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Effects of Moisture Content on Non-Fracture Dynamic Properties and Fracture Quality of Pacific Whiting Surimi

Okan Esturk[1], Jae Won Park[1], Moo-Yeol Baik, and Byung-Yong Kim*

Institute of Life Science and Resources, Department of Food Science and Biotechnology, Kyung Hee University, Yongin, Gyeonggi 449-701, Korea

[1]Department of Food Science and Technology, OSU Seafood Laboratory, Oregon State University, Astoria, OR 97103, USA

Abstract The effects of moisture content on non-fracture dynamic properties and fracture gel quality of Pacific whiting surimi were investigated to determine their relationships. Surimi samples were tested at various moisture contents (75, 78, and 81%). Torsion test showed that shear stress decreased rapidly and strain values decreased gradually as moisture concentration increased. Dynamic storage modulus (G') also decreased as moisture content increased. A strong positive correlation (R^2 = 0.90 to 0.99) was found between the G' measured at temperatures between 10 and 45°C and fracture stress values. The results indicate that dynamic rheological measurements could be used as a tool for early gel quality assessment.

Keywords: surimi, whiting, rheology, moisture, gel analysis

Introduction

Pacific whiting (*Merluccius productus*) represents the third most abundant fish resource used for surimi in the world. Surimi is refined fish myofibrillar proteins that are stabilized with cryoprotectants. Myofibrillar proteins can form a three dimensional network structure and bind a large amount of water when prepared within an optimum range of protein concentration, pH, ionic strength, and temperature. This gelation and the textural properties of fish myofibrillar proteins are considered the most important parameters in surimi production (1-3)

Rheological information obtained from surimi paste represents the gelation properties of fish proteins. It has been reported that the viscosity of dilute extracts of fish proteins correlates with the degree of protein denaturation, which in turn, determines the gelation properties (4, 5). In addition to viscosity, other dynamic rheological parameters, such as storage modulus (G') and loss modulus (G") obtained from temperature sweep and/or frequency sweep measurements, may rapidly estimate the quality of fish proteins. Dynamic tests measure small strains and so can be used to monitor the physical property changes of the gel that relate to molecular changes (6). Information obtained from dynamic tests could be used during processing or while developing product formulations, assuming a relationship to the textural quality of the surimi gel can be established. The rheological properties of fish proteins have been extensively characterized (1). Limited information is available however regarding the dynamic properties of Pacific whiting surimi paste and their relationship to fracture gel properties.

The objectives of this study were to investigate the effects of moisture content on the rheological properties of surimi gels based on dynamic rheological measurements and torsion testing, and to determine a relationship between the results of small strain and fractural failure tests for possible early prediction of surimi gel quality.

*Corresponding author: Tel: 82-31-201-2627; Fax: 82-31-202-0540
E-mail: bykim@khu.ac.kr
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Materials and Methods

Materials Frozen Pacific whiting surimi was obtained from local manufacturers. Surimi contained 4% sugar, 4% sorbitol, and 0.3% sodium phosphate as cryoprotectants, as well as 1.4% beef plasma protein (BPP) as a protease inhibitor. Ten kg blocks were divided into 1 kg blocks, vacuum packed, and stored at -30°C until tested.

Gel preparation Surimi batch formulations with 2% salt were adjusted to obtain various moisture concentrations. Surimi gel preparation and testing were conducted according to the method of Park *et al.* (7) and during chopping; the paste temperature was maintained below 5°C. A small portion (100 g) was saved for dynamic rheological testing, while the remaining sample was cooked in tubes (i.d. = 1.87 cm, length = 17.75 cm) for fracture analysis. Samples containing 75, 78, and 81% moisture were used to measure the fracture gel quality and the dynamic properties.

Dynamic testing Dynamic tests were conducted using a Bohline Rheometer (CS-50; Bohline Instruments Inc., East Brunswick, NJ, USA). Dynamic rheological properties of surimi paste were monitored using a 4.0 cm dia/4° angle cone and plate (CP-4/40). The region of linear viscoelastic response of surimi paste was determined by stress sweep. The lowest and highest stress values used for the stress sweep test were 0.5 and 1,500 Pa, respectively. During the temperature sweep, surimi samples were heated from 10 to 80°C at a 1°C/min of heating rate with 0.1 Hz frequency. Dynamic rheological parameters such as storage modulus (G'), phase angle (δ), and loss modulus (G") were obtained.

Fracture gel analysis The torsion test was used to determine the fracture properties of the gels (8). The gels were cut (2.9 cm length, 1.9 cm i.d.), glued on both ends to plastic disks, and milled into a dumbbell shape (minimum center diameter = 1.0 cm) using a milling machine. Each gel segment was then assessed using the Hamann Torsion Gelometer (Gel Consultants Inc., Raleigh, NC, USA). The samples were twisted and shear stress was calculated based on the torque whereas shear strain was calculated based on the torque and the angular displacement (8).

Statistical analysis SAS statistical package (Version 8, SAS Inc., Cary, NC, USA) was used to analyze data. Least significant difference (LSD) was used to determine significant differences between mean values at $p<0.05$.

Results and Discussion

Fracture properties Fracture shear stress and strain values of Pacific whiting surimi significantly decreased as moisture content increased ($p<0.05$, Fig. 1). The higher moisture content in surimi gel, the lower the fracture shear stress and fracture shear strain. Yoon *et al.* (9) reported a similar trend for Pacific whiting. Reppond and Babbitt (10) demonstrated that higher water contents had a negative effect on fracture shear stress of various fish species. A similar trend was also reported for the fracture shear stress values of Alaska pollock surimi (6, 9). However, these studies stated that moisture concentration had no effect on the fracture shear strain of Alaska pollock within the studied range (75-81%)

Fracture shear stress showed a significantly negative linear correlation with moisture content ($R^2 = 0.98$). Shear stress values dropped from 41.67 to 14.83 kPa as moisture concentration increased from 75 to 81%. Fracture shear strain, which is an indicator of protein quality (6), also showed a negative linear correlation with moisture content ($R^2 = 0.97$). However, the moisture content appeared to have a larger impact on the change of fracture shear stress than the change of fracture shear strain. Fracture shear stress is significantly affected by protein concentration, moisture, ingredients, and processing variables (11). According to Hamann and MacDonald (6), fracture shear stress is proportional to the concentrations of cross-linked polymers at a constant temperature.

Dynamic properties The linear viscoelastic range of a polymer is generally determined by stress sweep at a constant frequency. The effect of applied stress at the sol/paste state on G' is shown in Fig. 2. The linear region extended significantly as the moisture concentration decreased. The linear region was from 20-150, 20-75, and 20-46 Pa and strain values were 0.0242 at 150 Pa, 0.0217 at 75 Pa, and 0.0197 at 46 Pa for 75, 78, and 81% moisture, respectively. From the results, we also concluded that increasing protein concentration enforced polymer structure and increased the required stress for structural deformation.

The change of G', G", and phase angle (δ) with respect to moisture content is shown in Fig. 3. When moisture content increased from 75 to 81%, G' and G" significantly decreased, while phase angle (δ) slightly increased. This linear relationship between protein concentration and dynamic rheological measurements, however, only applied within the range of the specific moisture contents.

Storage modulus (G') values of Pacific whiting surimi paste during the temperature sweep tests are shown in Fig. 4. There was a small drop of the G' value starting at 30°C. G' reached its lowest value at around 45°C, and then

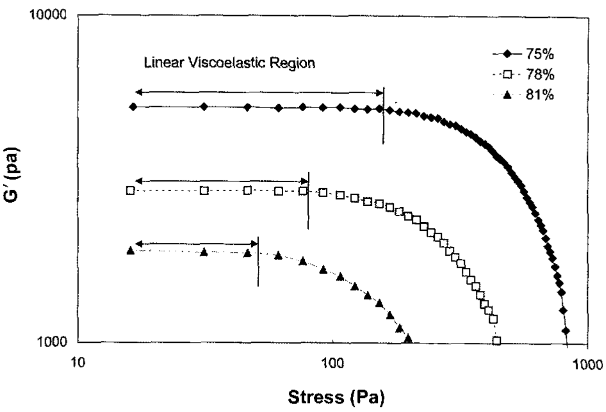

Fig. 2. Effect of stress on G' of Pacific whiting surimi as affected by moisture concentration at 20°C and 0.1 Hz.

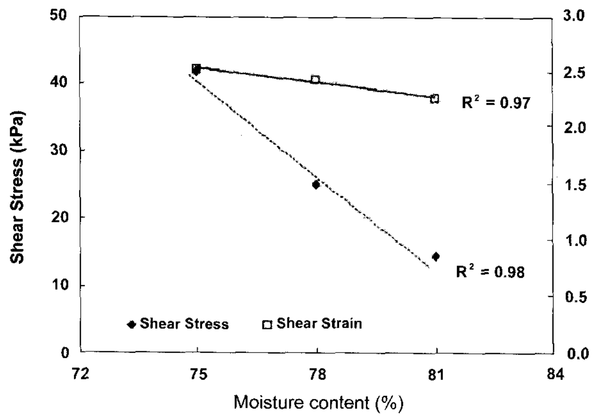

Fig. 1. Fracture shear stress and strain values of Pacific whiting surimi as affected by moisture concentration

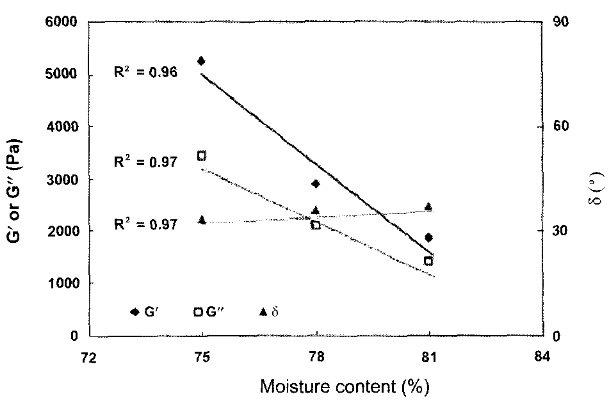

Fig. 3. Changes of G', G", and phase angle (δ) of Pacific whiting surimi as affected by moisture concentration (0.1 Hz, 46 Pa)

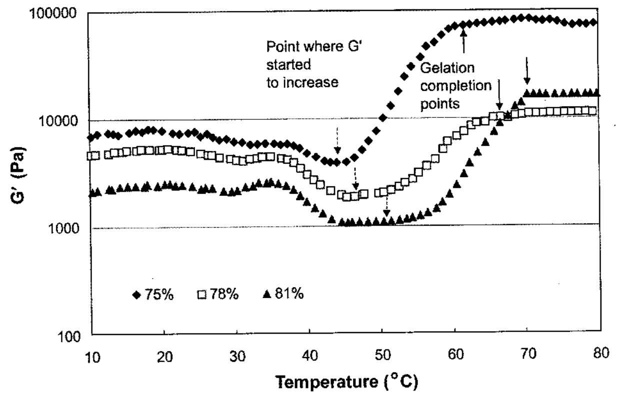

Fig. 4. Change of storage modulus (G') of Pacific whiting as affected by moisture concentrations

increased rapidly until reaching 60-70°C. Thermal gelation was completed at the temperature where G' reached a maximum plateau. The lowest G' values occurred at around 40-50°C and were probably due to the effect of the structural changes of actomyosin since a-helices in the tail portion of myosin molecules unfold at 40°C (12). Stone and Stanley (13) also reported a disruption of the fish muscle gel network at 45-50°C. An increase in G' above 45°C indicated gel formation or gel stabilization by hydrophobic interactions (14, 15). Moisture content also affected the point at which G' started to increase. As the moisture content increased from 75 to 78 and 81%, the temperature at which G' started to increase was 44, 48, and 52°C, respectively.

Phase angle (δ), a measure of the ratio of energy lost to energy stored in a cyclic oscillatory deformation, was another good parameter for monitoring changes during gelation from sol to gel state. The change of phase angle with temperature along with G' and G" for a sample containing 78% moisture is given in Fig. 5. Phase angle started to decrease at around 30°C, corresponding to an initial rise of G' and indicating the start of unfolding. It should be also noted that the phase angle was always smaller than 45°, indicating that the surimi paste behaved as a solid-like material rather than a liquid-like one. This was probably due to the high protein concentration and molecular entanglement of proteins in the surimi paste.

Relationship between gel fracture and dynamic properties The relationship between the dynamic storage modulus at 30°C and fracture stress values is given in Fig. 6. A similar trend was observed for different surimi batches (R^2 = 0.9-0.99), if the G' was selected within a certain temperature range (20-45°C). However, temperature sweep above 45°C did not yield a high correlation (R^2 < 0.9) with fracture stress. Model equations obtained from multiple linear regression analysis resulted in a similar trend, and predictions were more accurate when the dynamic data output was within the range of 25-35°C.

The equations of the best fitting models were developed for temperature sweep data at 25°C (Eq. 1 and 2) and 30°C (Eq. 3 and 4) for fracture shear stress and fracture shear strain.

Fracture shear stress$^{25°C}$ = 312.61 - 4.02 moisture content (%) - 2.15 Log(G') + 10.14 Log(G") Eq.1

Fracture shear strain$^{25°C}$ = -0.4068 + 0.7692 Log(G') Eq.2

Fracture shear stress$^{30°C}$ = 304.16 - 3.96 moisture content (%) - 16.00 Log(G') + 26.31 Log(G") Eq.3

Fracture shear strain$^{30°C}$ = -0.5150 + 0.8096 Log(G') Eq.4

As for model verification, experimental and prediction values of new surimi batches were compared using the equations developed for 25 and 30°C. At 75% moisture, predicted shear stress values were 39.59 and 39.86 kPa using Equation 1 and 3, respectively. The corresponding fracture shear stress value from the experiment was 40.45 kPa (Fig. 7), indicating that the prediction model using dynamic parameters was well fitted to predict the real gel shear stress value. However, the prediction of fracture shear strain was not as successful as for fracture shear stress (Fig. 8). It was noted that the relationship between the dynamic rheological measurements at the sol state and the fracture measurements at the gel state could be used for surimi get strength prediction, but not for deformation

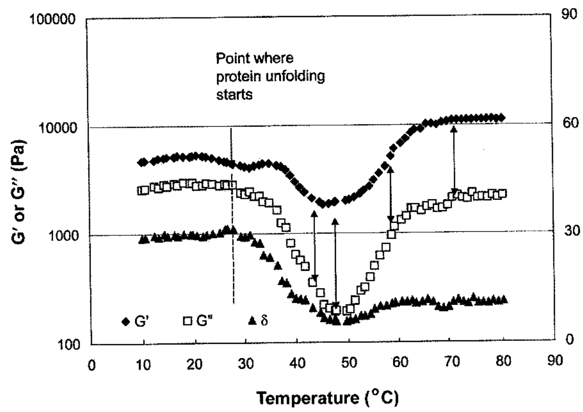

Fig. 5. Change of G', G", and phase angle (δ) of Pacific whiting surimi containing 78% moisture.

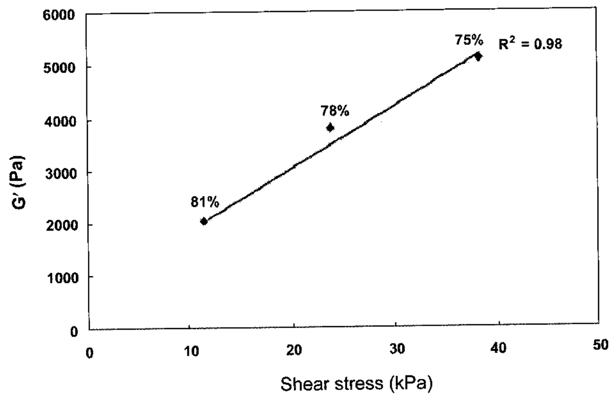

Fig. 6. Relationship between storage modulus (G') at 30°C and fracture shear stress as affected by moisture contents.

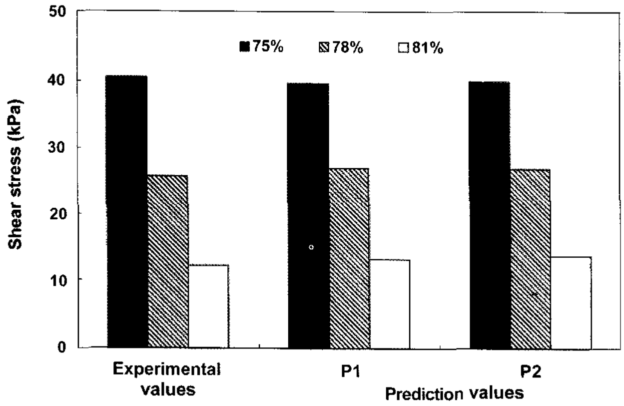

Fig. 7. Experimental fracture stress values from torsion test and predicted values of fracture shear stress using the best fitting models. P1: Predicted fracture shear stress using G' data at 25°C. P2: Predicted fracture shear stress using the G' at 30°C.

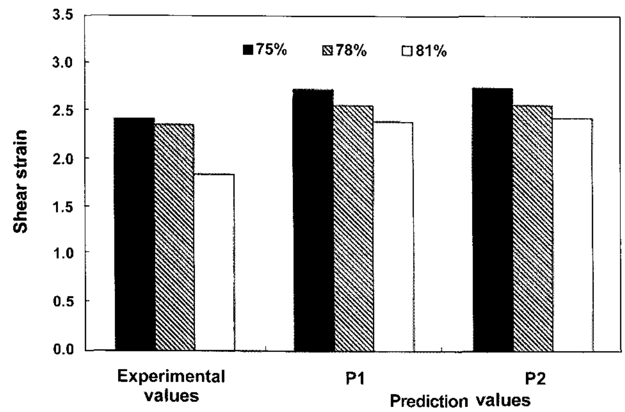

Fig. 8. Experimental fracture strain values from torsion test and predicted values of fracture shear strain using the best fitting models. P1: Predicted fracture shear strain using the G' data at 25°C. P2: Predicted fracture shear strain using the G' data at 30°C.

prediction.

Conclusively, moisture content had a significant effect on the rheological properties of Pacific whiting surimi. Fracture shear stress and shear strain values of gels decreased as moisture concentration increased within the studied range (75-81%). The results show that the fracture shear stress and shear rate could be predicted well by dynamic rheological measurements. Consequently, the dynamic rheological parameters could be a useful tool for early gel quality assessment.

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