INTRODUCTION

Recently, the hot preparation of surimi products, commercially referred to as Tokyo-style stew or eden, has become popular in Taiwan. These products must be kept in heated water at around 70°C during selling. Since surimi gels become rubbery and soft during reheating, the texture of such products is thus an important quality indicator. However, a change in rheological behavior is a concern for surimi products with a long cooking period.

Utilization of dark-fleshed, fatty fish has been minimal in comparison to that of lean species, although small-scale commercial production has existed for some time in Taiwan. Most of the surimi prepared from horse mackerel has been used to make low-priced traditional products because of the weak gelation and undesirable color and flavor. Chen and Lee attempted to improve the gel-forming ability of horse mackerel surimi by decreasing its water content, which increased myofibril concentration and the cross-link density of the protein network in surimi gel. Although the gel strength increased considerably, cooking tolerance was not improved.

Curdlan gum has been used as a key ingredient in Tokyo-style stew products to increase their cooking tolerance. An aqueous suspension of curdlan forms a thermo-irreversible gel at 80°C or higher. However, such products exhibit different texture, and are more firm and inflexible than the traditional surimi products. To maintain high-quality texture, food-grade protein additives have been used in surimi formulations. Lee et al. reported that when egg white and soybean protein isolate are added to surimi as gelation aids, they do not contribute to the formation of the protein network of kamaboko gel. However, it is not known whether the non-muscle proteins interact directly or indirectly with myofibrillar protein during the formation of the gel network. The main objective of this study was to clarify thermogelation aid by analyzing the temperature dependence and dynamic rigidity of horse mackerel surimi with added non-muscle proteins, as well as to consider the gel strength and color changes of heated surimi (kamaboko) during cooking under 70°C.

Original Article

Effect of non-muscle protein on the thermogelation of horse mackerel surimi and the resultant cooking tolerance of kamaboko

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SUMMARY: Four kinds of non-muscle proteins, including liquid egg white, plasma protein concentrate, wheat gluten and whey protein concentrate were added as gelation aid materials to horse mackerel surimi. Decrease in on-set temperature of first heat gelation and resolution degree were observed in the surimi containing these non-muscle proteins. Addition of plasma protein clearly increased the surimi rigidity, reflecting its excellent thermogelation ability. Addition of the proteins also enhanced the gel strength and cooking tolerance of heated surimi products (kamaboko). Plasma protein effectively increased the gel strength of kamaboko, giving a firm and elastic gel, which still had high gel strength in cooking under 70°C. Addition of the proteins also inhibited the browning of kamaboko during cooking.

KEY WORDS: cooking tolerance, egg white, horse mackerel, plasma protein, surimi, wheat gluten, whey protein.

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MATERIALS AND METHODS

Materials

Frozen horse mackerel (Trachurus japonicus) was purchased from Cheer-Foods Enterprise Co. Ltd. (I-Lan, ROC). The fish block (10 kg), previously frozen for 2 months at -20°C, was thawed at 25°C for 24 h. The ordinary muscles were collected from the thawed fish and then squeezed through a 3 mm diameter sieve.

Non-muscle proteins

Liquid egg white (LEW) was prepared from fresh egg purchased at the local market in I-Lan. Whey protein concentrate (WPC, TY-WP005) was purchased from Toong Yeuan Enterprise Co., Ltd (Taipei, ROC). Wheat gluten (WG) and plasma protein concentrate (PPC, AMP 600N) were purchased from Yih-Yuan Food Additives Co., Ltd (Taipei, ROC). The LEW was added to obtain eventual concentrations of 0.25, 0.5, 1, 2 and 4% in the surimi. The other protein flours were weighed and adjusted to 5, 10, 15 and 20% in the surimi. The water content of all the surimi was adjusted to 80%.

Preparation of gel

Surimi was prepared as described in a previous paper. The mince was placed in a beaker and washed, with a water/mince ratio of 5:1. The mince was washed for three cycles with cold distilled water under 100 rpm rotation (Stirrer-PC320; Corning Co. Ltd., NY, USA). NaCl was added to the wash water in the third cycle to give a final salt concentration of 0.25%. The washed mince was centrifuged at 1800 rpm for 1 min. Moisture of the dewatered mince was determined with an infrared drying moisture meter (YST-YL-1; Kao Shing Enterprise Co. Ltd., Chang-Wha, ROC) and adjusted. About 500 g mince was then chopped in a Stephan vertical vacuum cutter (Model UM 5 Universal; Stephan Machinery Co., Germany) with a circulating chiller to keep samples at below 10°C. Mince was first chopped for 1 min at low speed (1600 rpm). Salt equivalent to 2.5% weight of the mince and the protein solution were added. And then, the mince was chopped at high speed (3200 rpm) for another 2 min under vacuum at ~600 mmHg.

The kamaboko was prepared by injecting the surimi into a polyvinylidene chloride casing 10 cm in circumference, 15 cm in length and by heating it at 85°C for 30 min. The kamaboko was then immediately cooled with cold water and kept at 4°C overnight before cooking tolerance tests and measurement of physical properties were conducted.

Cooking tolerance model test

Kamaboko was cut into 3 mm and 30 mm sections for color and gel strength measurement, respectively. Six slices of each were cooked at 70°C for 0.5, 1, 2, 4 and 8 h in a temperature-controlled water bath. The gel strength and color of cooked specimens were measured immediately before the temperature dropped to 65°C.

Measurement of physical properties

The rigidity of surimi was measured in a thermal scanning rigidity monitor (TSRM) assembled as previously described. Briefly, the surimi was pasted evenly in a testing cell to 5 cm in height. The blade (adapter No. 24 of the SUN RHEOMETER CR-150; Sun Scientific Co., Ltd., Tokyo, Japan) was moved by 1 mm within surimi at 2°C intervals. Temperature was scanned at 1.5°C/min over the range 15–90°C. The rigidity of surimi was then calculated according to Hamann et al. and Sue et al.:\[ R = (F/A)/(D/T) = F \times T/(2L \times W \times D) \]

where R was the rigidity (N/m²), F the pulling force (kgw) applied to specimen, A the contact area (m²) between blade and specimen, D the moving distance (m) of the blade, T the thickness (m) of specimen, and L and W the depth and width (m) of the blade in contact with the specimen.

According to Chen and Lee, the gel strength of 30 mm thick kamaboko was determined by the above rheometer by pressing a 5 mm diameter spherical head plunger into one end of each sample at 60 mm/min deformation rate. The gel strength was calculated as: \[ B \times D \]

where B represented breaking force (gw) and D deformation (cm). The mean value of six replicates was determined.

The color of 3 mm slice specimens was measured with a color difference meter (JP7200F; Juki Co. Ltd., Tokyo, Japan) and standardized with a calibration white plate (X = 82.48, Y = 84.23, Z = 99.61; L* = 93.55, a* = -0.22, b* = -0.01). Tristimulus color coordinates were used to measure the degree of lightness (L*), redness (+a*) or greenness (-a*), and yellowness (+b*) or blueness (-b*). Whiteness was calculated by the equation:

\[ 100 - \left[ (100 - L^*)^2 + a^*^2 + b^*^2 \right]^{1/2}. \]

RESULTS AND DISCUSSION

Thermogelation properties

Multistage changes of rigidity were observed in horse mackerel surimi as temperature increased (Fig. 1). An
addition of four kinds of non-muscle proteins reinforced surimi rigidity. Four distinct stages, 20–40°C, 40–54°C, 54–64°C and higher than 64°C, were observed in the TSRM curve of surimi without the addition of proteins. At the first stage, rigidity decreased with temperature increase, possibly caused by softening of surimi. Rigidity increased at the second stage but decreased at the third stage, the former due to the heat gelation and the latter owing to the resolution of surimi gel around 60°C. A rapid increase of rigidity was observed at the fourth stage caused by the second heat gelation. The first, second and third break-points of TSRM curves were the on-set temperature of first heat gelation ($T_1$), gel resolution ($T_2$) and the second heat gelation ($T_3$), respectively.

The surimi containing 10% LEW showed the highest rigidity among the surimi containing various amounts of LEW, and $T_1$, $T_2$ and $T_3$ shifted to lower temperatures. The rigidity decrease in surimi was diminished during the gel resolution stage (from $T_2$ to $T_3$) (Fig. 1a). This phenomenon indicated that the addition of LEW reinforced the rigidity of horse mackerel surimi, lowered the on-set temperatures of first heat gelation and gel resolution, and also lowered resolution degree.

The rigidity increased with increase in PPC (Fig. 1b). For the lower addition level, 0.5% or 1.0%, the $T_1$ shifted to lower temperatures but the $T_2$ and $T_3$ shifted to higher temperatures in the TSRM curves. This suggested that the lower addition level of PPC lowered the on-set temperatures of first heat gelation and gel resolution, and also lowered the resolution degree. For the higher addition level, 1.5% or 2.0%, the rigidity decreased gradually up to 70°C but increased rapidly thereafter. This suggested that the higher addition level noticeably reinforced the rigidity of horse mackerel surimi which overcame the first heat gelation. However, the high rigidity of PPC-added surimi was maintained presumably due to a strong mixed protein network caused by the aggregated gel structure, and was available at a lower temperature.

The rigidity increased with increase in WG (Fig. 1c). The TSRM curves showed a similar pattern to that of LEW-added surimi. Although the addition of WG as a gelation aid increased the rigidity of horse mackerel surimi and lowered the on-set temperature of first heat gelation and extended the gelation process, the TSRM curves showed a similar pattern to that of surimi without WG.

When WPC was added to surimi, $T_1$ shifted to lower temperatures but $T_2$ and $T_3$ shifted to higher temperatures in TSRM curves, extending the first heat gelation temperature range (Fig. 1d). This suggested that such reactions of WPC contributed to the gelation of horse mackerel surimi within 30 to 60°C and delayed the on-set temperature of gel resolution and the second heat gelation.

Overall, the effects of the four kinds of non-muscle proteins on surimi rigidity varied in the TSRM curves. They all reinforced rigidity and lowered the on-set temperature of first heat gelation and diminished the rigidity reduction caused by the resolution. Since the surimi rigidity increased at higher temperature, it was clear that...
these proteins improved thermogelation in horse mackeral surimi, especially the PPC.

Cooking tolerant properties

The gel strength of kamaboko without the gelation aid was not detectable when the specimen was cooked for longer than 0.5 h at 70°C, whereas, the gel strength of kamaboko with non-muscle proteins was detectable throughout the cooking time, the only exception being with the addition of 5% of LEW (Fig. 2).

When LEW was added at 10% level in surimi, the highest gel strength was kept during cooking for the surimi containing various amounts of LEW, thus giving the highest cooking tolerance (Fig. 2a). The main reason for the increase in gel strength of LEW-added kamaboko is the increase in deformation (Table 1). Lee et al. reported that the egg white displayed protease inhibitory effects for preventing gel softening of surimi gels. However, egg white forms the soft gel after heating. The overuse of egg white may destroy the original protein network of surimi and result in an undesirable texture in heated surimi products.

Addition of PPC also increased gel strength of kamaboko. When the addition level was 2%, kamaboko had 1183.3 gw·cm gel strength. Although the gel strength decreased when cooking time was extended, kamaboko still had high gel strength above 600 gw·cm after 8 h of cooking (Fig. 2b). Plasma protein contains fibrinogen, serum albumin, serum globulin and stroma proteins. The gel strength of heated mixed gel from fibrinogen and myosin is higher than that of the sum of separate fibrinogen and myosin. This synergistic effect reflects the gelation caused by the interaction of fibrinogen and myosin molecules with non-covalent and disulfide bindings. Serum albumin is a protein with good gelling property. Both disulfide bonds and β-structure contribute to gel forming of bovine serum albumin (BSA) on the alkaline side of the isoelectric point, and the gel-forming temperature decreases with an increase in the protein concentration. Furthermore, BSA will aggregate with other proteins by disulfide bonds and form strong gel. Park reported that the addition of beef plasma protein to Alaska pollock surimi increased its shear stress and shear strain and made the gel tougher.

The main reason for increase in gel strength in WG- or WPC-added kamaboko is the increase in breaking force (Table 1). The WG prepared from washed dough forms the protein matrix, with low water holding capacity and acts as functional filler in surimi gel.

Table 1  Breaking force and deformation changes during gel strength measurement of non-muscle proteins added to kamaboko

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<th>LEW</th>
<th>PPC</th>
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<tr>
<td>Breaking force</td>
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<td>Deformation</td>
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○, –20% to 20%; +, 20% to 50%; ++, above 50%. LEW, liquid egg white; PPC, plasma protein concentrate; WG, wheat gluten; WP, whey protein.

![Fig. 2](image-url)  The gel strength change of kamaboko with (a) liquid egg white (LEW), (b) plasma protein concentrate, (c) wheat gluten and (d) whey protein concentrate during 70°C cooking.
Fig. 3  The color change of kamaboko with (a) liquid egg white (lew), (b) plasma protein concentrate (ppc), (c) wheat gluten (wg) and (d) whey protein concentrate (wpc) during 70°C cooking.
aliphatic hydrophobicity of unfold protein, as well as the sum of sulfhydryl and disulfide groups, has been shown to correlate with the thermogelation properties of whey protein. An addition of WG or WPC generally reduces the firmness of surimi gel caused by the low water-binding ability that resulted in a weak gel. However, with an increase in the addition level, lower reduction of gel strength after extended cooking time was observed.

The texture modification by non-muscle proteins was illustrated as a function of breaking force and deformation. The addition of WG or WPC made the gels more brittle. However, PPC and LEW appeared to improve the binding functionality (deformation) of surimi through protein–protein interactions. Hamann and Park also reported that deformation (i.e., strain), as an indicator of protein interactions, was strongly affected by protein functionality. Although the proteins-added kamaboko exhibited various textures, gel strength was improved regardless of cooking. This confirms that the non-muscle proteins improved cooking tolerance.

Color changes

The lightness ($L^*$) and whiteness of kamaboko increased within 0.5 h after cooking and then decreased slightly (Fig. 3). The greenness ($-a^*$) decreased while yellowness ($+b^*$) increased gradually. Addition of LEW to kamaboko increased its lightness and whiteness but reduced its greenness and yellowness (Fig. 3a). Reduction of lightness and whiteness was observed when the other proteins were added, while the lightness and whiteness of kamaboko increased within 0.5 h after cooking and then decreased. However, after 5 h of cooking, the lightness and whiteness of PPC-added kamaboko were still higher than those of kamaboko without the addition (Fig. 3b–d). The yellowness of proteins-added kamaboko was lower than that of kamaboko without the addition when cooking time was extended. It is suggested that the non-muscle proteins promoted the water-holding capacity of surimi products, thus diminishing browning during cooking.

CONCLUSIONS

The non-muscle proteins reinforced thermogelation of horse mackerel surimi and cooking tolerance of kamaboko, as well as diminished browning during cooking. In particular, the consistency of rigidity and gel strength indicated that plasma protein prevented surimi gel from becoming rubbery or soft during cooking. The plasma protein acted as very functional binders in surimi and formed a tougher texture in kamaboko. Plasma protein has the potential to replace egg white or starch as a gelation aid in surimi products.

REFERENCES