Gelation Characteristics of Paddlefish (*Polyodon spathula*) Surimi Under Different Heating Conditions

X. LOU, C. WANG, Y.L. XIONG, B. WANG, AND S.D. MIMS

ABSTRACT: Gelation properties of paddlefish surimi were investigated with different heating procedures. Without pre-incubation, gel strength of paddlefish surimi increased as temperature increased from 40 to 60 °C. Pre-incubation at 40 °C caused myosin degradation and reduced gel strength by 55% compared to the control. Pre-incubation at 70 °C followed by cooking at 90 °C produced gels with maximum strength. Isothermal heating between 40 and 50 °C produced rheological transitions between 0 and 15 min. Beef plasma powder reduced myosin degradation and enhanced gelation of surimi incubated around 40 °C. These results indicated that the gel-weakening phenomenon in paddlefish surimi was due to the degradation of myosin by some endogenous protease(s).

Key Words: paddlefish, surimi, gelation, protease, proteolysis

Introduction

PADDLEFISH (*POLYODON SPATHULA)* IS THE LARGEST FRESH WATER fish in North America. It grows rapidly (up to 5 kg/year) with an average size of 18 kg commonly found in Kentucky (Mims 1991). Aquacultural studies indicate that paddlefish has tremendous potential for large scale production through reservoir ranching or polyculture with other species (Semmens and Shelton 1986; Mims 1991). However, the market for paddlefish meat is limited because consumers are not familiar with it (Semmens and Shelton 1986; Wang and others 1994). This has hindered the production and marketing of paddlefish. We speculated that paddlefish meat could be a valuable material for surimi production because it has the attributes which are essential for surimi production: white meat, low fat content, and bland taste (Babbitt 1986). Using paddlefish meat for surimi manufacturing could enhance the economic value of paddlefish and provide nutritious food products for consumers. This would greatly promote the aquacultural production of paddlefish because of the added market and profitability. The increased aquacultural production of paddlefish will ease the pressure on the natural stock of Alaska pollock and paddlefish.

Surimi is a Japanese term referring to the intermediate product manufactured by washing ground fish meat (Lee 1986). It is used primarily to produce products such as imitation crab meat, lobster tails, and other seafood analogs. Alaskan pollock (*Theragra chalcogramma)* has been the major fish species used for surimi manufacturing, contributing to 80% of the surimi produced in the United States. However, there are indications of pollock overexploitation.The U.S. government has established rules over pollock catching (Sproul and Queirolo 1994). These rules prohibit foreign companies from fishing in American waters, causing a significant reduction in international pollock supply. This has forced surimi processors to search for alternative fish species for surimi production. Converting paddlefish meat into surimi can help meet the growing demand for surimi as well as promote the aquacultural production of paddlefish.

One of the most important attributes of surimi, its gel-forming ability, is affected by the fish species, formulations, and cooking procedures (Lee 1986). Among these factors, cooking procedure has been recognized as one of the critical steps that can be controlled to improve the gel quality of surimi, but its impact may vary depending on the fish species. For some fish species, extended incubation at certain temperatures (generally below 40 °C) can enhance the gelation of surimi (defined as setting or "suwari"), whereas for other species, extended incubation around 60 °C may weaken the surimi gel (defined as gel-softening or "modori") (Shimizu 1990). Despite extensive research, the underlying mechanisms for "suwari" and "modori" are not fully understood. "Suwari" phenomenon may be explained by the enhanced formation of gel-networks from fish myosin at relatively low temperature (Montejano and others 1984). The most likely cause of "modori" with certain fish surimi is the degradation of myosin by heat-activated proteases (Wasson 1992). However, there is still uncertainty regarding the origin and nature of proteases involved in specific fish species (Kolodziejsk and Sikorski 1996). Nevertheless, some food-grade ingredients, for example, beef plasma powder, can improve the gel quality of some surimi, presumably by inhibiting the active proteases in surimi (Weerasinghe and others 1996).

Ideal cooking conditions for surimi may vary substantially depending on the fish species. To our knowledge, there are no data that characaterizes paddlefish surimi. Accordingly, we conducted this study to explore the suitability of paddlefish meat for surimi production. Specifically, our objectives were to investigate the effects of various heating conditions, the potential role of endogenous proteases, and the impact of beef plasma powder on the gelation of paddlefish surimi.

Results and Discussion

Gel strength

With one-step cooking, paddlefish surimi sol formed extremely weak gels at temperatures below 45 °C (Fig. 1). As the cooking temperature was raised to above 50 °C, the gel strength increased dramatically and reached a maximum value of 82 N and 73 N for 0.5 and 2 h heating, respectively. When the cooking temperature was above 60 °C, gel strength deceased progressively. The gels cooked for 2 h were weaker than the gels cooked for 0.5 h, indicating that prolonged cooking was detrimental to the paddlefish surimi gel structure. According to Ferry (1948), proteins form gel networks through a coordinated transition from denaturation to gelation. When protein molecules were denatured in-

stantly by intense heating, the denatured protein molecules were randomly extended or coiled so that they could not form a cohesive gel matrix system through coordinated interaction, resulting in low gel strength. Apparently, when the cooking temperature was too high (in this case >60 °C for paddlefish surimi) the gel networks were compromised. This adverse effect of overheating was also found in other fish surimi such as round herring and Alaska pollock (Shimizu 1990).

For two-step cooking, the gel strength of paddlefish surimi varied with the pre-incubation temperature. Pre-incubation at 40 °C for half an hour produced gels with much lower strength compared to the control (cooked at 90 °C for 30 min), however, pre-incubation at 70 °C produced gels with maximum strength which was slightly higher than that of the control (Fig. 2). It appeared that "modori" occurred near 40 °C with paddlefish surimi, which was significantly below 60 °C, the modori temperature for other fish surimi such as Pacific whiting, Atlantic menhaden, and Alaska pollock (Chang-Lee and others 1990; Lanier 1986; Lee1986). Although two-step cooking is widely used to enhance the gelation of surimi from some fish species, such as Alaska pollock (Lee 1986), our results indicated that pre-incubation at 40 °C actually caused gel-weakening with paddlefish surimi. The cause of gel-weakening in other fish species, such as Pacific whiting and mackerel, has been ascribed to the degradation of myosin by endogenous proteases (An and others 1994; Jiang and others 1996). Therefore, we hypothesized that the degradation of myofibrillar proteins might also be responsible for the gel-weakening of paddlefish surimi pre-incubated at 40 °C.

Pre-incubation conditions may vary depending on the fish species, processing equipment, and the nature of the final products (Lee 1986). For some fish species, such as Alaska pollock, pre-incubation at 40 °C substantially enhances the gel elasticity and strength of the surimi, which is desirable for the processing of fiberized products (Lee 1986). The underlying mechanisms for the enhanced gelation may include coordinated protein-protein interactions and increased action of transglutaminase which facilitates the formation of covalent bonding between polypeptides (Wu and others 1991; Joseph and others 1994). However, it seemed that pre-incubation at 40 °C should not be recommended for paddlefish surimi. If the processing requires pre-incubation, it should be carried out around 60 °C to minimize the gel-softening problem.

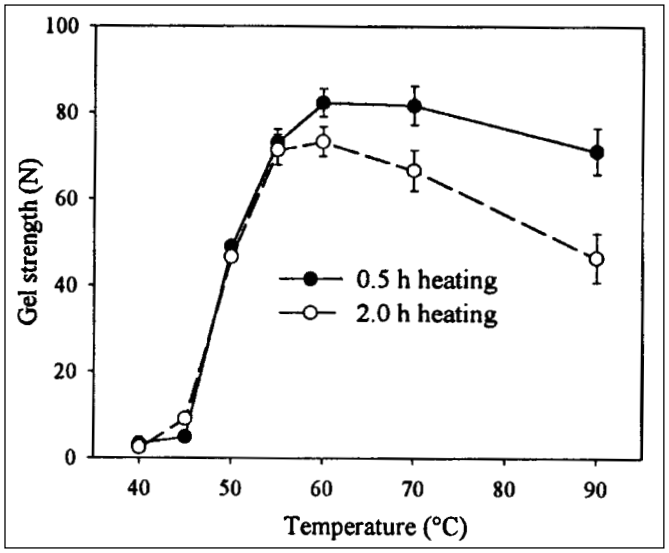

Fig. 1—Gel strength of paddlefish surimi (180 mg/mL protein, 2.5% NaCl, pH 6.5) heated at various temperatures for 0.5 or 2.0 h (Mean ± SE).

Dynamic rheological testing

With linear heating, the G′ of paddlefish surimi sol showed three transitions (Fig. 3). Initially, between 20 to 43 °C, G′ increased gradually but accelerated at 38 °C to reach a peak around 43 °C. Between 43 to 55 °C, G′ declined rapidly. Toward the end, G′ increased gradually within the range of 55 to 73 °C. Egelandsdal and others (1986) suggested that the initial increase in G′ resulted from the cross-link between myosin filaments accompanying the denaturation of heavy meromyosin. When the temperature was above 45 °C, the decrease in G′ was attributed to the denaturation of light meromyosin and the increase in the "fluidity" of myofibrillar filaments. The final increase in G′ (>60 °C) probably arose from the formation of irreversible gel networks.

Isothermal incubation resulted in two distinctive trends of rheograms (G′) over incubation time (Fig. 4). When temperature was below 40 °C or above 50 °C, G' gradually increased as incubation time prolonged. In contrast, when the incubation temperature was at 40 °C, 45 °C, or 50 °C, G′ reached a peak between 0 and 15 min and declined thereafter. Since the rheological data

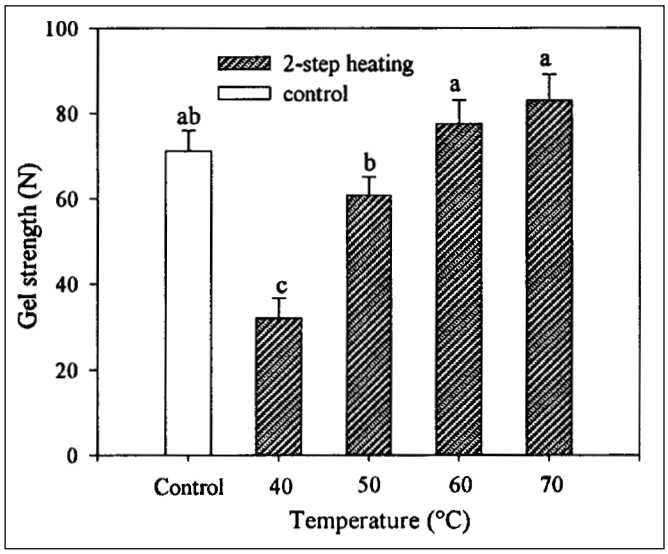

Fig. 2—Gel strength of paddlefish surimi (180 mg/mL protein, 2.5% NaCl, pH 6.5) pre-incubated at selected temperature for 30 min followed by final cooking at 90° C for 30 min (Mean ± SE). The control was cooked in a 90° C water bath directly. The bars sharing the same letter a, b, or c were not significantly different.

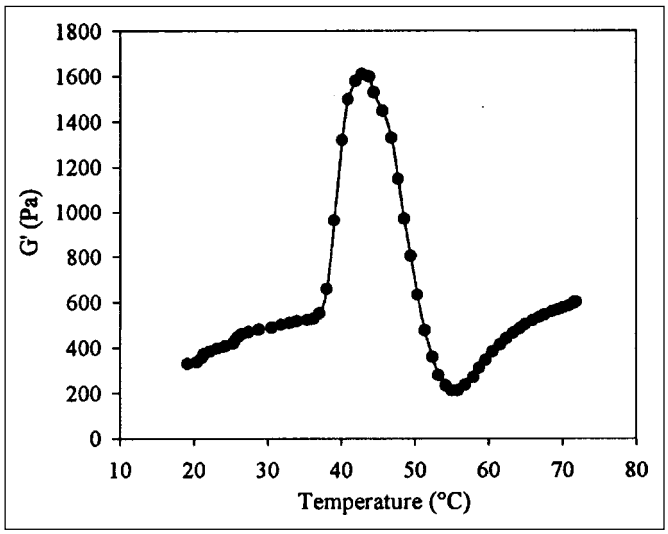

Fig. 3—Typical rheogram of paddlefish surimi sol (40 mg/mL protein, 2.5% NaCl, pH 6.5) heated from 20 °C to 73° C at 1° C/min.

were recorded only after the temperature of the sol had equilibrated to the target values, the graph (Fig. 4) reflected the G′ changes of paddlefish surimi with incubation at the selected constant temperatures. It seemed that the changes of G′ with isothermal incubation were related to the transition during linear heating. When the incubating temperature was below 35 °C, the surimi sol had not reached the phase for myosin head to denature. Hence, G′ increased only slightly due to the conformational changes of myosin head. When the incubating temperature was above 55 °C, the surimi sol had passed the phase wherein myosin tail was denatured and was entering the phase for a complete gel network formation. As a result, G′ also increased as incubation time prolonged. The decline of G′ with incubation at 45 and 50 °C was expected because these temperatures coincided with the declining phase of G′ with linear heating. The initial increase of G′ at 40 °C could be explained by the hypothesis of Egelandsdal and others (1986). However, the decline of G′ at 40 °C could not be accounted for solely by the conformational changes of myosin, because at this temperature, G′ peaked with linear heating. We suspected that the degradation of myosin might have contributed to the decline of G′, as the following SDS-PAGE pattern of paddlefish surimi would indicate.

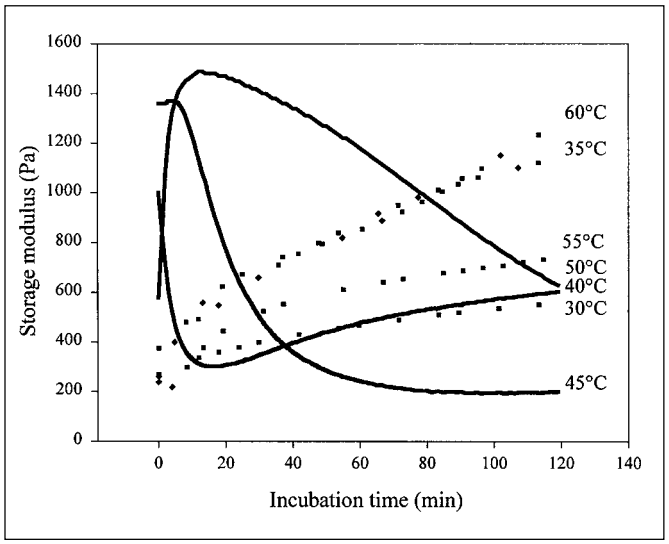

Fig. 4—Gel elasticity (G') of paddlefish surimi sol (40 mg/mL protein, 2.5% NaCl, pH 6.5) incubated at selected temperatures for 2 h. (Solid lines show the G' with declining trend from the initial peak; dotted lines show the G' with increasing trend).

SDS-PAGE pattern

The pattern of SDS-PAGE showed varied degradation of myosin heavy chain (MHC) depending on the incubation temperature and time. The most noticeable changes occurred with heating at 40 °C, where the MHC band was much lighter after 30 min and became almost invisible after 2 h heating. Concomitantly, new bands appeared which were particularly dense near the C-protein band (Fig. 5). There were no apparent changes in other myofibrillar proteins, including actin, within the temperature range examined in this study. It seemed that the degradation of MHC corresponded to the weakened gel strength and the decline in G′ associated with pre-incubation at 40 °C. Therefore, SDS-PAGE pattern supported our hypothesis that myosin degradation was the likely cause for the gel-weakening of paddlefish surimi.

Effects of beef plasma powder

Incorporation of BPP not only substantially reduced the loss of gel strength (Fig. 6) but also inhibited the reduction of G′ during extended incubation at 40 °C (Fig. 7). More importantly, BPP also suppressed the degradation of MHC (Fig. 8) during incubation at 40 °C. According to Weerasinghe and others (1996), BPP

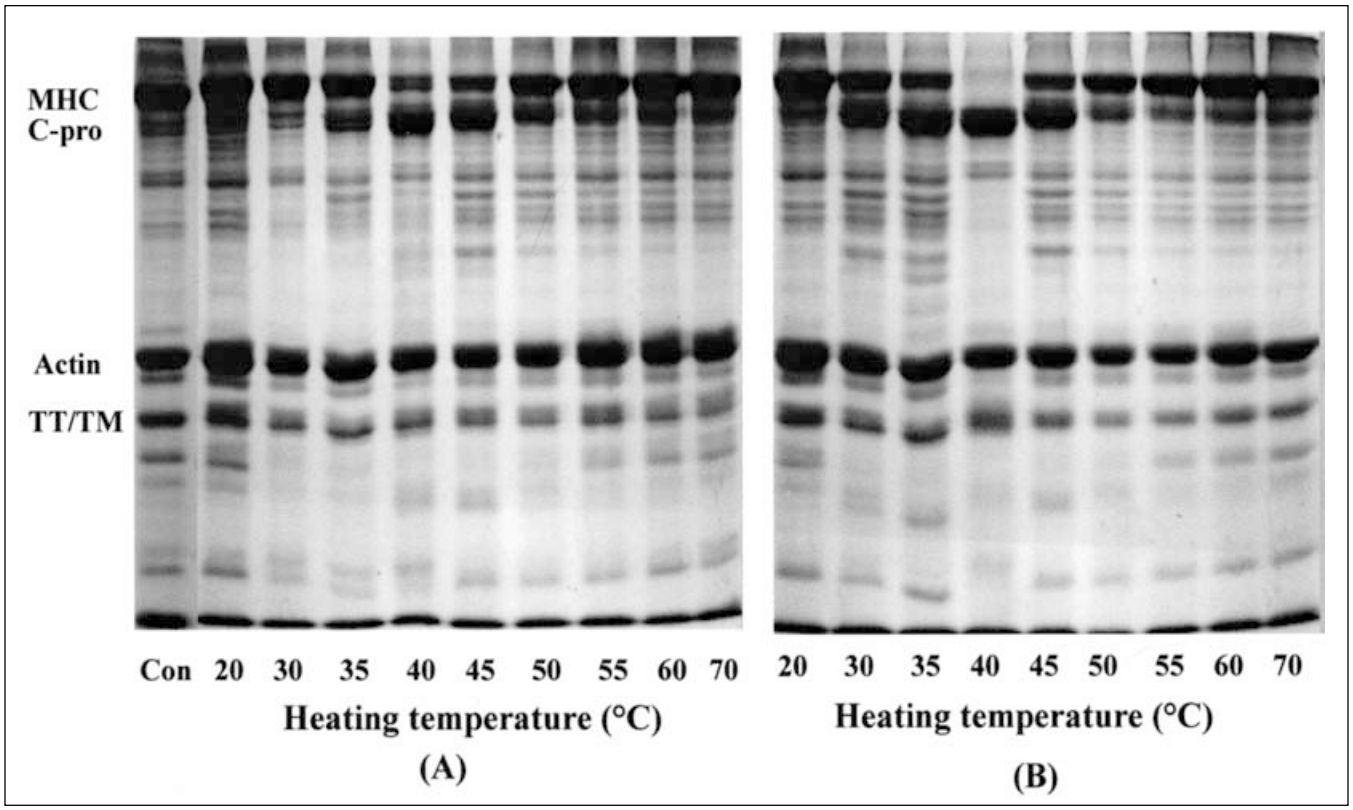

Fig. 5—SDS-PAGE pattern of paddlefish surimi heated at selected temperatures for 0.5 h (A) or 2.0 h (B). Con: control, fresh surimi without cooking; MHC: myosin heavy chain; C-pro: C-protein; TT/TM: troponin/tropomyosin.

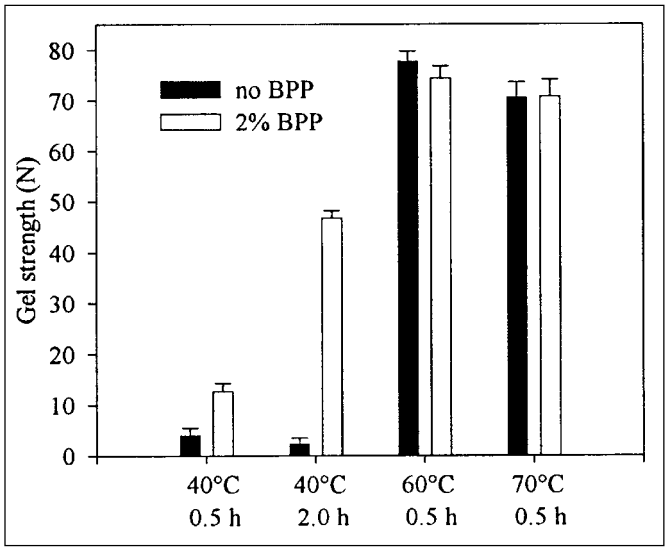

Fig. 6—Gel strength of paddlefish surimi (180 mg/mL protein, 2.5% NaCl, pH 6.5) with beef plasma powder cooked at selected temperatures for 0.5 or 2 h.

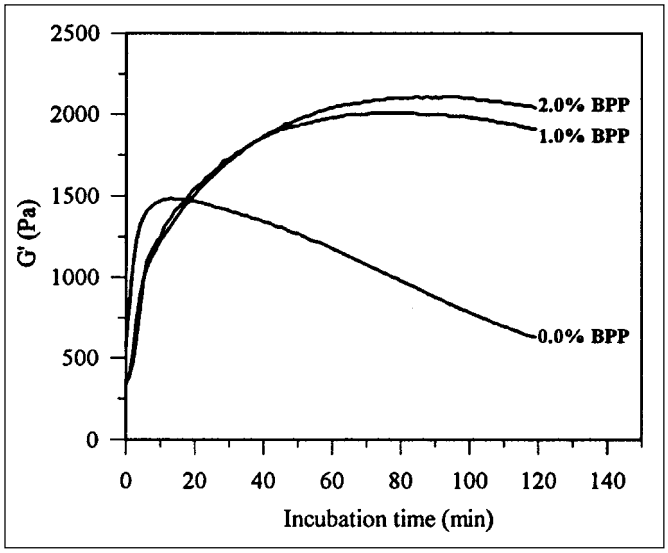

Fig. 7—Gel elasticity (G') of paddlefish surimi (40 mg/mL protein, 2.5% NaCl, pH 6.5) with selected levels of beef plasma powder incubated at 40° C for up to 2 h.

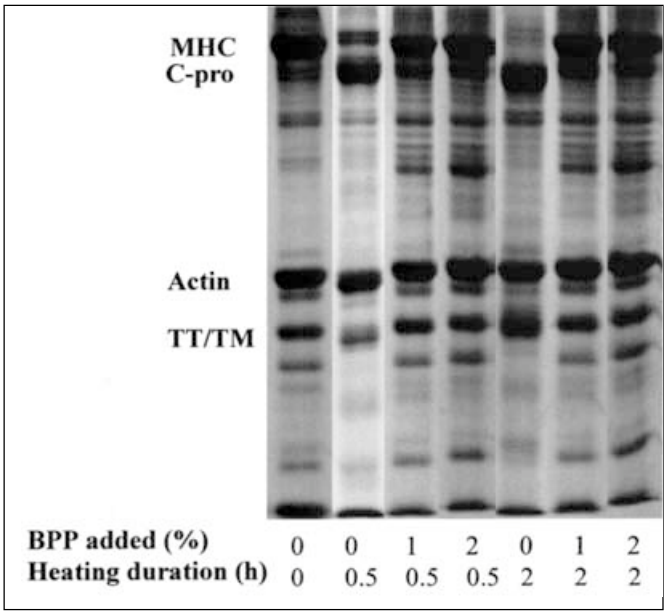

Fig. 8—SDS-PAGE pattern of paddlefish surimi with selected levels of beef plasma powder cooked at selected temperatures for 0.5 or 2 hours. Con: control, fresh surimi without cooking; MHC: myosin heavy chain; C-pro:C-protein;TT/TM: troponin/tropomyosin.

enhances gelation mainly by inhibiting endogenous proteases responsible for the degradation of myofibrillar proteins, particularly myosin. However, they did not exclude the possibility for BPP acting as a gel-forming component, because BPP contains multiple polypeptides which may facilitate the gelation of surimi proteins. Another potential factor is that BPP contains active transglutaminase which catalyzes the formation of covalent bonds and hence assists the gel network formation. In this study, we found that relatively low level of BPP (1%) effectively inhibited MHC degradation and improved the gel strength, and doubling the level of BPP (2%) only brought about negligible additional protection. These results might suggest that BPP acted as a protease inhibitor rather than as a major gel-forming component. Hence, BPP could be used to improve the texture of paddlefish surimi products.

Conclusions

THE GELATION OF PADDLEFISH SURIMI WAS TEMPERATURE-DEpendent. Pre-incubation at 70 °C for 0.5 h followed by cooking at 90 °C for 0.5 h seemed to give the best gel strength. Pre-incubation at 40 °C caused gel-weakening, which could be attributed to the degradation of myosin by some endogenous protease(s). Addition of beef plasma powder could effectively prevent the degradation of myofibrillar proteins. Therefore, pre-incubation at 40 °C should be avoided and beef plasma powder could be added to improve the texture of paddlefish surimi-based products.

Materials and Methods

Preparation of paddlefish surimi

The paddlefish used in this study were raised in reservoirs located in Western Kentucky. Six fish, weighing between 7–15 kg, were filleted by hand, stored at −22 °C, and used within 30 days. The frozen fillets were thawed at 4 °C for 15 h and ground through a plate with 4.5 mm orifices on a food grinder (Kitchen Aid Inc., Model KSM90, St. Joseph, Mi.). One kilogram of ground meat was washed three times with 8 volumes of iced tap water, followed by one washing with 0.15% NaCl in the iced water to facilitate the de-watering process. The resulting slurry was wrapped in double-layered cheese cloth and compressed to remove water. With the protein concentration measured using the Biuret method (Gornall and others 1949), a portion of 600 g de-watered mince was blended with 2.5% NaCl and ice water to give a final protein concentration of 18%. The resulting paste, referred to as "paddlefish surimi sol", had a pH value close to 6.5 and was used for gel preparation.

Surimi gel preparation

The paddlefish surimi sol was filled into individual Pyrex brand glass tubes (19 mm in diameter,150 mm in length) with stoppers (Lee and others1997). Then, the tubes were centri-

fuged at 900 × *g* for 5 min to exclude the air pocket from the tubes. Two cooking procedures (one-step or two-step heating) were used for gel preparation. For one-step heating, the samples were heated in water baths at 40, 45, 50, 55, 60, 70, and 90 °C for 0.5 or 2 h. For two-step heating, the samples were immersed into water baths that had been heated to 40, 50, 60, and 70 °C, incubated at the above temperatures for 30 min, and transferred to a water bath heated at 90 °C for another 30 min. The control was cooked in a water bath at 90 °C for 30 min directly. After cooking, the gels were immediately chilled in ice water for 20 min and kept at 4 °C overnight before analysis.

Gel strength testing

Gel strength was determined by compressing the gel on a Model 4301 Instron universal testing instrument with a crosshead speed of 20 mm/min (Instron Corp., Canton, Mass.). Before the Instron testing, the cooked gels were equilibrated at room temperature for 30 min, cut into 19 mm tall cylinders with 17 mm diameter. The cylinder-shaped gel sections were compressed axially until they were ruptured. Gel strength was calculated based on the height of the first peak registered on the chart recorder.

Dynamic rheological testing

In order to observe the dynamic changes of gel-forming ability of paddlefish surimi during thermal incubation, paddlefish surimi was diluted into a suspension (40 mg/mL protein, 2.5% NaCl, pH 6.5) and stored at 2 °C for 15 h. A Model VOR Bohlin rheometer (Bolin Instruments, Inc., Cranbury, N.J.) was used to carry out the rheological test. Two heating procedures, similar to those reported by Wang and Xiong (1998), were used: 1) linear heating from 20 to 73 °C at 1 °C/min and 2) isothermal incubation at 30, 35, 40, 45, 50, 55, or 60 °C for 2 h. The isothermal incubation was conducted with the sol heated from 20 °C to the target temperature at 1 °C/min and the rheological data were collected 10 seconds later so that the temperature of the sample could equilibrate to the target value (Xiong and Blanchard 1994). Shear stress was applied at a fixed frequency of 100 mHz with a small strain of 0.02 to ensure the integrity of the gel network. Storage modulus (G′), a parameter reflecting gel elasticity, was used to evaluate the dynamic changes in the gel-forming ability of paddlefish surimi.

Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE)

The procedure of Xiong (1993) for SDS-PAGE was used to determine whether any myofibrillar proteins might be degraded by heating. The proteins of the cooked surimi gels were extracted and diluted to 1 mg/mL (Wasson and others 1992). An aliquot of 25 μL was loaded onto each gel slot with the resolving gel containing 10% acrylamide. The separated protein bands were visualized with Coomassie Brilliant Blue R-25. The protein bands were identified by comparing their mobility with published data (Porzio and Pearson 1977).

The impact of beef plasma powder on the gelation of paddlefish surimi

The impact of beef plasma powder (BPP 600, AMPC Inc., Ames, Iowa) on the gelation of paddlefish surimi was examined by blending 1% or 2% (w/v) BPP into the surimi sol before heating. For dynamic rheological testing, the paddlefish surimi sol was incubated at 40 °C for 2 h with 0% BPP as control. For gel strength testing, the paddlefish surimi sol was incubated at 40 °C for 0.5 or 2.0 h, or at 60 and 70 °C for 0.5 h because previous results indicated that paddlefish surimi sol formed the strongest gel with incubation at 60 and 70 °C for 30 min. The gels were analyzed as described above.

Statistical analysis

Data were analyzed using the GLM procedure of SAS program (SAS Institute 1990). The study was replicated three times, using a randomized complete block design with the replicate as the block. Therefore, replicate and cooking method were the independent variables in the model. When the overall F test was significant, means were compared with the Tukey's test. Significant differences were declared at $p \leq 0.05$.

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MS 1999-0628 received 9/21/99; revised 11/15/99; accepted 12/28/99.

This study was supported by the USDA Capacity Building Grant KY 94-38814-0473.

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