Comparison of Gel Properties of Surimi from Alaska Pollock and Three Freshwater Fish Species: Effects of Thermal Processing and Protein Concentration

Y.K. Luo, R. Kuwahara, M. Kaneniwa, Y. Murata, and M. Yokoyama

ABSTRACT: The gel strength of surimi made from Alaska pollock, common carp, grass carp, and silver carp was determined and compared for different incubation temperatures and periods. Gel strength and setting of the 3 freshwater fish species were inferior to that of Alaska pollock. Effects of the protein concentration, heating temperature and heating period on the gel strength were evaluated and compared utilizing the response surface methodology. Models for the breaking force and breaking distance of the surimi of the 4 species were established. Protein concentration was the major factor affecting the gel strength. Effects of heating temperature and heating period had differed somewhat among the surimi of the 4 species.

Key Words: gel strength, setting, protein concentration, heating temperature, heating period.
pan. Grass carp (Ctenopharyngodon idellus; body length: 82.6 ± 4.5 cm; weight: 8.3 ± 1.4 kg) were purchased from the Fisheries Association Community in Saitama Prefecture, Japan. Silver carp (hypophthalmichthys molitrix; body length: 83.9 ± 4.5 cm; weight: 10.5 ± 1.8 kg) were provided by the Ibaraki Prefecture Fisheries Association Community at Kasumigaura Lake, Japan. The 3 species freshwater fishes were transported live to the laboratory. The beheaded and gutted common carp, silver carp, grass carp were washed with water, then filleted (only white muscle was used) by hand and washed. Fillets were minced using a mincer (K-4, Fuji Electric Co., Ltd. Japan). The minced muscle was washed 4 times (firstly, twice with distilled water, secondly, twice with 0.3% NaCl (each time for 15 min) at about 4 °C with a solution/fish mince ratio of 4 (v/w). Final dewatering was carried out in a pressing machine (Bibun Co., Ltd., Japan). Sorbitol (4 g), sucrose (4 g) and polyphosphate (0.3 g) were added per 100 g of the dewatered mince as cryoprotective agents, mixing for 5 min in a silent cutter (Bibun Co., Ltd. Japan) at a temperature below 10 °C. These surimi were kept frozen at −40 °C until used in the experiments.

Moisture and total nitrogen content of these surimi were determined using standard oven and Kjeldalh procedures (AOAC, 1984). Moisture and protein content (% total nitrogen × 6.25) of Alaska pollock surimi were 74.26 ± 0.25% (mean ± standard deviation) and 17.20 ± 0.26%, respectively. The other surimi were 72.5 ± 0.32% and 16.68 ± 0.3% for silver carp, 75.6 ± 0.26% and 15.2 ± 0.19% for grass carp, 77.6 ± 0.21% and 13.4 ± 0.18% for common carp.

Preparation of gels
Frozen surimi was thawed at room temperature for 1 h and cut into small pieces (about 2.5 cm cubes). Surimi cubes were placed in a vertical vacuum cutter (Model UMC 5E, Stephan Machinery Co., Hameln, Germany) connected with a Sibata constant temperature circulating chiller (Model C-503; Sibata Instruments, Japan). The surimi was chopped for 2 min. Salt (2.5% w/w) and ice water (final protein concentration of surimi pastes was adjusted according to the experimental design) was added and chopping was continued for 5 min. The paste was chopped under vacuum for 2 min to remove any air pockets in the surimi paste. The temperature was maintained below 10 °C.

The paste was stuffed into vinylidene chloride casings (30 cm length, 3 cm diameter, Kureha Chemical Industry Co., Ltd. Japan) and incubated in water baths for setting (incubating period and temperature according to experimental design). After incubating, the surimi was heated in an agitating water bath (heating temperature and time according to the experimental design). After heating, the gel was cooled immediately to stop any further action of the heat in iced water for 60 min. Gel strength tests were carried out within a day of gel production.

Gel strength measurement
The heat-induced gels were cut into 3 cm height cylindrical specimens. The breaking force and breaking distance were determined with a 5.0 mm diameter spherical head plunger to press into one end of each specimen by a rheometer (Rheometer NR M-2002, Fudoh Industry Co., Ltd., Tokyo). The speed of the sample table was maintained in an upper direction at a rate of 6 cm/min. Each measurement was replicated 4 times.

Experimental design and statistical analysis
To examine the effect of incubation temperature and period on the texture of the gels, the protein concentration was fixed at 13.4% in each surimi. Five incubation temperatures (30, 35, 40, 45, and 50 °C) and three incubating periods (30, 60, 120 min) were used. After incubation, all treatments were heated at 85 °C for 30 min.

Response surface methodology (RSM) was used to study the effect of protein concentration, heating temperature, and heating period on the gel strength. Two-stage heating was used for all treatments and the optimal incubation conditions were selected according to the first experimental result. Namely for Alaska pollock surimi: 35 °C, 30 min; common carp surimi: 35 °C, 60 min (the breaking force of 35 °C, for 60 min incubation was significantly higher than that of no incubation, not significantly different with that of 35 °C for 120 min incubation); grass carp surimi: 40 °C, 30 min; silver carp surimi: 35 °C, 60 min. The experimental design adopted 3 factors [protein concentration (X1), heating temperature (X2) and heating period (X3)], 5 levels central composite rotatable design (Hinchken 1968). The coded values of the independent variables (−1.68, −1, 0, 1, 1.68) were calculated according to a rotatable design (Gacula and Singh 1984). Correspondence between these coded values and actual values are given in Table 1. The complete design consisted of 23 experimental points that included 9 replications of the center point. The 2 dependent Y variables to evaluate the gel properties were breaking force and breaking distance.

To estimate the effect of the incubation step on breaking force and distance, the analysis of variance (ANOVA) procedure of Microsoft Excel (Microsoft Corp 1997) was used to determine the difference. A significance level of P < 0.05 was chosen for all statistical analyses. Four replications were used for texture measurements.

Data were analyzed by response surface regression (IMP 3.2, SAS Institute Inc., 1999) to fit the following second-order polynomial to all dependent Y variables:

\[
Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} \sum_{i=j}^{k} b_{ij} X_i X_j
\]

Here \(b_0, b_i, b_{ij}\) and \(b_{ij}\) are constant and regression coefficients of the model \(b_0\) for \(X_0\) (constant), \(b_i\) for linear terms, \(b_{ij}\) for quadratic terms, \(b_{ij}\) for interaction terms. \(X_i\) are the independent variables in coded values. The significance of the equation parameters for each response variable was assessed using the F-test to check the reliability of the model. The level of significance was defined at \(P < 0.05\). Three-dimensional response surface plots were generated using Mathcad software (Mathsoft, Inc. USA) to illustrate the main effects of the independent variables on the gel strength.

Results and Discussion

Influence of various incubation temperatures and periods on the texture of the gels
The breaking force of Alaska pollock surimi at 30-45 °C for 30 min incubation was significantly higher (\(P < 0.05\)) than that of no incubation (direct heating at 85 °C for 30 min) (Figure 1). The breaking forces of surimi incubated at 30 °C and 35 °C were higher (\(P < 0.05\)) than that of other temperature incubations for 30-120 min. For 30 °C surimi, after 120 min incubation the model was significantly higher than that of the other incubation temperature. In surimi from Alaska pollock, similar phenomena have been observed in other studies (Shimizu and others 1981; Niwa and
The breaking force of 50 °C incubation was lower (P < 0.05) than for other temperatures, and decreased as the incubation period increased, and was significantly lower (P < 0.05) at 60 and 120 min incubation than for no incubation. The effect of incubation period on the breaking distance was determined at various temperatures (Figure 2). The trends observed for the breaking distance of Alaska pollock surimi were similar to the trends observed for the breaking force.

For 30 min incubations, the breaking force of common carp surimi gel had no significant difference for incubation temperatures increasing from 30 to 50 °C (Figure 1). The breaking force increased with increased incubation period at 30 and 35 °C, but decreased with incubation period increasing at 40, 45 and 50 °C. After 120 min incubation, the breaking force of the 30 and 35 °C incubations was 50 °C was significantly higher (P < 0.05) than no incubation and other temperature incubations, but the breaking force of 40, 45 and 50 °C incubation were inferior to that of no incubation. The trends observed for the breaking distance of common carp surimi were also similar to those of the breaking force (Figure 2).

<table>
<thead>
<tr>
<th>Table 1—Response of dependent variables to the gelation conditions</th>
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<tbody>
<tr>
<td>Independent Variables</td>
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<tr>
<td><strong>Protein concentration</strong> (g kg⁻¹)</td>
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<tr>
<td>1</td>
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<td>23</td>
</tr>
</tbody>
</table>

* Values in parentheses are the coded levels of independent variables.

Figure 1—Effects of incubation time on the breaking force of Alaska pollock, common carp, grass carp and silver carp surimi at various incubation temperatures (breaking force was determined after heating at 85 °C for 30 min)
Little difference was detected in the breaking force of grass carp at 30 °C incubation regardless of incubation period (Figure 1). The breaking force of grass carp surimi increased and the declined with incubation period extended for the 35-50 °C incubation. Incubation of 40 °C and 30 min was the optimal setting condition, and the breaking force was significantly higher (P < 0.05) than for no incubation. In Figure 2, the breaking distance of grass carp was not significantly different within the experimental parameters. The results show the grass carp belonged to difficult-disintegrating group (Shimizu and others 1981).

The breaking force of silver carp surimi for 30 °C incubation was not significantly different within the 120 min period (Figure 1). The breaking force of the 50 °C incubation decreased as the incubation period increased, and was significantly less (P < 0.05) than that of no incubation after 120 min of incubation. At the initial stage, the breaking force of the 35 °C and 40 °C incubations gradually increased as the incubation period increased, and reached a peak at 60 min and then decreased as the incubation period increased. In Figure 2, the breaking distance of silver carp significantly decreased with the increase of incubation period at 50 °C. At 30-40 °C incubation, there was no significant difference within 120 min.

Since the work of Ferry (1948), it has been generally accepted that the formation of a heat-induced gel requires the denaturation of the proteins. This process is accompanied by a conformational change and exposure of the reacting groups and is followed by a second stage in which the denatured proteins establish protein-protein interactions; which lead to aggregation. The process of making thermo-irreversible gels from surimi normally consists of two steps. The first is setting of a salt-surfimi sol, a process in which the protein, denatured by the action of the salt and the mixing are oriented; this ensures a gradual sol-gel transition so that an orderly initial protein mesh is formed. The second step is high-temperature cooking to form the final kamaboko network. Alvarez and others (1999) suggested that the final structure of the kamaboko network was the outcome of denaturation-aggregation during setting of the surimi sol, and that this determined the possibility of reorganization of the molecules to form the final network. This result indicates that the better setting conditions of Alaska pollock surimi require a shorter time and lower temperature than those for the freshwater fishes. This may be explained as the myofibrillar protein of these freshwater fishes are more stable to heat than Alaska pollock, and therefore the effects of setting on the gel formation are somewhat different among these fishes.

**Figure 2**—Effects of incubation time on the breaking distance of Alaska pollock, common carp, grass carp and silver carp surimi at various incubation temperatures (breaking distance was determined after heating at 85 °C for 30 min)

**Assessment of model**

Equation (1) was fitted to the experimental data (Table 2). Eight equations were obtained and tested for adequacy and the goodness of fit was evaluated. The main results of this multiple regression were developed for each of the independent variables, with the corresponding coefficients of determination (R²). The models for the breaking force gave coefficients of determination for Alaska pollock surimi Y₁ (R² = 0.95), common carp surimi Y₂ (R² = 0.99), grass carp surimi Y₃ (R² = 0.99), silver carp surimi Y₄ (R² = 0.99), grass carp surimi Y₅ (R² = 0.98). The models for the breaking distance gave coefficients of determination for Alaska pollock surimi Y₆ (R² = 0.66), common carp surimi Y₇ (R² = 0.88), grass carp surimi Y₈ (R² = 0.89), silver carp surimi Y₉ (R² = 0.79). The model developed for breaking force and breaking distance, protein concentration, heating temperature, heating time indicated how these variables are related. The regression analysis showed that the experimental results were well described by the model within the experimental field.

**Effect of protein concentration**

From the analysis of coefficient estimates for the 8 regression models, protein concentration had a major positive effect on the breaking force and breaking distance (Table 2, Figures 3 & 4). For all 4 species, the regression coefficients of breaking force and breaking distance had a highly significant (P < 0.01) linear component (1st order). The results indicated that the system’s protein concentration (10-13.4%) was most closely correlated with the breaking force and distance. The quadratic component (2nd order) was likewise positive for the breaking force in common carp and Alaska pollock, but was not significant in silver carp and grass carp. The quadratic component was negative for the breaking distance in silver carp and grass carp surimi. Some researchers have reported that the effect of protein-solvent interaction predominates and there is a linear relationship be-
tween viscosity and protein concentration (Borderias and others 1985; Chen and others 1988; Cofrades and others 1993; Yoon and others 1997). Reppond and Babbitt (1997) demonstrated torsion stress and strain decreased linearly with increased moisture content of surimi. Chen and others (1988) indicated the rigidity of surimi and gel strength of kamaboko decreased with increases in the water content, the tensile strength and cohesiveness increased up to 76% water content, but decreased at higher water contents. The gel-forming ability of surimi decreased with an increase in water content due to lower myofibril protein concentrations and a decrease of the cross-link density (Hama da and Inamasu 1983; Sylvia and others 1994).

Effect of heating temperature
From the analysis of linear coefficient, the effect of heating temperature was less marked than that of the protein concentration on the breaking force and breaking distance in all 4 species (Table 2, Figures 3 & 5). The influence of heating temperature on the breaking force and breaking distance was somewhat different among the 4 species. Bertak and Karahadian (1995) studied the effects of heating methods

<table>
<thead>
<tr>
<th>Response variables</th>
<th>Alaska pollock surimi</th>
<th>common carp surimi</th>
<th>grass carp surimi</th>
<th>silver carp surimi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>breaking force</td>
<td>breaking distance</td>
<td>breaking force</td>
<td>breaking distance</td>
</tr>
<tr>
<td>Coefficients</td>
<td>$Y_1$</td>
<td>$Y_2$**</td>
<td>$Y_3$**</td>
<td>$Y_4$**</td>
</tr>
<tr>
<td>Constant</td>
<td>552.32</td>
<td>14.75**</td>
<td>0.90</td>
<td>0.85**</td>
</tr>
<tr>
<td>Linear</td>
<td>151.73**</td>
<td>1.33**</td>
<td>9.08</td>
<td>1.12**</td>
</tr>
<tr>
<td>$b_1$</td>
<td>6.63</td>
<td>-0.06</td>
<td>0.89</td>
<td>-0.11</td>
</tr>
<tr>
<td>$b_2$</td>
<td>-7.96</td>
<td>-0.70</td>
<td>5.35</td>
<td>-0.37**</td>
</tr>
<tr>
<td>Quadratic</td>
<td>34.29**</td>
<td>0.28</td>
<td>13.18**</td>
<td>-0.1</td>
</tr>
<tr>
<td>$b_{11}$</td>
<td>0.10</td>
<td>-0.44</td>
<td>1.16</td>
<td>0.27**</td>
</tr>
<tr>
<td>$b_{22}$</td>
<td>-1.77</td>
<td>0.06</td>
<td>2.04</td>
<td>0.26</td>
</tr>
<tr>
<td>Interactions</td>
<td>7.88</td>
<td>-0.38</td>
<td>16.39*</td>
<td>-0.20</td>
</tr>
<tr>
<td>$b_{12}$</td>
<td>2.88</td>
<td>-0.73</td>
<td>1.14</td>
<td>0.15</td>
</tr>
<tr>
<td>$b_{23}$</td>
<td>23.13</td>
<td>-0.56</td>
<td>-1.00</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Variability explained

- $R^2$ = 0.95
- $F$ = 29.06
- Probability of $F$ = 0.0000
- Model in which $X_1$ = protein concentration, $X_2$ = heating temperature, $X_3$ = heating time is

$$Y = b_0 + \sum b_i X_i + \sum b_{ii} X_i^2 + \sum b_{ij} X_i X_j$$

$b_0$ for constant, $b_i$ for linear terms, $b_{ii}$ for quadratic terms, $b_{ij}$ for interaction terms

* significant at 0.05 level

** significant at 0.01 level

Figure 3—Effects of protein concentration and heating temperature after heating for 30 min at various temperatures on the breaking force of Alaska pollock, common carp, grass carp and silver carp surimi.
on commercially produced leg style surimi seafood and reported that extra heating reduced the firmness and chewiness. The extra heating may have destroyed the gel network matrix causing a lower shear strain. Harper and others (1978) reported that the viscosity of bovine plasma protein suspensions reached a maximum in a shorter time at 90 °C rather than 70 °C. In this study, the effect of the heating temperature was not so marked. Therefore, after setting, the heating temperature might not be the main factor to influence the gel strength of surimi from 15 to 45 min heating.

Effect of heating time

The effect of heating time also was less marked than that of protein concentration in all four species (Table 2, Figures 4 & 5). The slight negative effect of heating time on breaking force and distance can be attributed to 2 possible mechanisms. One is the thermal dissociation of protein, and the other is the enzyme hydrolysis of protein. Deng (1981) reported that when mullet muscle was heated at various temperatures ranging from 55-85 °C, the shear force value increased during the initial stage of heating and then decreased. Hickson and others (1982) indicated that at 8% protein concentration and heated for 0-120 min at 80 °C, the penetration force of egg albumin and bovine protein showed a maximum value between 60 and 80 min of heating. In this study, the results indicated that the heating time from 15 to 45 min was not the main factor to influence the gel strength.

Interactive effect of protein concentration-heating temperature and heating period

Protein concentration versus heating temperature: both process variables influenced the change in breaking force (Figure 3) with the protein concentration being the more influential. The magnitude of the linear coefficient $b_1$ in equation 1 was 10 times greater than $b_2$. For the quadratic coefficient, the changes of $b_{11}$ and $b_{22}$ differed for the four species. The surface plot indicated the protein concentration had a major influence on the breaking force in comparison to temperature for all four species. The slight curvatures of surface in Alaska pollock, grass carp, and silver carp were due to the quadratic effects for protein concentration being positive and temperature being negative.

Protein concentration versus heating time: the surface plot of protein
concentration versus heating time (mean temperature \( T_0 = 0 \)) for breaking force (Figure 4) indicated that the protein concentration had a major influence in comparison to heating time. The magnitude of the linear coefficient \( b_1 \) in equation 1 was 10 times greater than \( b_3 \). The surface showed slight curvature in Alaska pollock and silver carp.

### Effect of species

Analysis of the breaking force and distance revealed some significant inter-species differences between Alaska pollock and the 3 freshwater fishes species. The breaking force of Alaska pollock surimi was significantly higher (\( P < 0.01 \)) than the freshwater fishes at no incubation and at the optimal setting conditions (Table 3). The Alaska pollock surimi had a stronger setting than these freshwater fishes. After the optimal setting conditions, the increment of breaking force of Alaska pollock surimi was more than 500 g. The increment for the freshwater fish surimi was 125 g for grass carp, 60 g for common carp, and 85 g for silver carp. The best setting conditions were a little different among species, the best condition was 30-35 °C, 30-60 min for Alaska pollock surimi; 35 °C, 60-120 min for common carp surimi; 40 °C, 30 min for grass carp surimi; 35-40 °C, 60 min for silver carp surimi. The breaking strength was similar among these freshwater fishes. CJF, SML, and TML evaluated the effects of protein concentration, pH, and ionic strength on the viscosity of actomyosin, no inter-species differences were reported. The absence of species difference may be due to the low protein concentrations (0.5-1.5%) that they used.

### Conclusions

Although the gel forming ability of silver carp, grass carp, and common carp surimi was inferior to that of Alaska pollock surimi (SA), these freshwater fishes can be utilized as materials for surimi and processed foods by processing at appropriate gel-forming conditions. Under the range of conditions studied, the protein concentration affected the gel strength most significantly, heating temperature and period were found not to be the main factor influencing the gel strength. The optimum heating temperature and time for the breaking force and distance were somewhat different among the surimi produced from the 4 species. The regression model was an effective method to evaluate the influence of factors affecting the rheological properties of the heat-induced surimi gel.

### References


**Table 3—Effect of species on the breaking force(g) of surimi gel at different setting conditions**

<table>
<thead>
<tr>
<th>Species</th>
<th>Alaska pollock</th>
<th>Common carp</th>
<th>Grass carp</th>
<th>Silver carp</th>
</tr>
</thead>
<tbody>
<tr>
<td>85 °C for 30 min (no setting)</td>
<td>508±41</td>
<td>380±41</td>
<td>379±30</td>
<td>362±29</td>
</tr>
<tr>
<td>Optimal setting</td>
<td>1113±17</td>
<td>440±15</td>
<td>502±14</td>
<td>447±13</td>
</tr>
</tbody>
</table>

**a**-means in the same row and column with different superscript differ (p < 0.05)

**b**-Optimal setting: Alaska pollock: 35 °C for 30 min; common carp: 35 °C for 120 min; grass carp: 40 °C for 30 min; silver carp: 35 °C for 60 min.

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