Recent advances in surimi technology

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SUMMARY: Since the first commercial development of surimi technology with the discovery of cryostabilization technique in 1959, surimi technology has made a series of advances. Developments in surimi processing include recovery maximization through decanter centrifugation and pH-modified protein solubilization for all fish species, and micronization and leaching under vacuum for oily, dark flesh pelagic fish. New developments in surimi seafoods are the use of protease inhibitors and TGase for gel enhancing, modified starch for freeze-thaw stability, improved pasteurization and packaging for extended shelf-life, nonconventional heat-setting processes, high shear extrusion for fiberization, surimi gel as a protective matrix for oxidation-sensitive nutrients, and acid-induced gelation. The surimi technology has also been introduced in non-fish muscle product processing for refinement and functionality improvement. The global status of surimi industry with future prospect is also discussed.

KEY WORDS: surmi technology, new developments, cryostabilization, decanter centrifuge, pH-modified protein solubilization, micronization leaching, TGase, modified starch, ohmic heating, extrusion texturization, emulsified surimi, acid-induced gelation

INTRODUCTION

With the discovery of cryostabilization technique by Nishiya and his group at Hokkaido Fisheries Research Station in 1959, surimi technology has made a series of advances. With the cryostabilization technique based on the addition of cryoprotectants to washed, refined fish mince to prevent freeze-induced protein denaturation, an intensive joint effort by Japanese government and industry led to a mechanized on-board surimi production in 1965. The productin of surimi in Japan peaked (350,000 - 400,000 metric tons) from 1972 through 1986, and the current world production of surimi is estimated to be 500,000 metric tons based on landings and production figures around the world (Table 1).

Table 1. World surimi production (1000 metric tons)

<table>
<thead>
<tr>
<th></th>
<th>Alaska pollock</th>
<th>Threadfin bream</th>
<th>Southern blue whiting</th>
<th>Pacific whiting</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>436.8</td>
<td>30.0</td>
<td>8.3</td>
<td>14.5</td>
<td>94.3</td>
<td>583.9</td>
</tr>
<tr>
<td>1990</td>
<td>389.5</td>
<td>40.0</td>
<td>5.8</td>
<td>20.0</td>
<td>87.1</td>
<td>542.4</td>
</tr>
<tr>
<td>1991</td>
<td>329.7</td>
<td>50.0</td>
<td>10.7</td>
<td>39.8</td>
<td>85.4</td>
<td>515.6</td>
</tr>
<tr>
<td>1992</td>
<td>357.0</td>
<td>50.0</td>
<td>19.8</td>
<td>46.9</td>
<td>82.8</td>
<td>556.5</td>
</tr>
<tr>
<td>1993</td>
<td>258.0</td>
<td>49.0</td>
<td>19.8</td>
<td>30.0</td>
<td>67.0</td>
<td>423.8</td>
</tr>
<tr>
<td>1994</td>
<td>302.8</td>
<td>60.0</td>
<td>29.0</td>
<td>45.0</td>
<td>72.7</td>
<td>509.5</td>
</tr>
<tr>
<td>1995</td>
<td>324.3</td>
<td>66.5</td>
<td>24.0</td>
<td>36.6</td>
<td>87.0</td>
<td>538.4</td>
</tr>
<tr>
<td>1996</td>
<td>274.7</td>
<td>69.0</td>
<td>30.0</td>
<td>39.0</td>
<td>86.2</td>
<td>498.9</td>
</tr>
<tr>
<td>1997</td>
<td>250.0</td>
<td>74.0</td>
<td>31.0</td>
<td>43.0</td>
<td>83.0</td>
<td>481.0</td>
</tr>
</tbody>
</table>

During the early phase of surimi technology development, most of pioneering works were led by Okada and his group at the Tokai Regional Research Lab. Some include processing variables, frozen storage, and ingredients on surimi gel-forming properties. With interest in surimi manufacturing from the dark-flesh pelagic fish, in 1965 Shimizu at Kyoto University introduced “alkaline saline leaching” using a wash water made up with 0.15% NaCl in 0.2% NaHCO3 which raises the post-mortem pH, typically below 6, to neutral for maximum protein functionality and the ease of fat separation.

Some of key contributions which were made during the last 30 years are as follows.

Seki and Arai at Hokkaido University - gel setting, thermostability of myofibrillar proteins
Tamoto - water quality on frozen storability of surimi
Matsumoto and Noguchi at Sophia University - cryostabilization mechanisms
Shimizu at Kyoto University - species variations in gel forming ability
Niwa at Mie University - gelation chemistry and setting mechanism
Makinodan and Kinoshita - alkaline protease in gel weakening (himodori)
Motoki and Seki - TGase and its biochemistry in surimi gelation
Hamann and Lanier at North Carolina State University - rheological aspects of thermal gelation
Kimura at Nippon Suisan Kaisha Co. and Noguchi at Taiyo Fishery Co. - advancement of science and technology for Japanese surimi industry
Lee at University of Rhode Island - development of surimi technology in the U.S., surimi manufacturing from red hake, introduction of modified starch for freeze-thaw stabilization of surimi-based products, and the role of hydrodynamic biopolymeric ingredients in composite surimi gels. Park and Morrissey at Oregon State University - surimi manufacturing from Pacific whiting, optimum pasteurization, ingredient and formulation technology, and establishment of the OSU Surimi School for education and training worldwide.

DEVELOPMENTS IN SURIMI PROCESS TECHNOLOGY

Micronization and washing for dark-flesh fish
Fish muscle is disintegrated in a vacuum homogenizer to control oxidation. The fine muscle particles facilitate effective leaching of lipid and heme pigments. Washing with a mixture of 0.05-0.1% tetrasodium pyrophosphate (TSPP) and 0.1% sodium bicarbonate (SB) where TSPP is for dissociation of actomyosin to myosin and actin to enhance gel-forming ability, and SB for pH adjustment. Being fine particles, washed mince needs to be recovered by a decanter centrifuge. Leaching is carried out under vacuum (two cycles at about 30 torr for 20-30 min) to release lipids, heme and odorous substances as gases vigorously escape from the muscle particles at a low pressure. The sardine and mackerel surimi prepared by this process showed 50% additional removal of lipids and 20-30% increase in gel strength with fish odor almost completely removed compared to the conventional process.

Further improvement of the process was made by employing an underwater mincing in the TSPP-SB solution which was believed to be due to a rapid dilution of blood hemoglobin. Despite the superior quality, the system is not being adopted by the surimi industry because of low yield and the high cost of the system for the return.

Use of Pacific whiting (Merluccius productus) for surimi manufacturing
Starting in 1990, Pacific whiting currently represents 20 -25% (around 30 metric tons/yr) of surimi production in the U.S. The presence of protease associated with a Myxosporida parasite prevented the Pacific whiting from surimi manufacturing. The discovery of food grade protease inhibitor such as beef plasma protein (used at about 1%), most effective among known inhibitors, led to a commercial production of whiting surimi. However, Park observed that surimi may not need to be treated with an enzyme inhibitor if intended product, such as fiberized crab analog, is based on thin extrudate providing that heating is rapid enough to inactivate protease. Because of the enzyme activity, it is critical to bring the fish in the refrigerated seawater or chilled seawater system and process them within 24 hours. Otherwise, the tissue softening and degradation occur making the fish unsuitable for surimi manufacturing.

Use of decanter centrifuge for yield improvement
The first commercial application of decanter centrifuge in the Alaska surimi process to recover fish meat particles from the leaching water was introduced by Ozaki at the Taiyo Fishery in 1985. With use of decanter centrifuge, the half of fine mince passed through the rotary screen in the conventional process can be recovered. Important considerations for the optimum result include solids to liquid ratio of feed, centrifugation speed, and temperature tolerance of mince proteins. The higher the speed, the drier the product, and the higher the product temperature. Additional removal of water will be accomplished by extending the centrifugation time or increasing the centrifugation speed at the expense of temperature tolerance of the myofibrillar proteins. If the product temperature reaches beyond the tolerance limit, significant losses of functionality, i.e. gel forming ability, and frozen storability may result. A process (AlfaPlus) based on a decanter centrifuge in place of rotary screen and screw press has been proposed for surimi manufacturing by Babbitt and engineered by Alfa Laval. It is intended for increased recovery by up to 50% from the loss by the conventional rotary screen process and for streamlining the process by eliminating several stages as shown in Fig 1. The main advantages are increased yield and a shorter throughput time. In sardine surimi production, a decanter centrifuge was first used in place of screw press to dewater washed micronized fish flesh by Nishioka and his group in 1989.
Protein recovery by acid/alkali solubilization

The process was first developed by Hultin and Kelieher. Muscle tissue is homogenized at 1 part muscle to 9 parts water. The pH of the mixture is adjusted to 2.5-3.5 for acid solubilization or to 10.5-11.5 for alkali solubilization depending on the species and muscle type. In these pH ranges, muscle protein will be solubilized and upon centrifugation the homogenate will separate into lipid (top layer), soluble protein (supernatant) and insoluble (sediment) fractions. After removal of non-protein fractions, the protein fraction is recovered by isoelectric precipitation at pH in the vicinity of 5.5 with added NaOH and another centrifugation step. A general acid-solubilization process scheme (200 g batch) of mackerel light muscle with recoveries and yields is shown in Fig. 2. Cryoprotectants are added to the resulting protein isolate for the product to be stored frozen. The pH adjustment to neutral with NaHCO₃ is preferably done at the time of gel preparation. Neutralization of protein isolate tends to lead to unassisted gelation during frozen storage. An interesting observation made later in the development was the decanter separation of supernatant was better achieved under the cold environment (2-3°C) while acid/alkali solubilization was done at 10°C. When cod and mackerel light tissue were tested, this new process resulted in significant improvements in yield (over 90% on a protein weight basis), gel strength and color, and the BOD reduction in the effluent.

At present, a pilot plant scale production system is being designed by Alfa Laval. The protein isolate recovered by this process can be used not only for surimi seafood, but also for other applications.

ADVANCES IN PROCESSING TECHNOLOGY FOR SURIMI SEAFOOD

Ohmic heating

Ohmic (or joule) heating is a process in which alternating electrical current is passed through an electrically conducting food product (Fig. 3). Heat is internally generated as a result of the electrical resistance of the food sample, resulting in a rapid heating. Significant improvements in gel strength of Alaska pollock, threadfin bream, white croaker, and sardine surimi both unseasoned and seasoned were first reported by Shiba. The report showed that the gel strengths of sardine and 2nd grade pollock surimi increased 4 fold and 2.5 fold for unseasoned and seasoned, respectively, with slight increases in the gel
strengths of seasoned SA grade pollock and croaker surimi. The rates of temperature increase by the ohmic heating and the 90°C water bath were 47°C/min and 0.9°C/min, respectively. It was thought that at such heating rate the surimi passes so rapidly through the modori temperature zone (about 60°C) that it forms a uniform gel network with a firmer texture. No changes in myosin heavy chains, actin and other myofibrillar protein components by ohmic heating were observed. In Pacific whiting, the ohmic heating brought about a twofold increase in gel strength even without a protease inhibitor compared to heating in a 90°C water bath, while Alaska pollock surimi was less responsive to a fast heating rate. The ohmically heated Pacific whiting gel showed a continuous structure under the SEM and a minimum degradation of the myosin heavy chain and actin as revealed by SDS-PAGE. All above results suggest that the gel forming response to ohmic heating varies with species, surimi quality, and the presence of protease.

A commercial ohmic unit is developed in Japan for both kamaboko and filament-type surimi-based products. Surimi paste is passed through a series of electrodes which induce heat directly through the paste resulting in a rapid and uniform heating with increased gel strength.

Extrusion texturization

The basic principle of extrusion texturization is based on high moisture extrusion cooking (HMEC) which involves protein melting or plasticizing and material texturization in protein-rich formulations with the moisture content ranging 50-80%. Premixed surimi with ingredients is fed into a twin extruder. The mix initially undergoes thawing/melting while being continuously mixed. As it further proceeds to the 2nd stage under extensive shear and high temperature (140-180°C), the plasticization (melting) of myofibrillar proteins occurs. In the final stage, melted proteins undergo crosslinking and texturization in a fashion similar to a thermoplastic extrusion of soy protein, followed by gradual cooling in the cooling die where the fiberization occurs without product expansion yielding a fine fibrous structure from surimi that resembles crab meat. The process was developed with a joint effort between National Food Research Institute and Nippon Suisan Kaisha.

Stabilization of omega-3 fatty acid rich fish oil in surimi gel through emulsification

Emulsion has been used to stabilize oils in processed food systems. Good examples are mayonnaise, salad dressing and frankfurter in which oil or fat remains relatively stable. It is believed that finely dispersed oil droplets or fat particles are protected by either protein membranes or a cohesive protein matrix. The same principle can be applied in stabilizing fish oil in a surimi gel. In order for the surimi gel to have a good protective function, the gel should have a highly cohesive structure which allows uniform dispersion of fine oil droplets in a fashion similar to encapsulation. In this way, the surimi gel can serve as a carrier of omega-3 fatty acid rich oil. This can be achieved by the use of high quality surimi. Table 2 confirms that a high gel strength surimi yields fine oil droplets with high stability index (reciprocal of droplet size).

<table>
<thead>
<tr>
<th>Gel strength (compressive force, kg)</th>
<th>Oil droplet size (mm)</th>
<th>Stability index (droplet size$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>0.19 - 10.75</td>
<td>5.26 - 0.10</td>
</tr>
<tr>
<td>1.8</td>
<td>19.6 - 176.7</td>
<td>0.05 - 0.006</td>
</tr>
</tbody>
</table>
Okazaki and her group demonstrated that fish oil can be stabilized in an emulsified surimi gel. They also found that polyols helped stabilize oil in surimi gel during a long-term frozen storage.

**Acid-induced surimi gel**

Generally, with lowering pH from the neutral the gel strength decreases. However, acid-induced gelation occurs at around pH 4 which is below the isoelectric point of myosin (pH 5.4), where protein molecules have net positive charges leading to limited intermolecular dissociation (solubilization) compared to complete dissociation seen in acid solubilization at pH 2.5-3.5. Such limited solubilization enables gelation upon heating without salt added (Table 3).

**Table 3. Properties of acid-induced Alaska pollock surimi gel**

<table>
<thead>
<tr>
<th>pH</th>
<th>Punch Force (g)</th>
<th>Deform Force (mm)</th>
<th>EM (%)</th>
<th>CL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5% NaCl</td>
<td>7.05</td>
<td>158</td>
<td>7.38</td>
<td>22.66</td>
</tr>
<tr>
<td>2% HAc</td>
<td>4.08</td>
<td>346</td>
<td>6.63</td>
<td>39.74</td>
</tr>
</tbody>
</table>

EM: centrifugal expressible moisture; CL: cooking loss

**Surimi production from nonfish meat sources**

Nonfish meat-based functional proteins (surimi) have been produced from the underutilized parts of beef, pork, poultry, and lamb using the conventional surimi manufacturing process. Attempts began with mechanically deboned chicken meat (MDCM) for its surimi making process and gelation behavior, followed by beef heart, beef and pork, and spent hen. Nonfish meat surimi serves as a low-fat, high gelling and texture supporting muscle protein ingredient which finds applications in processed meat products. Various commercial processes and applications have been developed worldwide.

**Global status and future prospects**

With a steady decline in demand coupled with a limited supply of raw materials, the volumes of surimi and surimi seafood production have slightly decreased worldwide. With the introduction of decanter centrifuge-based manufacturing system, the surimi industry enjoys production with a higher yield, but struggles with balancing between surimi and fillet production for an economic reason. Historically, Japan, U.S., and Korea have been the leading producing as well as consuming countries, followed by Thailand, Russia, and China. In Europe, the main activity led by France, Spain and Italy has been in surimi seafood whose markets continue to grow with creative and innovative development of new products. The new products include squid ring, baby eel, anchovy fillet, bologna, and ham, all in the analog product form.

As surimi seafood became a commodity product from a specialty item, the overall demand has slowed down in recent years. The enthusiastic market demand seen in the early 80’s could be revived if a new product line with a health or pleasure food concept is strategically introduced.

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**REFERENCES**

11. Lee,C.M. 1983. Effect of ingredients on texture and freeze-thaw stability of surimi gel during frozen storage. 28th
Atlantic Fisheries Technological Conference, Quebec.


28. Alfa Laval Fish and Meat Engineering, Soborg, Denmark (www.alfa-laval.se)


38. Yoshitomi B, Personal communication, 2001


