forming

solutions were dissolved at buffer containing 1 % w/v SDS, 20 % v/v glycerol, 0.01 % w/v bromphenol blue, 50 mM Tris–HCl (pH 6.8). However, electrophoresis samples for films were prepared after dissolved in a solubilising solution (8 M urea, 2 % SDS, 20 mM Tris–HCl, pH 8.8) with or without β -mercaptoethanol (β -ME). Electrophoresis was performed at a constant current of 15 mA per gel. The resulted gels were stained with 0.025 % Coomassie Brilliant Blue R-250 (Merck, Darmstadt, Germany) in methanol/acetic acid/water (5:10:85 %, v/v/v), and destained in methanol/acetic acid/water (30:10:60 %, v/v/v). The standard protein marker (Fermentas Life Sciences, Hanover, MD, USA) ranged in molecular mass from 10–200 kDa.

Statistical analysis

Analysis of variance (ANOVA) was performed and mean comparison was carried out by Duncan's multiple range test (Steel and Torrie 1980). Analysis was performed using the SPSS package (SPSS statistics 17.0, SPSS Inc, Chicago, IL). Significance was defined as $P < 0.05$.

Results and discussion

Effects of blend ratio on the properties of composite films prepared from surimi-gelatin

The mechanical properties and solubility of edible composite films prepared from surimi and gelatin at different ratios are shown in Table 1. The TS and EAB of edible films based on silver carp surimi were 8.7 MPa and 193.9 %, respectively. This is lower than that of edible films prepared from Alaska pollack surimi without adding plasticizer (TS=12.5, EAB=59.6 %; Weng et al. 2009), probably due to differences in the type and grade of surimi. On the other hand, the TS of gelatin films from silver skin reached 35.6 MPa (Table 1), similar to the result as reported by Byun et al. (2012), who prepared edible films from warm-water fish gelatin with similar level of glycerol content compared with this study. It is interesting to note that the lower TS and higher EAB of surimi films than that of gelatin film. A similar trend was observed in the myofibrillar protein films (TS=15.2 MPa, EAB=27.6 %; Shiku et al. 2003) and fish skin gelatin films (TS=27.3 MPa, EAB=72.4 %; Limpisophon et al. 2009) at the same conditions of films preparation. It has been known that strong bonds such as disulfide bond are involved in stabilization of film matrix from surimi (Artharn et al. 2007), while hydrogen bond or hydrophobic interaction are the major bonds in gelatin films (Hoque et al. 2010). However, gelatins have linear structure and limited monomer composition (Simon-Lukasik and Ludescher 2004), resulting in excellent film-forming property. When gelatin was blended into surimi

Table 1 Tensile strength (TS), elongation at break (EAB), film water solubility (FWS) and soluble proteins (SP) of edible films prepared from surimi and gelatin at different ratios

Surimi:gelatin	10:0	8:2	6:4	5:5	4:6	2:8	0:10
TS ^x (MPa)	8.75±0.84 ^a	16.14±1.52 ^b	20.01±0.86 ^c	23.16±1.06 ^d	26.26±3.40 ^e	30.21±3.56 ^f	35.64±3.33 ^g
EAB ^x (%)	193.91±14.07 ^f	173.55±18.45 ^e	132.35±7.60 ^d	112.74±14.51 ^c	84.31±4.89 ^b	71.61±5.67 ^{ab}	58.15±9.54 ^a
FWS ^y (%)	31.42±0.89 ^a	39.35±0.17 ^b	43.69±1.15 ^c	42.86±0.68 ^c	48.20±2.08 ^d	64.56±5.78 ^e	100.00 ^f
SP ^y (%)	2.42±0.09 ^a	14.64±0.21 ^b	27.79±0.37 ^c	29.97±0.49 ^c	35.83±1.56 ^d	51.54±0.14 ^e	97.64±5.73 ^f

Any two means in the same row followed by the same letter are not significantly different ($p>0.05$)

^x Mean ± standard from ten determinations

^y Mean ± standard from five determinations

and edible composite films were prepared, the TS significantly increased with increasing proportion of gelatin (Table 1). Same phenomenon was reported in edible soy protein isolate films incorporated with bovine bone gelatin (Cao et al. 2007). However, Denavi et al. (2009) found that the blend films containing 25 % soy isolate protein and 75 % cod skin gelatin revealed the maximum strength, which was higher than that of the films made from gelatin alone. The mechanical properties in the TS of composite films from different sources or materials might be due to differences in type, nature, molecular weight, amino acid composition of proteins which involved in the film forming matrix (Hoque et al. 2011).

On the other hand, the EAB of films based on silver carp surimi alone was highest (Table 1). The EAB of composite films prepared from surimi and gelatin decreased with increasing the ratios of gelatin. Generally, EAB values, which indicate the ability of films' flexibility and extensibility, are

inversed to the TS. A similar tendency was also observed in this study (Table 1).

Film water solubility (FWS) can be viewed as measures of the water resistance and integrity of a film (Rhim et al. 2000). As can be seen from Table 1, the films prepared from surimi alone exhibited the lowest FWS than other films, but higher than that of the Alaska pollack surimi film which was approximately 21 % (Weng et al. 2007). In contrast, gelatin films dissolved in water completely, probably due to the high content of hydrogen bonds in the gelatin film matrix (Hoque et al. 2010). It is also obvious from Table 1 that FWS increased gradually with the increasing proportion of gelatin from 20–80 % in the composite films, while no significant changes were observed between 4:6 and 5:5 of surimi-gelatin blend ratio. It is of interest to notice that the solubility of the composite films containing 80 % gelatin is only half of that of the films prepared from gelatin alone. These results suggested that the protein network of surimi films is more stable

Fig. 1 Protein patterns of composite films prepared from surimi and gelatin at different ratios in the absence and the presence of β -mercaptoethanol (β -ME). *M* Standard molecular weight mixture

than that of gelatin films, and gelatin might be interacted with surimi protein or distributed evenly in the surimi protein network, resulting in the decreased aggregations of surimi protein chains.

Soluble proteins (SP) of films prepared from silver carp surimi were significantly lower than that of other films (Table 1). Although the SP of surimi films increased with the increasing proportion of gelatin, the SP of composite surimi-gelatin films was lower than the proportion of gelatin, which was dissolved in the water completely despite they formed films. The results suggested that the main associative forces involved in composite surimi-gelatin films could come from surimi protein, which may form intermolecular covalent bonding with secondary hydrophobic interactions, as was pointed out by Rangavajhyala et al. (1997), Rhim et al. (2000) and Choi and Han (2002), resulting in decreased film solubility.

SDS-PAGE patterns of protein subunits in films were determined and shown in Fig. 1. In the case of edible films prepared from surimi alone, an abundant of high molecular weight fractions (HMWF) were observed, except for the myosin heavy chain (MHC, 200 kDa) and actin (around 40 kDa) which represent 60 % and 20 % respectively of myofibrillar proteins (Schwartz and Bird 1977), while low molecular weight fractions between 30 kDa and 40 kDa was also observed. In contrast, the protein subunits of γ , β , α_1 and α_2 were observed in the protein composition of films prepared from skin gelatin alone. Furthermore, in the composite films, the intensity of protein subunit bands varied from surimi protein to gelatin protein with increasing the proportion of gelatin. Compared to the films made from surimi, gelatin films had less HMWF which was too large to enter the polyacrylamide gel. However, gelatin films had stronger strength than surimi films, probably due to higher amount of cryoprotectants in the surimi, which act as plasticizer.

On the other hand, a marked increase in intensity of MHC and actin bands in surimi or composite films was observed at the SDS-PAGE patterns with the presence of β -ME, while protein patterns of gelatin films were not changed (Fig. 1). This suggested that disulfide bonds were involved in the films containing surimi protein, which might contribute to the FWS and SP of films (Table 1).

From the above results it is concluded that edible composite films prepared from surimi and gelatin can improve their mechanical properties and water resistance. However, the interaction of surimi protein and gelatin in the composite films was hardly observed by electrophoresis studies, suggesting that the dissolved surimi and gelatin protein might play an important role during film formation by hydrophobic interactions. It has been reported that the mechanical properties of protein films could be improved by increasing protein solubility in the film-forming solutions (Weng et al. 2007). In general, the solubility of protein, especially myofibrillar proteins, could be increased via

Table 2 Protein solubility and surface hydrophobicity in the film-forming solutions of composite films prepared from surimi and gelatin at different pH

pH	3	7	10
Protein solubility (%)	95.00 $\pm$ 3.54 ^c	38.47 $\pm$ 5.18 ^a	83.66 $\pm$ 6.09 ^b
Surface hydrophobicity (relative value)	3.58 $\pm$ 0.22 ^c	1.00 ^a	2.60 $\pm$ 0.14 ^b

Any two means in the same row followed by the same letter are not significantly different ($p > 0.05$)

Values are mean $\pm$ standard from five determinations

adjusting the pH value of film-forming solutions, resulting in improved film strength significantly (Limpan et al. 2010; Shiku et al. 2003). Therefore, in the next attempt of this study, the ratio of the surimi/gelatin at 5/5 was chosen to further reveal influence factors on the properties of composite films.

Effects of pH on the properties of composite films prepared from surimi-gelatin

The protein solubility and surface hydrophobicity in the film-forming solutions at different pH were determined and shown in Table 2. The solubility of protein in the film-forming solutions prepared from surimi and gelatin at pH 7 was about 38 %, but their solubility increased at pH 3 or pH 10 to around 95 % or 83 %, respectively. Similar trend had been reported in the solubility of Alaska pollack surimi (Weng et al. 2007), while gelatin protein was almost dissolve in distilled water

Fig. 2 SDS-PAGE of dissolved proteins in the film-forming solutions prepared from surimi and gelatin at different pH. S Surimi; G Gelatin; B Blend of surimi and gelatin; M Standard molecular weight mixture

Table 3 Tensile strength (TS), elongation at break (EAB), film water solubility (FWS) and soluble proteins (SP) of composite films prepared from surimi and gelatin at different pH

pH	3	7	10
TS ^x (MPa)	24.20±1.15 ^b	19.14±1.93 ^a	30.25±1.90 ^c
EAB ^x (%)	83.56±9.07 ^c	50.93±3.74 ^a	71.11±10.64 ^b
FWS ^y (%)	46.00±1.14 ^b	74.59±0.39 ^c	32.62±3.18 ^a
SP ^y (%)	57.68±2.80 ^b	69.85±4.01 ^c	53.63±1.76 ^a

Any two means in the same row followed by the same letter are not significantly different ($p > 0.05$)

^x Mean ± standard from ten determinations

^y Mean ± standard from five determinations

irrespective of pH (Benjakul et al. 2009). Consequently, the protein solubility of the composite film-forming solutions might be mainly contributed to surimi protein solubility. Moreover, the protein molecules in film-forming solutions under acidic and alkaline conditions were partially unfolded due to the exposed hydrophobic groups of protein (Hamaguchi et al. 2007). Thus, the surface hydrophobicity of proteins in the film-forming solutions prepared from surimi and gelatin at different pH was measured, and a similar trend was observed (Table 2). These results may suggest that when pH of film-forming solutions was adjusted to acidic or alkaline

condition, the proteins were caused to unfold, thus involving in the film formation.

To examine the protein composition dissolved in the film-forming solutions, SDS-PAGE patterns of protein subunits were determined (Fig. 2). When the composite film-forming solutions were prepared at pH 3, it was found that the protein components were mainly from surimi and gelatin. Furthermore, the protein subunits of dissolved surimi, gelatin or surimi/gelatin (Fig. 2), were mostly analogous to those of film with the presence of β -ME (Fig. 1), indicating that unfolded surimi proteins and gelatin proteins were interacted each other to form composite films partly through disulfide bonds during the drying phase of film preparation. Similar result was also observed in the composite films prepared at pH 10, but the interaction seemed to occur partially in the film-forming solutions since the HMWF which entered the polyacrylamide gel reduced, actin and tropomyosin (TM, 35 kDa; Cao et al. 2004) disappeared (Fig. 2). This is due to cross-linking in the proteins of MHC, actin and TM, and it was comparable to similar studies based on tilapia kamaboko which had been pretreated under alkaline conditions (Rawdkuen et al. 2009). At pH 7, individual surimi proteins with TM were major proteins in the SDS-PAGE. On the other hand, the gelatin protein patterns were similar to that of pH 3, but the HMWF was less than that of pH 3.

After water was evaporated from the surface of film-forming solutions, resulted films were peeled off and their TS and EAB were determined (Table 3). The TS of composite films prepared at pH 7 was lower than that of samples from other pH, since MHC of surimi was hardly dissolved and they might be retarded to form strong composite films from

Fig. 3 SDS-PAGE of dissolved proteins in the water from composite surimi-gelatin films prepared at different pH. *M* Standard molecular weight mixture **Fig. 4** Protein patterns of composite films prepared from surimi and gelatin in the absence and the presence of β -mercaptoethanol (β -ME). *M* Standard molecular weight mixture

dissolved surimi proteins and gelatin proteins (Fig. 2). Similar result was reported by Shiku et al. (2003) who made myofibrillar protein films at pH from 2–12. On the other hand, the highest TS of composite films prepared at pH 10 were observed. It did not agree with the result of surimi protein films (Chinabhark et al. 2007) and fish muscle protein films (Hamaguchi et al. 2007), which had similar TS at extreme acidic and alkaline conditions. The result was probably caused by the effect of pH on gelatin films, which has now been studied in our laboratory.

On the other hand, the tendency of high EAB in proportion to low TS was observed at pH 3 and pH 10, while both EAB and TS were lowest at pH 7, further suggesting that mechanical properties of composite films from surimi and gelatin might relate to the protein solubility extent in film-forming solutions.

In order to confirm the cohesive network of composite film prepared at different pH, the water resistance and integrity of these films were determined through measuring their FWS and SP (Table 3). The composite films prepared at pH 10 had the lowest FWS among these films, while the highest FWS about 75 % was observed when they prepared at pH 7. It is quite apparent from these results that the film matrix prepared from pH 10 was more cohesive than that of pH 7. A similar result was observed in the SP of films, probably due to undissolved proteins in the film-forming solutions which are difficult to form film matrix. This was confirmed by SDS-PAGE patterns of protein components dissolved in the water from composite films shaken gently and continuously at 30 °C for 24 h (Fig. 3). The band intensity of HMWF in neutral films (pH 7) was higher than that in acidic films (pH 3), while there was no HMWF band observed in alkaline films (pH 10), indicating that the dissolved proteins in film-forming solutions could increase the density of network structure of composite films, especially under alkaline conditions. From these observations (Fig. 3) together with protein solubility in film-forming solutions (Table 2), it was suggested that the composite surimi and gelatin film network structure was formed by random aggregation of dissolved proteins into clusters, which could form strong film matrix during drying phase, thus improved their mechanical properties.

Figure 4 depicts SDS-PAGE patterns of composite surimi and gelatin protein films in the absence and presence of β -ME. In the case of composite films prepared at acidic and alkaline conditions, the protein compositions in the formed films (Fig. 4) were quite similar to that of dissolved in the film-forming solutions (Fig. 2), indicating the cross-linking reactions between surimi and gelatin could hardly take place during film formation. On the other hand, the protein compositions of the films prepared irrespective of pH were almost identical (Fig. 4), but the main proteins dissolved under neutral pH condition were different as mentioned above, further indicating that undissolved proteins were also involved into film formation, thus decreased the mechanical properties of

films (Table 3). Furthermore, the bands intensity of HMWF on the top of SDS-PAGE decreased significantly in the presence of β -ME, concomitant with the bands intensity of MHC, actin and TM increased, suggesting that the HMWF came from surimi proteins in the composite films, and aggregated via disulfide bonds.

Conclusions

The edible films were successfully prepared and characterized from surimi or skin gelatin of silver carp in this study. As a result, the TS of gelatin films were stronger than that of surimi films, while the water resistant properties of gelatin films were poorer. The edible composite films could be formed by combining surimi with gelatin, and their poor physical properties were improved. However, it was revealed from SDS-PAGE patterns that there was no polymerization between surimi proteins and gelatin proteins occurred in the composite films. Furthermore, the effect of pH on surimi-gelatin composite film properties was determined. The composite films of surimi and gelatin could be formed irrespective of pH, and they became stronger under acidic or alkaline conditions. It was found that dissolved proteins were mainly involved in the formation of surimi-gelatin films, especially surimi proteins.

Acknowledgments This work is sponsored by Program for New Century Excellent Talents in University of Fujian Province (JA11143), National Natural Science Fund (31271984), and Xiamen Science and Technology Project (3502Z20123025).

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