DEVELOPMENTS IN ENGINEERED SEAFOODS

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INTRODUCTION

Engineered seafoods marketed in the United States in 1986 amounted to 100 million pounds with a retail value of $350 million. It is indeed safe to say that these products have become a well recognized line of food products in the US marketplace and enjoyed by many consumers. The arrival of these modern food products and their current prominence in the US marketplace was not by coincidence; rather it has been the result of a well planned, orchestrated, and executed series of actions undertaken by the Japanese fish harvesting, processing and marketing industries. Noting a very rapid consumer acceptance of these products, representatives of the U.S. Fishing Industries, Trade Associations, Fishery Development Foundations and US Government joined forces to evaluate the Japanese technologies and attempt to apply them to the living marine resources under US jurisdiction, to derive maximum economic and social benefits for U.S. fishermen and processors.

The National Marine Fisheries Service's (NMFS) involvement in stimulating the development of minced fish and surimi technology within the United States has centered around the Saltonstall-Kennedy (S-K) grant research program for fishery development coupled with some highly focused in-house research. For the past 6 years NMFS has been partners with the US industry providing funds through cooperative S-K agreements to conduct research and development projects in the areas of minced fish and surimi.

Three major technological breakthroughs in seafood processing and preservation have taken place during the past two and a half decades:

(1) Mechanical separation and recovery of edible fish meat from skin and bones.
(2) Stabilization of processed minced fish meat as
surimi for good frozen storage shelflife.

(3) Fabrication that takes advantage of the functional
(gel forming) ability of fish flesh.

These developments have stimulated a renewed interest in the
fishing countries of the world for increasing the production
of food from underutilized species. Research in all three
areas by several countries over twenty five years has
suggested that careful application of technical advancements
in these three areas may make it technologically and
economically feasible to achieve full and near-optimum
utilization of most fishery resources for human food
purposes. Further, the state-of-the-art fabrication
technology suggests that the variety of end products is
nearly limitless, since they can be engineered to meet
product edibility preferences unique to many different
consumer groups of the world.

Surimi as we have all come to know is a Japanese term
meaning "a semi-processed wet fish protein", that is,
mechanically deboned minced fish meat which has been
washed to remove fat and undesirable matters (such as blood,
pigments, and odorous substances) and subsequently mixed
with cryoprotectants (such as sugar, and/or sorbitol) to
achieve good frozen shelflife. At this stage surimi is an
intermediate product, like flour made from a cereal grain,
that can be used in the production of a limitless variety of
end products.

Two extremely important discoveries about surimi were made
at a very early date in its development in the U.S. that
continue to influence this expanding US industry.

(1) Surimi is the common thread that links many
fisheries together -- pollock, menhaden, whittings,
hakes and all other species used in its produc-
tion. In the process of making surimi, the normal
organoleptic and edibility characteristics of the
particular species are lost resulting in a near-
neutral fish protein product.

(2) Surimi is a basic link between the seafood industry
and the food business in general. Its availability
as an animal protein and its unique functional properties have caught the attention of the entire food manufacturing complex in the US and abroad.

**RESOURCE AVAILABILITY FOR SURIMI**

The literature on surimi research and development abounds with reports and data about species with respect to gel-forming ability (GFA) which is the primary characteristic for determining suitability in making surimi. In Japan more than 50 species have been analyzed and their GFA established and ranked. Similar studies are being executed throughout the world and well over 100 species beyond those identified by Japan have been or are currently being tested to establish their GFA and thus their potential for making surimi.

In the United States, several target species have been the subject of similar investigation as shown in Table I. At this time no attempt has been made to generate, evaluate, and organize GFA data for many US species due in part, to the early stage of many of the investigations.

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>Species</th>
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<tbody>
<tr>
<td>New England and Northwest Atlantic</td>
<td>Red Hake</td>
</tr>
<tr>
<td></td>
<td>Silver Hake</td>
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<tr>
<td></td>
<td>Spiny Dogfish</td>
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<td></td>
<td>Ocean Pout</td>
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<td></td>
<td>Sand Larse</td>
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<td></td>
<td>Sculpin</td>
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<tr>
<td></td>
<td>Sea Robin</td>
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<tr>
<td>South Atlantic and Gulf of Mexico</td>
<td>Crocker</td>
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<tr>
<td></td>
<td>Atlantic Menhaden</td>
</tr>
<tr>
<td>West Coast</td>
<td>Rockfish Species</td>
</tr>
<tr>
<td></td>
<td>Pacific Whiting</td>
</tr>
<tr>
<td>North Pacific and Alaska</td>
<td>Alaska Pollock</td>
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<td></td>
<td>Atka Mackerel</td>
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</table>

Table 1.—US Species under Investigation
Three species (Alaska pollock, Atlantic menhaden, and Pacific whiting) which represent major US resources, are the target of extensive fishery development activities specifically for utilization in the production of surimi.

A brief description and comments about the status of development of these resources will highlight the stage of progress that has been achieved or not, and the existing challenges associated with the conversion of these resources into surimi.

Industrial development of the Alaska pollock resource in just a few years is hailed by all factions of the domestic fishing industry as "spectacular". The nature of the changes in this fishery are well illustrated in Table II. Much of the credit for this growth goes to a project funded by an S-K grant to the Alaska Fisheries Development Foundation (AFDF).

<table>
<thead>
<tr>
<th></th>
<th>1982</th>
<th>1986</th>
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<tbody>
<tr>
<td>Pollock Catch,</td>
<td>131,000 Metric Tons</td>
<td>1,077,000 Metric Tons</td>
</tr>
<tr>
<td>US Vessels</td>
<td>2,325, Metric Tons</td>
<td>169,000 Metric Tons</td>
</tr>
<tr>
<td>Pollock Processed by US Firms</td>
<td>$14.5 Million</td>
<td>$118.5 Million</td>
</tr>
<tr>
<td>Catch Value Ex-Vessel</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>U.S. Factor Trawler Processors</td>
<td>$830,000</td>
<td>$59.5 Million</td>
</tr>
<tr>
<td>Processed Value Ex-plant</td>
<td>???</td>
<td>$100 Million</td>
</tr>
<tr>
<td>Pollock Product Sales</td>
<td>19 Million Lbs.</td>
<td>120 Million Lbs.</td>
</tr>
<tr>
<td>US Sales of Surimi/Kamaboko</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>US Analogue Manufacturers</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

Source: Alaska Fisheries Development Foundation
The abundance of Alaska pollock is generally described in terms of abundance in both the Bering Sea and the Gulf of Alaska stocks which are believed to be almost exclusively separate from one another. There are substantial quantities of Alaska pollock from the US exclusive economic zone (EEZ) taken by Japan, and purchased by the Japanese from US boats, that can be directed into surimi by the US industry. In 1985 the US quota of Alaska pollock to Japan was 670,101 metric tons; and Japan purchased 430,076 metric tons from US catcher vessels. While the total harvest was not processed into surimi, the figures provide a useful benchmark to understanding the existing potential for continued US expansion in the Alaska pollock fishery at the same time as the overall developmental activities are shifting to improving the efficiencies in using this resource.

The second major US fishery resource subject to research and development via the surimi scenario is menhaden. This resource occurs along the Southeast Atlantic Coast and the Gulf of Mexico. Menhaden is the largest harvested US resource by volume of landings. Combined landings of Gulf and Atlantic menhaden purse-seine fisheries for reduction amount to about 1,202,000 metric tons annually (5 year average for 1981-86). In contrast to the non-oily, white-fleshed Alaska pollock, menhaden is an oily, darker fleshed species which historically has been used in the manufacture of fish meal for use in animal feed, and semi-refined fish oil that has been exported to Europe for use in margarine.

A third major resource available to U.S. fishermen in the EEZ off the West Coast of the US is Pacific whiting. Recent estimates put the harvestable biomass at between 300,000 - 400,000 metric tons, a significant quantity even when compared to Alaska pollock. The total tonnage of this resource fished annually by American and foreign fishermen in the territorial waters during the past five years amounted to 80-100,000 metric tons, most of which has been utilized by the Soviets. Historically there has been limited utilization of Pacific whiting in domestic products because a relatively large proportion of the fish are infected with a myxosporidian parasite. This infectious organism produces protease - an enzyme which induces undesirable textural changes in whiting products.

Investigations by Japanese researchers in the early 1970's included examination of the GFA of four species of
Merluccius including Pacific whiting. These early results showed that the GPA for these species was moderate to good, that is, the GPA's scored between 6 and 8 on a 10 point scale (very superior: 9-10); very low: 0-1). used by the Japanese at that time. There was one exception to this GPA rating for the four species, and that was parasitized Pacific whiting taken off the US Coast which scored very low.

Other less significant fishery resources exist in the US EEZ and inshore water which have the potential for utilization as raw materials for surimi. Without identifying and quantifying them, these fishery resources appear to have the potential to meet a continuing demand for surimi for the next 2-3 decades.

TECHNOLOGICAL DEVELOPMENTS AND PROCESSING RESEARCH

A stage of maturation in the processing of Alaska pollock has been achieved by the industry as a result of applying the results of technological investigations and processing research efforts that have been completed over the past 5 years. Early handling and storage studies, and investigation of functional properties impacted by handling and storage, provided essential information to the fishing sector on how to supply good quality fish to shore based surimi plants.

Armed with a working understanding of the Japanese surimi-making technology and the results of handling and storage studies, a pilot plant project was initiated in October 1984 with a requirement to produce a million pounds of surimi. The surimi production contract to Alaska Pacific Seafood in Kodiak, Alaska focused on quality, consistency and production economics, with the final product being surimi that met Japanese quality standards.

Technological improvements of the processing steps, performance of and use of different equipment was the next focus of research and development. This effort addressed improving processes, improving yields, lowering production costs, and assessment of waste stream materials including the potential for conversion of reclaimable material to marketable products. The contribution of data and
information from this work is expected to significantly improve the overall US surimi manufacturing process and US competitiveness.

Technology transfer to industry of the state-of-the-art surimi processing procedures from the Japanese industry, and US research and development experience was accomplished through a cooperative project among Federal, State, industry, and Japanese surimi processing experts. A manual, Introduction to Surimi Manufacturing Technology, was prepared and a training school was held in Alaska to transfer the technical know how, in a uniform manner, to production and quality control personnel of a number of US surimi processing firms. This has had a favorable impact of accelerating the industry application of the best available surimi processing technology and expanding domestic surimi production from Alaska pollock.

Shifting to surimi from menhaden, the US is still at a very early stage of research and development since there is no organized body of knowledge available from other scientists describing a good industrial process for producing surimi from fatty fishes. To generate this needed information, the NMFS awarded a research and development contract in February 1986, to the Zapata Haynie Corporation (ZHC) for a two year period to construct and equip a demonstration plant and investigate the technical and economic feasibility of producing surimi from Atlantic menhaden. A strategy similar to that used in Alaska calls for that project to supply 40 tons of menhaden surimi to a wide-range of researchers and food manufacturing firms for investigation of its functional and performance characteristics and to carry out new product development research. Because of problems with scheduling equipment deliveries, testing and operating-requirements, results were not conclusive in the first year. Menhaden from the Gulf of Mexico which is the same genus but somewhat different in size, composition and season of harvest, also likely will be investigated for use in the production of surimi following completion of the research on the Atlantic species. A technically-oriented conference on the manufacture of surimi from fatty fishes, tentatively scheduled to be held late in 1987, will provide an open forum for reporting progress on the surimi from menhaden project, and for exchanging results with international scientists investigating various aspects of producing surimi from other fatty fishes.
It is important to recognize that the processing equipment, its configuration, and the manufacturing process for the surimi from menhaden project was developed from the results of the Alaska pollock project and now is 4 years old. Newer equipment has been developed and alternative processing procedures more appropriate to menhaden, are evident from some experimental work already conducted at the demonstration plant. It is unclear at this time whether or not the technical and economic feasibility of producing surimi from Atlantic menhaden can be adequately demonstrated within the established parameters and schedule of the project currently in progress.

Recent research data show that parasitized Pacific whiting, could, when properly processed, provide a new source of surimi. Bench level research results suggest that by proper processing and treatment, the earlier described protease induced changes can be easily and economically neutralized. Pacific whiting surimi tested following such treatment exhibited functional properties that are comparable to surimi from Alaska pollock. However, additional work is needed on Pacific whiting to validate these research findings and demonstrate what are the optimum processing parameters for producing consistently good quality surimi from this resource.

Other laboratory scale research results on producing acceptable quality surimi from Pacific whiting suggest that neither the processing procedures for surimi from Alaska pollock, nor the experimental level processing regime for making surimi from menhaden are directly applicable to Pacific whiting. A demonstration plant type research project may be required to fully develop and provide the necessary data and information on handling, treatment and processing techniques that will facilitate the conversion of this resource and other groundfish species off the West Coast into surimi.

Assuming that the research and development period for a fishery to industrial maturation is roughly 6 years, based upon the model for Alaska pollock, and assuming that a Pacific whiting development project is implemented in 1990, the U.S. production of surimi from pollock, menhaden and Pacific whiting could easily reach an estimated 150,000 tons by the year 2000.
PRODUCT SAFETY

There have been only scant reports of gastroenteritis resulting from the consumption of surimi based foods marketed primarily in the form of analogue products. This is a good record for the industry in view of the rate of increase and volume of consumption of these imitation products in the United States.

Because of the rapid growth of this industry and its future stability, it is extremely important that the industry continue to produce consistent high quality products free of microbiological or other public health problems.

In-house research has been completed by NMFS at its Northwest and Alaska Fisheries Center that defines the processing, product, packaging and storage requirements necessary for the inhibition and/or destruction of Clostridium botulinum (bacterium responsible for botulism) in surimi analogues. Results of experiments showed that imitation crab legs from seven different processors would not support growth and toxin production by nonproteolytic C. botulinum during a 67-day storage period at 50°F. When the products were stored at an abuse temperature of 77°F, toxin production was delayed between 3 and 6 days. The results of these severe tests indicate that the ingredients of the products (2.4% to 2.6% water-phase salt among other things), provide significant protection from nonproteolytic C. botulinum and that small increases of salt and other ingredients could result in complete inhibition of growth and toxin production.

Based on the results of the research on C. botulinum a set of interim recommendations by Dr. Mel Eklund has been developed, published and provided to the industry as a first effort to assure that good manufacturing, packaging, and distribution practices are implemented by the industry. These recommendations are provided in an Appendix.

Information from the Food and Drug Administration indicates that over 900 surimi based analogue samples of foreign and domestic origin, obtained at retail stores in the US, were tested during the past 3 years. Of the 921 samples tested, two samples of breaded scallops and 2 samples of imitation
breaded shrimp contained *C. botulinum* type A spores. Five samples of imitation lobster contained type D spores. None of the products to date, contained type E spores (the type normally associated with fishery products). Sampling at the retail level and testing will continue for some time.

A collaborative effort between the surimi industry, NMFS, USDA, FDA and the Alaska Fisheries Development Foundation has been initiated to develop a Hazard Analysis of Critical Control Points (HACCP) program for surimi during the next year. The program was conceived to (a) establish industry consistency in product quality and safety, and (b) to facilitate industry efforts to achieve utilization of surimi as a raw ingredient in other processed foods, including meat and poultry products. The question of a need for a HACCP for the secondary processing and fabrication of surimi into end products already has been raised. However, a decision and action plan for its development have not been made at this time.

The diversity in application of surimi as an ingredient in processed food products, as well as in pharmaceuticals and cosmetics, promises dynamic growth to the US surimi industry. The progressive posture exhibited by the surimi processors in assuming a participating role in the development of a HACCP shows a commitment to long term planning and exercise of leadership by this emerging industry.

**DEVELOPMENT OF SURIMI BASED PRODUCTS**

Surimi based analogues currently are the major end products marketed in the United States. Products in the form of imitation legs, flakes and chunks, shrimp, scallops and lobster tails continue to be the major products in the marketplace.

In 1986 the U.S. market consumed 45,000 tons of products and industry experts predict consumption will exceed 50,000 tons in 1987. If consumption continues at the same rate as the past 3 years it will hit 70,000 tons in 1990, which is consistent with the trends indicating increased overall consumption of seafoods in the US. A recent prediction by the U.S. Department of Agriculture is that US seafood
consumption could double to 30 pounds per capita by the year 2020.

Use of surimi as a functional protein material is the centerpiece concept behind much of the latest research and development underway in the United States. Food technologists and others have been experimenting with surimi in new product development activities in a variety of ways as follows:

- in traditional salmon products such as patties and jerky
- in combination with blue crab meat to formulate uniform units of lumped crab meat.
- in sausage and processed meat products
- in ice cream
- in pet food
- in cosmetics such as face cream.

Other completed research has demonstrated that analogues can withstand the more vigorous heat sterilization process of canning and maintain acceptable product texture, color, flavor and odor when preserved in retortable pouches. This research, however, was limited to imitation crab chunks in sauce, that was packed in retortable pouches, processed, and stored. No difference in the organoleptic and color characteristics were apparent due to storage for periods up to one year, the length of the storage studies.
SURIMI AS AN INTERMEDIATE

Introduction of fish-protein products in the form of intermediates, for use as ingredients in other foods, is a new area for exploration by the industry. A window of opportunity for the seafood industry is in producing and marketing high-quality intermediate fish protein products, such as minced fish meat and surimi (from various species and in many styles of intermediates), that can be offered at attractive prices to food processors. Some limited research results show that fish protein products can be added to traditional meat and poultry products to improve binding properties, improve nutritional composition, change flavor and color, and reduce costs. They may also be used as extenders and protein supplements. One on-going activity focusing on this type of use is a S-K project undertaken by the AFDF in 1986 to obtain USDA approval for using surimi in a surimi/meat product. Recently the AFDF achieved approval of a sketch label for pork/surimi nugget patties. Final approval hinges on assurance to USDA that surimi entering meat and poultry plants is microbiologically safe on a consistent basis.

On an international level, the Codex Committee on Processed Meat and Poultry Products has been examining the question of a need to develop guidelines for the use of other protein products such as milk powder, casein, caseinate and fish in processed meat and poultry products. The Codex Committee on Fish and Fishery Products identified minced fish meat and surimi as two fish protein products that merit consideration for inclusion in processed meat and poultry products. While no action has been taken on the need for guidelines addressing the use of other protein products in processed meat products, the assertive action of the Codex Fish Committee should encourage world wide consideration of formulating new end products composed of meat and fish ingredients.

The direction of new product development research clearly indicates that surimi used as an ingredient in other foods and non-foods for many different purposes will continue to create real opportunities for developing seafood industries. While the market forecast is for consumption of analogues to level off slightly about 1990, new applications for surimi should create growth opportunities for the foreseeable future.
QUALITY AND FUNCTIONAL ASSESSMENT

Quality grades and grading procedures have been used by the Japanese surimi industry for several years. That system specifies (a) standard methodologies for the analysis of various compositional and functional properties of surimi and (b) application of the measurements to assignment of grades for surimi which are specific to the species of fish and location of the surimi process (factory ship or shore plant). At an early date, the emerging US surimi industry considered the Japanese approach, and then decided in favor of developing a different system of quality specifications rather than quality grades.

A research effort headed by Dr. Tyre Lanier of North Carolina State University was designed to critically evaluate both the current Japanese testing methodology and other available methodologies and to determine the optimum testing procedures to elaborate quality specifications for surimi in the U.S. The results of the three year research effort have been organized into a proposed standardized system of quality specifications for surimi that allows surimi users to purchase raw material according to its characteristics (compositional) and functional properties.

A decision has been made to prepare a manual of standard test methods for raw surimi that will contain the following level of detail:

- identity of properties to be tested
- identity of a "standard" method for testing each property
- a procedure for applying each method to achieve uniformity of measurement
- units of measurement to be used
- description of how results shall be expressed

The draft specification system presently is under review and consideration by a surimi technical committee for adoption as standardized test methods. It tends to parallel the system now used in the US meat industry by meat processors who purchase product (raw materials) by specifications based on product functionality.
The concluding efforts under this project will be to publish the standardized methods for quality and functionality assessment of surimi in a Manual of Methods for distribution and use by the industry. Steps have already been taken to familiarize industry quality control and inspection personnel with the methods and use of them.

END PRODUCT QUALITY STANDARDS AND PURCHASE SPECIFICATIONS

Secondary processing of surimi into seafood analogues has increased dramatically in the US from 1 plant in 1982 to 14 processing establishments in 1986. Additional plants and floating processors are scheduled to commence processing fish into surimi in 1987. As this industrial expansion was occurring in 1985, NMFS was requested to start the process of developing voluntary U.S. Quality Grade standards for the major end products, i.e., imitation crab legs, chunks and flakes, scallops, lobster tails, and shrimp.

An announcement of this request was published in the November 25, 1985 issue of the Federal Register and comments were invited from interested parties. In view of varied responses received and noting that the US surimi industry is in a very dynamic state at this time, it is unlikely that NMFS will proceed to develop voluntary quality grading standards for analogues in the near future.

Interest in using analogue products has been developing in the military services, motivated in part, by an evaluation of a crab food product by the Armed Forces Product Evaluation Committee (AFPEC). Additional product evaluation was carried out by the U.S. Army Natick Research Development, and Engineering Center (NRDEC) which resulted in a decision to develop a Commercial Item Description (CID) that can be used by the military services to purchase imitation crab products.

A draft CID has been prepared and circulated to interest groups and industry for views and comments. Once the CID is developed and approved, the product will be added to the Federal Supply Catalog as an approved item for military food service programs. Upon completion of these actions military purchasing of imitation crab products can commence, perhaps by the end of 1987. Assuming good acceptance by military personnel similar to that of US consumers generally,
opportunities for using analogues in a variety of prepared food items such as in half steam table tray packs, may be pursued on a timely basis.

INTERNATIONAL DEVELOPMENTS

The Codex Committee on Fish and Fishery Products responsible for elaborating international standards and codes of practice for fish and fishery products, at its 17th Session, took note of the global developments in the production of surimi and the implications for the Committee of the potential uses in fish and other food products covered by existing and draft international standards. In response to a request from the Committee, the US delegation agreed to prepare a background paper on the world-wide status of surimi and products manufactured therefrom for consideration by the Committee at its 18th session in 1988.

Other international developments in surimi and engineered seafoods have moved rapidly in the past year. Japan has substantial research underway investigating the technology for making surimi from oily fish, and may be somewhat ahead of the US at this time.

From investigations on making surimi from sardines and mackerels, Japanese scientists have announced the use of a new vacuum flow process which allegedly produces a better quality surimi resulting from a more thorough separation of oil and flesh. They visualize using this type of surimi in a number of the traditional fried kamaboko products for their domestic market. In addition, Japanese researchers and vessels have been active in several regions of the world conducting investigations as follows:

(a) in Peru, Chile, and Argentina researching jack mackerel and hakes
(b) in Europe working on blue whiting
(c) in New Zealand working on hoki and southern blue whiting

Recent curtailments of fishing in other countries' waters have prompted this flurry of Japanese activity.
The Koreans have stepped up activity in both surimi production and export of engineered seafoods. Korean exports of Alaska pollock surimi to Japan and the US have grown substantially in the last few years. This year, the Koreans outfitted several new factory vessels to process surimi off Alaska.

Much of the activity in Europe has concerned Japanese joint ventures, although the Faroe Island industry had undertaken surimi production on their own with blue whiting. Japanese analogue plants have been constructed in Great Britain and efforts to utilize blue whiting, cod frames, and Norway pout are in the test stages.

Norway has been conducting pilot plant operations on a number of species and has a mobile plant which moves from port to port as seasons and target species change. The rest of Europe has had little activity in surimi processing, but there are plans for analogue plants in several EEC countries.

In South America, Peru has made and distributed to school children, fish milk and fish cookies. These products combine processes reminiscent of fish protein concentrate as well as minced fish and surimi. Chile and Argentina have large quantities of mackerel and hake which they are planning to utilize in conjunction with Japanese interests.

Canada has one plant operating on the East Coast with a second one planned for operation under U.S./Canadian joint venture arrangement.

INTERNATIONAL TRADE

After Japan, the United States is the largest consumer of surimi based products. An estimated 110 million pounds will be sold in the U.S. in 1987. Until 1984, Japanese exports of surimi were small, while exports of analogue doubled each year. Now that the U.S. has close to 20 plants making either surimi or analogue products, the situation is changing. In 1986, Japan exported about 26,000 metric tons of analogue products to the US, a drop of about 6,000 tons from 1985. At the same time, US imports of surimi blocks, used for making the analogues, rose from less than 1000
metric tons in 1974-81 to 4,800 tons in 1985 and almost 8,000 tons in 1986. The increased secondary processing capacity built in the US in the last two years is the cause of this turnaround. In addition, there are three shore-based surimi plants in Alaska and three new processing vessels either operating or ready to produce surimi this year. The US recently started exporting surimi to Japan and this trade is expected to increase steadily.

Japan is exporting surimi and analogue products to about 24 countries. Over 80% of the volume comes to the United States with very small amounts entering Australia, Canada, U.K. and Europe. Some small amounts being shipped to Spain, Hong Kong and Singapore, are transhipped to the United States.

CONCLUSION

The efforts in the US and other countries for using underutilized fish species for human food purposes are largely concentrated on adapting raw material for processing into foods by controlling and engineering their appearance, flavor and texture keyed to consumer taste preferences. Much of this effort includes studying the characteristics of under-utilized species for GPA, thereby giving food processors the ability to accurately predict the performance and therefore the utility of the raw material in various food systems. Beyond these general conclusions there are others that can be drawn:

1. A wide-range of fatty and non-fatty species are being researched for potential use as food through the surimi and food processing technologies.

2. Many fishing countries of the world perceive that the surimi technology offers new opportunities for better uses of under utilized resources.

3. A single handling and processing technology is unworkable for all species. Technology is not directly transferrable between species groups. Technical developments and improvements in the surimi process are contining at a rapid rate and processing protocols are being refined depending upon the species being investigated.
4. Excellent equipment is readily available for producing surimi and end-products for some species; and improvement in both equipment, and process configuration continue to be made.

5. Process controls, and product safety and quality concerns are being addressed and implemented at a rate paralleling technological advancements.

6. The type and variety of surimi based end products will continue to expand well beyond the shellfish analogue that now dominate the market place.

7. Surimi as raw material for use in formulating all types of stand-alone foods and reformulating traditional foods is the next major wave of developments in the food industry. Some complex labeling issues may emerge from these developments.

8. International trade in both surimi and surimi based end products should continue to increase over the next two decades.

REFERENCES


TEXTURE AND FREEZE-THAW STABILITY OF
SURIMI GELS PREPARED WITH A COMBINATION
OF ATLANTIC POLLOK AND WHITE HAKE

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INTRODUCTION

It has been reported that species variation of muscle protein may be due to the differences in fishing ground, method, and season. Studies on the behavior of the purified fish actomyosin suggests there is no species difference in the intrinsic viscosity value, electrophoretic mobility, salting-in and salting-out range, etc., while the temperature at which denaturation takes place, and the velocity of denaturation differs from species to species. It is generally believed that actomyosin is related to the gel-strength of fish muscle products. From observations in the literature, it appears that hydrogen and hydrophobic bonding participate in species difference in "setting" temperature, i.e., formation and deformation of the setting and gel network formation, but the role of disulfide bonding is still uncertain.

Atlantic pollock and white hake are regionally abundant fish species off the coast of Maine and they demonstrate good gel-forming ability. Pollock muscle is brown to grayish and regarded as not really suitable for a crab or lobster meat-analog products. Little published information is available about the effects of blending surimi of different species and how variations of blending of surimi affect the gel characteristics of the finished product. Therefore, the objectives of this study were (1) to evaluate and compare rheological properties of surimi gels prepared with varying combinations of regionally abundant fish species, Atlantic pollock and white hake, and (2) to determine the relationships of their rheological properties to gross microstructure of the gels before and after successive freeze-thaw cycles.

MATERIALS AND METHODS

Preparation of surimi

Surimi was prepared separately from fresh Atlantic pollock (Pollachius virens L.) and white hake (Urophycis tenuis) within 24 hr after being caught off the coast of Maine. Fresh fillets were run through a mincer (Model 84141, Hobart MFG. Company, Troy, OH) with a die having perforations of 5 mm in diameter. The minced meat was washed four times with water, using 1 part fish meat to 4 parts water (W/W). After the fourth washing and draining, the slurry was dewatered by centrifugation (Model K, International Equipment Company, Needham Hts., MA) at 3000 xg. The meat pellet was chopped in a silent cutter (Model 84141, Hobart MFG. Company, Troy, OH) with sugar, sorbitol, and sodium tripolyphosphate (4%, 4%, and 0.2%, W/W, respectively) and subsequently packed in cryobags to be stored at -20°C until used.
Preparation of thermally induced surimi gel

The thawed pollock and hake surimi (overnight in a refrigerator, 78% moisture) were separately weighed and recombined in varying proportions. The blended surimi was chopped with 2% salt in a silent cutter for 9 min followed by 3 min additional chopping with or without 6% starch and with the addition of ice-chilled water to adjust the moisture level to 78%. The chopped surimi paste was extruded into 30 mm diameter cellulose casings and cooked at 90°C for 40 min in a water bath. These were immediately cooled in running tap water for 20 min. Ten types of samples were prepared using varying levels of pollock and hake surimi and incorporating either native potato or freeze-thaw stable modified starch, as shown in Table 1.

Table 1. Types of surimi pastes/gels prepared

<table>
<thead>
<tr>
<th>Types</th>
<th>Atlantic pollock</th>
<th>White hake</th>
<th>Starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>100</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>II</td>
<td>80</td>
<td>20</td>
<td>---</td>
</tr>
<tr>
<td>III</td>
<td>60</td>
<td>40</td>
<td>---</td>
</tr>
<tr>
<td>IV</td>
<td>40</td>
<td>60</td>
<td>---</td>
</tr>
<tr>
<td>V</td>
<td>20</td>
<td>80</td>
<td>---</td>
</tr>
<tr>
<td>VI</td>
<td>---</td>
<td>100</td>
<td>---</td>
</tr>
<tr>
<td>VII</td>
<td>100</td>
<td>---</td>
<td>6 (modified)</td>
</tr>
<tr>
<td>VIII</td>
<td>---</td>
<td>100</td>
<td>6 (modified)</td>
</tr>
<tr>
<td>IX</td>
<td>50</td>
<td>50</td>
<td>6 (potato)</td>
</tr>
<tr>
<td>X</td>
<td>50</td>
<td>50</td>
<td>6 (modified)</td>
</tr>
</tbody>
</table>

Measurement of textural properties

The prepared gels were left overnight at room temperature to equilibrate and were cut into cylindrical shapes (30 mm diameter and 25 mm long). The textural properties of the gels measured were compressive force, percent expressible moisture, and penetration force using an Instron testing machine (Model 1000, Instron Engineering Corp., Canton, MA) as an index of cohesiveness, water holding ability, and firmness, respectively. Compression was done uniaxially at a crosshead and a chart speed of 50 and 100 mm/min, respectively.

Compressive force was evaluated at 90% deformation with failure using a compression head of 10 cm in diameter. At the same time, the amount of moisture expressed upon compression was measured by collecting the fluid on filter paper and recorded in terms of % expressible moisture on a sample moisture weight basis. Penetration force was measured at 90% deformation with failure using a plunger of 9.5 mm diameter.

Samples were subjected to three freeze-thaw cycles to evaluate the freeze-thaw stability. Gel samples were frozen at -20°C for five days and thawed to equilibrate to room temperature before texture measurement for compressive force, percent expressible moisture, and penetration.
force.

A Hunter LabScan II spectrophotometer (Model PC100-B2, Hunter Associates Laboratory, Inc., Reston, VA) was used to measure the Hunter L, a, and b values of surimi pastes prepared with various combinations of pollock and hake surimi using a half inch aperture.

Structure analysis

For examination of surimi gels with a light microscope, small gel blocks were quickly frozen in liquid nitrogen and sectioned at 5 um with a Reichert cryostat microtome (Model 975C, AO Scientific Instruments, Buffalo, NY). Prepared sections were mounted on slides and stained for observation.

RESULTS AND DISCUSSION

Species differences in gel-strengthening ability have been well known. In this experiment, Atlantic pollock and white hake were used because they are abundant in the Gulf of Maine region. White hake, particularly, is an underutilized species. Even though preparation of surimi and surimi paste involves a vigorous chopping process, muscle associated collagen is seen (Fig. 1b). Collagen in the surimi paste shows its birefringence enhanced in polarized light (Figs. 1d and 1f). Intact potato and modified starches demonstrated characteristic Maltese cross patterns in polarized light (Figs. 1d and 1f).

The textural properties of surimi gels prepared with various combinations of Atlantic pollock and white hake, and with or without different types of starches, are shown in Figs. 2-4 for compressive force, percent expressible moisture, and penetration force, respectively.

Changes in color due to varying combinations of pollock and hake surimi are presented in Fig. 5. There were significant differences in whiteness and yellow and green colors between pollock and hake surimi.

Both pollock and hake surimi produced good surimi gels, but gels prepared with hake surimi, with or without starch, exhibited significantly higher compressive force, water holding ability (lower percent expressible moisture) and penetration force than those prepared with pollock surimi, with or without starch, respectively. It is well known that dark flesh, particularly red flesh meat, such as tuna, has weak gel strengthening ability. Usually, it has been said that the whiter the flesh, the stronger the gel-strengthening ability it has. Therefore, gradual increases in compressive force, water holding ability, and penetration force were observed with proportional increases in hake surimi (Figs. 2-4). Substantial increases in L (white) and b (yellow), and a (green) values were observed as the level of hake surimi increased (Fig. 5). In addition to improving the gel strength, the problem associated with the brown-gray color of pollock surimi can be alleviated by mixing with white hake surimi.

Modified starch used in this study is a blend of potato and tapioca starches (about 1:6 ratio, W/W) and modified by hydroxyalkylation for freeze-thaw stability.

The structure of a protein gel matrix of Type IV (Fig. 6b) was more uniform than that of Type I (Fig. 6a). Many air cells were observed
Fig. 1. surimi pastes before cooking. CG: collagen; MC: muscle associated collagen; MP: muscle protein; PS: potato starch; TS: tapioca starch. (a) Type I; (b) Type VI; (C) Type IX; (d) same as Fig. 1c, but photographed in polarized light; (e) Type X; (f) same as Fig. 1e, but photographed in polarized light.
Fig. 2. Effect of varying combinations of pollock and hake surimi, with or without different types of starch, on compressive force of gel.

Fig. 3. Effect of varying combinations of pollock and hake surimi, with or without different types of starch on % expressible moisture of gel.
Fig. 4. Effect of varying combinations of pollock and hake surimi, with or without different types of starch, on penetration force of gel.

Fig. 5. Effect of varying combinations of pollock and hake surimi on color of the paste.
throughout the latter protein gel (Type I). These observed structural differences in the protein gels were reflected by the differences in gel strength (Figs. 2 and 4) and water holding ability (Fig. 3) before the gels were frozen. On heat treatment the polarization became dull and potato starch lost its maltose cross (Fig. 6d).

When gels were subjected to repeated freeze-thaw cycles, there were slight decreases in compressive force in the case of the gels prepared without (Types I-VI) and with (Types VII, VIII, and X) modified starch (Fig. 2). A gel prepared with native potato starch (Type IX), however, showed a significant decrease in compressive force. Percent water expression and penetration force were significantly increased in the case of the gels prepared with native potato starch and without starch (Fig. 3), while gels prepared with modified starch did not show significant changes. During freezing, mechanically entrapped water in the gel matrix migrated to form ice crystals (Figs. 7a, 7b, 8a, and 8b). In this way, the protein gel matrix is densely packed and hardened due to the pressure exerted and dehydration of gel matrix resulting from the development of ice crystals. This resulted in increased freely moving moisture and firmness of the gel upon thawing to cause increased percent expressible moisture and penetration force. These changes were more pronounced when the gel was prepared with native potato starch because of the increased availability of water for ice crystal formation from collapsed potato starch. This process was visualized in Figs. 7c and 8c. On the other hand, there were no significant changes in compressive force, percent expressible moisture, and penetration force in the case of the gel prepared with freeze-thaw stable modified starch. Commercial freeze-thaw stable starches are modified by acetylation or hydroxyalkylation. These types of modification stabilize the starch gel by mutual repulsion of amylose molecules and thus hold the moisture between the molecules. This retards or eliminates the association of amylose molecules, i.e., crystallization or retrogradation phenomenon during cold storage. Starch granules embedded in the protein gel matrix which, when swollen, exerted pressure on and drew moisture from the matrix. This caused the gel matrix to become more compact and firm. The composite gel-reinforcing effect of starch in heat-induced surimi gel was demonstrated in Figs. 2-4. When the gel is frozen, water for ice crystal formation is available from the protein gel matrix and gelatinized starch. Availability of water for ice crystal formation is greater in the gel prepared with native starch because this type of starch cannot withstand drastic physical changes, such as freeze-thaw cycle and is collapsed resulting in increased availability of water for ice crystal formation. Furthermore, calculated water was added to adjust moisture content to 78% during gel preparation. This fact explains why more pronounced changes in textural properties occurred in the gel prepared with potato starch than those prepared without it (Figs. 2-4). This also reflected the difference in gel structure during freeze-thaw cycles (Figs. 7a-7c and 8a-8c). In contrast, gels prepared with modified starch (Types VII, VIII, and X) did not show significant changes in the textural properties because moisture imbibed by starch granules from the gel matrix during cooking lowered the moisture level in the surimi gel. This moisture is not available for ice crystal formation because it is held within the gelatinized starch as mentioned above during accelerated freeze-thaw cycles of the gel (Figs. 2-4). Gel microstructure analysis supports this phenomenon (Figs. 7d and 8d).
Fig. 6. Surimi gels after cooking at 90 °C for 40 min. AC: air cell; GC: gelatinized collagen; GP: gelatinized potato starch; GT: gelatinized tapioca starch. (a) Type I; (b) Type VI; (c) Type IX; (d) same as Fig. 8c, but photographed in polarized light; (e) Type X.
Fig. 7. Surimi gels after first freeze-thaw cycle. CP: collapsed potato starch; IC: ice crystal. (a) Type I; (b) Type VI; (c) Type IX; (d) Type X.
Fig. 8. Surimi gels after third freeze-thaw cycle. (a) Type I; (b) Type VI; (c) Type IX; (d) Type X.
In conclusion, 1) good surimi gels can be prepared from Atlantic pollock and white hake. The concept of the mixed species in this study was suggested by the brown to grayish color of the pollock muscle, 2) the problem associated with the color can be alleviated by mixing the pollock with white hake surimi, which also improves the texture, 3) presence or absence of starch and the type of the starch clearly influences the gel texture, and 4) changes in the textural properties were supported by the changes in the gross gel microstructure during the accelerated freeze-thaw cycles.

REFERENCES


ACKNOWLEDGEMENTS

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EFFECT OF POWDERED CELLULOSE ON THE TEXTURE AND WATER
BINDING PROPERTIES OF SURIMI-BASED PRODUCTS

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INTRODUCTION

The overall textural characteristics of surimi-based products are affected by moisture, the functional properties of surimi, ingredients and the temperature-time relationship during heat setting (Lee, 1986). Lately, various types of ingredients were tested in surimi-based products for their ability to strengthen gel or to modify gel texture. Most of work has been focused in starch (Okada, 1963, Lee, 1984, Wu et al., 1985, Kim and Lee, 1987) and protein (Lee, 1986). Starch was found to have a gel strength effect, while protein does have texture modifying effect at appropriate levels. Recently, interest has been directed to powdered cellulose because it can contribute to binding, strength, structure in food systems (Labell, 1986).

Powdered cellulose is purified from specially treated wood pulp which has the lignins and impurities removed (Labell, 1986). Chemically, it is relatively inert which means it will not interfere with any reactions taking place in a food system (Miller, 1986). Among ingredients, the application of cellulose in surimi-based products has not been investigated. The objective of this research was to study the texture-modifying and water-binding properties of cellulose in surimi-based products.

MATERIALS AND METHOD

Sample preparation.

Frozen surimi prepared from Alaska Pollock (Theragra Chalcogramma) was manufactured by the Alaskan Pacific Seafoods (Kodiak, AK) and obtained from the North Pacific Seafood (Seattle, WA). Surimi was kept at -20°C until used. Cellulose powder and modified starch (Nustar®) were obtained from James River Co. (Berlin, NH) and Staley Manufacturing Co. (Decatur, IL), respectively.

Surimi-based products, both molded and fiberized forms, were prepared from a 800g surimi block. Surimi was partially thawed to -2°C and chopped for 2 min with 2%
salt (on a surimi basis) in a silent cutter, followed by an additional chopping for 8 min with other ingredients, namely, cellulose, starch or ice-chilled water to adjust the necessary moisture level. Modified starch was also added in combination with cellulose to determine the freeze-thaw stabilizing ability of cellulose when used together with modified starch.

One portion of the resulting surimi paste was stuffed into cellulose casings (25 mm dia.) to make a molded gel (shrimp analog) and steam-cooked for 20 min in an autoclave at 90°C and atmospheric pressure. Cooked gels were immediately cooled with cold water and left overnight at room temperature before gel forming properties were measured.

The other portion was used to make a fiberized product (crab analog). It was prepared by extruding the paste into a thin sheet through a reactangular nozzle having a narrow opening (1.5 mm). The extruded sheets were then partially heat-set for 2 min in the oven at 110°C and scored into 1.5 mm-wide strips by a cutter similar to a noodle cutter. The resulting sheet of strips was folded manually into a rope, wrapped with a satin wrap, and steam-cooked for 15 min in an autoclave at 90°C and immediately stored in a refrigerator at 4°C before being evaluated for textural properties.

Formulation and Processing.

The following experiments were conducted: 1) the different sizes ranging from 11 μm to 55 μm were tested for their binding properties in surimi gel; 2) using the best performing size of cellulose from the result of first experiment, the effect of cellulose levels on the texture of surimi-based products was studied; and 3) the effect of varying cellulose levels at a 6% starch level on gel texture. Along with water binding and gel texture, freeze-thaw stability of both molded and fiberized gels was also studied by measuring textural change, such as increases in rubberiness and firmness, as well as by analyzing sensory properties. For this purpose, all samples were subjected to 1 freeze-thaw cycle.

Texture analysis

The textural properties of gels measured were compressive force at 90% deformation, expressible moisture and penetration force using the Instron Testing Machine.
(Model 1122). Testing was carried out following the procedures described by Lee (1984) except for shear test. The shear test was conducted only on the fiberized gel. In this test, the cylindrical fiber bundle was sheared longitudinally by a flat blade (1 mm thick) while the sample rested on a stationary plate. The maximum force required to cut the sample was measured as shear force and was used as an index of firmness and chewiness.

The texture evaluation was also conducted by a sensory panel of 7 people from the department who previously participated in the evaluation of the similar products. They were asked to score 4 textural characteristics (firmness, chewiness, rubberiness and moistness) for their intensity and desirability, as well as overall desirability using a structured 9-point scale (1:least, 9:greater). Samples were presented in the flake form of fiberized crab leg products.

Statistical analysis

The data were analyzed using the Statistical Analysis System Package (SAS, 1982). Correlation coefficients were calculated to determine relationships between sensory and instrumental parameters using the CORR program. Duncan's Multiple Range Test was used to determine the significance of the differences between treatments.

RESULTS AND DISCUSSION

Table 1 shows effect of various sizes of cellulose on the texture of surimi gel. Cellulose of the size from 11um to 20um performed better than ones larger than 20um in terms of gel cohesiveness and water binding. As the size of fiber increased beyond 20um, both gel cohesiveness and water binding ability decreased with increasing sense of chewing a thread.

Under the microscope, it was clearly seen that finer grade cellulose (11um) was dispersed finely throughout the matrix. Within the range of grade of 11um-20um, coarser grades tend to be better binders than the finer ones. Water absorption is also affected by the fibrous particles of powdered cellulose. The coarse grades have a more open structure, which allows them to absorb up to seven times their weight in water. Finer grades have a more dense structure, and they generally only absorb three to four times their weight in water (Miller, 1986). It can be suggested that gel forming of protein in surimi gel can be
affected by the amount of moisture held in cellulose.

Table 1. Effect of various sizes of cellulose on the texture of surimi gel.

<table>
<thead>
<tr>
<th>SIZE OF CELLULOSE(μm)</th>
<th>expressible moisture(%)</th>
<th>compressive force</th>
<th>GEL STRENGTH(kg)</th>
<th>penetration force</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>1.47 c</td>
<td>16.6 a</td>
<td>0.303 a</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2.10 b</td>
<td>9.91 c</td>
<td>0.196 c</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>1.48 c</td>
<td>12.3 b</td>
<td>0.253 b</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.37 c</td>
<td>13.2 b</td>
<td>0.257 b</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>2.37 b</td>
<td>8.0 d</td>
<td>0.195 c</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>3.80 a</td>
<td>5.46 e</td>
<td>0.195 c</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>2.76 b</td>
<td>6.5 ed</td>
<td>0.172 d</td>
<td></td>
</tr>
</tbody>
</table>

* tested at 2% and 78% moisture
** means within each column with different letter are significantly different (P<0.05).

Table 2. Effect of cellulose level on the texture of surimi based molded products

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>expressible moisture(%)</th>
<th>compressive force</th>
<th>GEL STRENGTH(kg)</th>
<th>%increase rigidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control(0)</td>
<td>0.49 ab</td>
<td>93.3 a</td>
<td>0.446 a</td>
<td>20.6</td>
</tr>
<tr>
<td></td>
<td>(4.70) (c)</td>
<td>(45.8) (b)</td>
<td>(0.538) (a)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.39 b</td>
<td>80.3 b</td>
<td>0.402 a</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>(3.0) (d)</td>
<td>(45.7) (a)</td>
<td>(0.430) (abc)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.51 ab</td>
<td>70 c</td>
<td>0.377 b</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>(2.36) (e)</td>
<td>(46.5) (a)</td>
<td>(0.393) (c)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.52 ab</td>
<td>60.1 d</td>
<td>0.365 bc</td>
<td>43.8</td>
</tr>
<tr>
<td></td>
<td>(5.24) (b)</td>
<td>(36.3) (b)</td>
<td>(0.523) (ab)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.57 a</td>
<td>44.8 e</td>
<td>0.319 c</td>
<td>31.0</td>
</tr>
<tr>
<td></td>
<td>(5.50) (a)</td>
<td>(37.3) (b)</td>
<td>(0.418) (bc)</td>
<td></td>
</tr>
</tbody>
</table>

* 20 μm powdered cellulose at 78 % moisture.
** ( ) indicates the value after 1 freeze-thaw cycle
Effect of cellulose level on the texture of surimi based molded products is shown in Table 2. Overall, compressive and penetration forces of molded products gradually decreased with an increase in the cellulose level.

After 1 freeze-thaw cycle, the gel showed a good freeze-thaw stability at 1% and 2% level with a least amount of expressible moisture and a smallest increase in rigidity. Cellulose at levels greater than 2% may have prevented its ability to reduce ice crystal growth upon freezing. This is in turn caused increases in expressible moisture and penetration force (rigidity).

The results of effect of cellulose level on the textural characteristics of crab leg products are shown in Table 3. There were no significant changes up to 2%, but beyond this level, there were significant decreases in firmness, chewiness and rubberiness with an increase in cellulose level (P<0.05).

Table 3 Effect of cellulose level on the textural characteristics of crab leg products

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>shear force (kg)</th>
<th>firmness</th>
<th>chewiness</th>
<th>rubberiness</th>
<th>moistness</th>
<th>overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>0.73 (1.48)</td>
<td>6 (7.0)</td>
<td>6.4 (7.25)</td>
<td>6.2 (7.5)</td>
<td>6 (5.75)</td>
<td>5.9 (6.5)</td>
</tr>
<tr>
<td>1</td>
<td>0.73 (1.26)</td>
<td>5.2 (7.38)</td>
<td>6.2 (7.5)</td>
<td>6.6 (7.13)</td>
<td>6 (5.75)</td>
<td>6.2 (7.5)</td>
</tr>
<tr>
<td>2</td>
<td>0.68 (1.14)</td>
<td>5.2 (6.13)</td>
<td>5.6 (7.13)</td>
<td>5.5 (7.0)</td>
<td>6.6 (6.5)</td>
<td>5.6 (8.0)</td>
</tr>
<tr>
<td>3</td>
<td>0.59 (1.02)</td>
<td>3.9 (5.38)</td>
<td>4.8 (6.13)</td>
<td>4.9 (6.0)</td>
<td>6.2 (6.5)</td>
<td>5.4 (6.63)</td>
</tr>
<tr>
<td>4</td>
<td>0.53 (0.98)</td>
<td>3.8 (5.25)</td>
<td>3.8 (5.75)</td>
<td>4.2 (5.75)</td>
<td>5.8 (5.75)</td>
<td>4.0 (6.63)</td>
</tr>
</tbody>
</table>

* 20 μm powdered cellulose at 78% moisture
** ( ) indicates the value after 1 freeze-thaw cycle.

No significant differences in texture score were noted between control and products with 1% level. However, the better overall texture value was obtained at a 1% level.
After 1 freeze-thaw cycle, there were slight decreases in firmness, chewiness and rubberiness with an increase in the cellulose level. There were no significant differences between control and at 1% level in the texture score of chewiness, firmness and rubberiness. However, the better overall texture score was marked at the 1% level cellulose due to a more meaty, less rubbery texture and a better mouthfeel. Crab leg products without cellulose showed the lowest desirability score due to a rubbery and dry texture. The highest overall texture score was received at the 2% level. The improvement in the texture of the cellulose-containing gel is probably due to the freeze-thaw stabilizing ability of cellulose. The microscopic examination revealed that cellulose was able to reduce ice crystal growth at a moderate moisture level during frozen storage.

Table 4 shows effect of addition of cellulose with 6% starch on the textural characteristics of molded products. Overall, cohesiveness and rigidity of molded products gradually decreased with an increase in the cellulose level with 6% starch. Gels without starch had a more rigid and less cohesive texture with high expressible moisture than the one with starch.

Table 4 Effect of addition of cellulose with 6% starch on the textural characteristics of molded products.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>expressible moisture(%)</th>
<th>compressive force</th>
<th>penetration (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>0.68 a</td>
<td>43.6 bc</td>
<td>0.473 a</td>
</tr>
<tr>
<td>S-C:6-0</td>
<td>0.57 a</td>
<td>60.2 a</td>
<td>0.370 b</td>
</tr>
<tr>
<td>S-C:6-1</td>
<td>0.66 a</td>
<td>49.3 b</td>
<td>0.325 c</td>
</tr>
<tr>
<td>S-C:6-2</td>
<td>0.64 a</td>
<td>41.0 cd</td>
<td>0.328 c</td>
</tr>
<tr>
<td>S-C:6-3</td>
<td>0.57 a</td>
<td>40.3 cd</td>
<td>0.320 dc</td>
</tr>
<tr>
<td>S-C:6-4</td>
<td>0.64 a</td>
<td>35.5 d</td>
<td>0.280 d</td>
</tr>
</tbody>
</table>

* S-C:modified starch:powdered cellulose
** means within each column with different letter are significantly different (P<0.05).
Addition of cellulose above 1% significantly reduced the cohesiveness and rigidity of surimi gels despite their ability to bind moisture. This could be its disruptive effect on the composite-reinforcing effect of starch.

Table 5 shows the effect of addition of cellulose with 6% starch on the textural characteristics of crab leg products. The highest textural strength and desirability was obtained at 1% cellulose level. Beyond 1% level, the textural values gradually decreased with an increase in the cellulose level.

Table 5 Effect of addition of cellulose with 6% starch on the textural characteristics of crab leg products.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>shear force (kg)</th>
<th>firmness</th>
<th>chewiness</th>
<th>rubberiness</th>
<th>moisture</th>
<th>overall texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>0.57 (1.55)</td>
<td>6.5 (7.13)</td>
<td>7 (7.13)</td>
<td>6.7 (7.13)</td>
<td>5.5 (6.0)</td>
<td>6.6 (4.75)</td>
</tr>
<tr>
<td></td>
<td>[172]</td>
<td>[6.4]</td>
<td>[+9.9]</td>
<td>[-28]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-C:6-0</td>
<td>0.45 (0.75)</td>
<td>5.3 (6.0)</td>
<td>5.8 (6.0)</td>
<td>5.2 (5.0)</td>
<td>5.7 (6.15)</td>
<td>5.92 (6.5)</td>
</tr>
<tr>
<td></td>
<td>[66.7]</td>
<td>[-3.8]</td>
<td>[+7.9]</td>
<td>[+9.8]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-C:6-1</td>
<td>0.45 (0.93)</td>
<td>5.83 (5.88)</td>
<td>6.8 (6.5)</td>
<td>5.3 (5.5)</td>
<td>5.7 (6.38)</td>
<td>6.25 (6.75)</td>
</tr>
<tr>
<td></td>
<td>[107]</td>
<td>[-3.7]</td>
<td>[+11.9]</td>
<td>[+8.0]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-C:6-2</td>
<td>0.40 (0.91)</td>
<td>5.0 (5.85)</td>
<td>5.5 (6.3)</td>
<td>5.1 (4.63)</td>
<td>5.2 (6.75)</td>
<td>6.13 (6.25)</td>
</tr>
<tr>
<td></td>
<td>[127]</td>
<td>[-9.2]</td>
<td>[+29.8]</td>
<td>[+1.95]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-C:6-3</td>
<td>0.38 (0.92)</td>
<td>4.8 (5.0)</td>
<td>5.0 (5.75)</td>
<td>4.7 (4.5)</td>
<td>5.75 (6.75)</td>
<td>6.0 (7.13)</td>
</tr>
<tr>
<td></td>
<td>[142]</td>
<td>[-4.2]</td>
<td>[+17.4]</td>
<td>[+18.8]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-C:6-4</td>
<td>0.34 (0.63)</td>
<td>4.5 (4.63)</td>
<td>4.6 (5.0)</td>
<td>4.0 (4.25)</td>
<td>5.6 (7.0)</td>
<td>5.6 (7.38)</td>
</tr>
<tr>
<td></td>
<td>[85.3]</td>
<td>[+6.25]</td>
<td>[+5.6]</td>
<td>[+31.8]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

( ) indicates the value of 1 freeze-thaw cycle
[ ] indicates % increase after 1 freeze-thaw cycle.
All starch-cellulose containing formulas (5.6-6.3) were slightly inferior to control(6.6) in the overall texture score. A moderate correlation(r=0.76) between shear force and rubberiness was observed at the 99% level of confidence. This suggests that shear test can be used to measure changes in rubberiness.

After 1 freeze-thaw cycle, the overall textural scores of cellulose-containing crab leg formulas at all levels were higher than those without cellulose. This was due to a decrease in rubberiness and an increase in moistness. As expected, the control without starch and cellulose became too rubbery and dry and received the lowest desirability score. As shown previously in Table 3, all textural values gradually decreased with an increase in the cellulose level. However, when crab leg products were formulated with starch, the ones having cellulose received better desirability score than those without cellulose. It means that cellulose prevents the toughening of fiberized crab leg products during frozen storage. This result demonstrates the advantage of adding cellulose to products to be distributed frozen.

CONCLUSION

Cellulose at 1-2% level helps keep products, both molded and fiberized forms, from becoming rubbery and dry during freeze-thaw cycles by effectively preventing freeze syneresis and improving water binding of a gel. Modified starch alone results in a less moist and starchy texture. However, with addition of cellulose, a product having a moist and less starchy texture can be produced after frozen storage.

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ACKNOWLEDGEMENT

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TEXTURE-MODIFYING EFFECT OF NONFISH PROTEIN IN SURIMI GEL

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INTRODUCTION

As a result of increasing consumption of surimi-based shellfish analog products, a marked advancement in the surimi technology has been made primarily in the manufacturing of surimi and shellfish analog products.

Texture of the product produced with surimi alone tends to be rubbery and less desirable to the Americans' taste. Not only to ease the rubberiness but also to allow flexibility in formulation, textural modification of surimi-based product has been attempted. Modification of texture can be achieved not only by a mechanical texturization process, but also by the incorporation of gel-forming ingredients such as starch and protein. Addition of ingredients to the surimi-based product can contribute to the improvement of textural properties as well as economic and nutritional benefits (Lee, 1986; Lee and Kim, 1986).

When nonfish proteins are incorporated into surimi, each protein contributes different functional and textural properties to the surimi gel. Therefore, understanding of the physicochemical properties of nonfish proteins and their interaction with fish protein is important to optimizing the textural property of the surimi-based products. There appear to be potential demands for high protein surimi-based products which stemmed from the idea of bringing the protein level of the surimi-based product (11-12 %) to that of the natural product (16-17 %). This may waive manufacturers an "imitation" labeling requirement according to a recent FDA ruling on "nutrition equivalency". The formulation of a high protein product needs to be developed without reducing the desirable textural quality which is normally found in the ordinary surimi-based product.

The objectives of this study were: 1) to study texture-modifying properties of nonfish proteins in surimi gels, and 2) to determine the relationship between functional properties of nonfish proteins and nonfish protein-incorporated surimi gel.
MATERIALS AND METHODS

Preparation of nonfish protein gel

Nonfish proteins evaluated were soy protein isolate (SPI), whey protein concentrate (WPC), lactoalbumin (LA), egg white (frozen raw, EW), milk protein isolate (MPI) and wheat gluten (WG). SPI was obtained from Grain Processing Corporation (Muscatine, Iowa); EW from Hygrade Egg Products (Elizabeth, NJ); WPC, LA and MPI from New Zealand Milk Products (Petaluma, LA); and WG from Ogilvie Mills (Minnetonka, MN). Protein gels were prepared by blending the proteins for 10 min in a silent cutter with addition of 1.5 % salt and a proper amount of water to adjust the moisture level to 78 %. One portion of paste was stuffed into a 25 mm diameter cellulose casing and the other portion placed into centrifuge tubes. Casings were cooked for 20 min in a steam-cooker.

Evaluation of gel texture and water binding ability of nonfish protein

Gel properties of samples were evaluated by a method reported by Lee (1984) using an Instron Testing Machine (Model 1122). Protein content of the samples were determined by the micro-kjeldahl method (1975). Water binding ability (WBA) of the nonfish protein was determined by a centrifugation method and expressed in % amount of water retained in the sample. Centrifugation was done for 10 min at 3000 g using a Sorvall centrifuge (Model RC 2B) after cooking the paste for 20 min in a steam-cooker while it was in the tube. The water binding ability of nonfish protein during heating was referred to "thermal hydration". The water binding ability was also determined by measuring the amount of moisture expressed from the plug of cooked protein gel (25 mm x 25 mm) upon compression and expressed in % moisture retained in the sample.

Preparation of surimi gel

The Alaska pollock (Theragra chalcogramma) surimi obtained from the Alaska Fisheries Development Foundation (Anchorage, AK) was used throughout the study. Half-thawed surimi was chopped for 10 min in a silent cutter with addition of 2% salt, 3% nonfish protein and a proper amount of water to adjust the moisture level to 78 %. All ingredients were added on a surimi weight basis. The resulting paste was divided into three portions. One part of
the paste was extruded into a sheet (1.5 mm thick, 25 mm wide and 70 mm long) and partially heat-set for 15 min at 50°C to run a tensile test. The second one was also extruded into a sheet, partially heat-set for 2 min at 110°C, and fiberized to run sensory evaluation and shear test. The third one was stuffed into a 25 mm diameter cellulose casing. Fiberized and casing-molded samples were cooked for 15 and 20 min, respectively, in a steam-cooker. The fiberized sample was cooled and kept in a refrigerator, while the casing-molded sample was cooled down in the running cold water for 10 min and kept overnight at room temperature prior to the evaluation of the textural properties.

Evaluation of textural and water binding properties

Textural properties of gels were evaluated following the method reported by Lee (1984) except for shear test using an Instron Testing Machine. Testing parameters included compressive force at failure (cohesiveness), penetration force (rigidity), and % expressible moisture (water binding ability) for the casing-molded samples; tensile and shear force for the fiberized samples. In the shear test, a fiberized sample was sheared longitudinally by a descending flat blade (1 mm thick) while the sample rested on a stationary plate. Water binding of casing-molded surimi gel was determined by expressible moisture measured by the compression test.

Sensory evaluation of fiberized products

Sensory evaluation of the textural properties of the fiberized surimi gel product was conducted by a group of 5 panelists. The textural characteristics evaluated were firmness, rubberiness, chewiness, moistness and overall texture acceptability. The panel was composed of graduate students and faculty of the department who had a prior experience in evaluating the quality of surimi gel products. The panelists were asked to score the intensity and desirability of each textural characteristic on a 9-point scale.

Analysis of data

Analysis of variance was used to determine the statistical significance of the sample variations in physicochemical properties of nonfish protein. The degree of correlation was determined between functional properties of nonfish protein and nonfish protein-incorporated surimi gel.
RESULTS AND DISCUSSION

The results of the textural evaluation of the nonfish protein-incorporated surimi gel was shown in Table 1. The control surimi gel exhibited a consistently and significantly higher compressive force (cohesiveness) than those gels with nonfish proteins ($p < 0.05$). There was a significant variation in cohesiveness among the nonfish protein-incorporated surimi gels ($p < 0.05$). A similar trend was found in the rigidity with exception of EW-containing surimi gel. On the other hand, the tensile force of control surimi gel was lower than that of the nonfish protein-incorporated surimi gel except WPC-containing gel. The higher gel strength shown by the control was attributed to the greater amount of gel-forming myofibrillar proteins in the control surimi gel than those in the nonfish protein-incorporated surimi gel. The decreased gel strength of the nonfish protein-incorporated surimi gel was due to a combination of reduced amount of myofibrillar proteins and the interference of nonfish protein, primarily albumin-type, with formation of cohesive gel matrix (Okada, 1964). On the

Table 1. Textural properties of nonfish protein-incorporated casing-molded surimi gel products

<table>
<thead>
<tr>
<th>PROTEIN SOURCE</th>
<th>COMPRESSIVE FORCE(Kg)</th>
<th>PENETRATION FORCE(g)</th>
<th>% EXPR. MOIST.</th>
<th>TENSILE FORCE(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT.</td>
<td>51.0 a</td>
<td>390.0 a</td>
<td>0.39 bc</td>
<td>41.3 bc</td>
</tr>
<tr>
<td>SPI-1</td>
<td>41.0 b</td>
<td>373.0 a</td>
<td>0.34 cd</td>
<td>43.0 bc</td>
</tr>
<tr>
<td>SPI-2</td>
<td>35.3 b</td>
<td>323.0 bc</td>
<td>0.26 d</td>
<td>44.3 abc</td>
</tr>
<tr>
<td>WPC</td>
<td>19.3 d</td>
<td>296.7 cd</td>
<td>0.33 cd</td>
<td>37.0 c</td>
</tr>
<tr>
<td>LA</td>
<td>21.0 d</td>
<td>273.3 d</td>
<td>0.48 ab</td>
<td>44.7 abc</td>
</tr>
<tr>
<td>MPI</td>
<td>16.7 e</td>
<td>213.3 d</td>
<td>0.50 a</td>
<td>42.0 bc</td>
</tr>
<tr>
<td>EW</td>
<td>38.7 b</td>
<td>400.0 a</td>
<td>0.53 a</td>
<td>51.3 a</td>
</tr>
<tr>
<td>WG</td>
<td>28.7 c</td>
<td>360.0 ab</td>
<td>0.44 ab</td>
<td>48.3 ab</td>
</tr>
</tbody>
</table>

* Significantly different between values with different letters ($p < 0.05$)
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<th>PENETRATION FORCE(g)</th>
<th>% EXPR.</th>
<th>TENSILE FORCE(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT.</td>
<td>51.0 a</td>
<td>390.0 a</td>
<td>0.39 bc</td>
<td>41.3 bc</td>
</tr>
<tr>
<td>SPI-1</td>
<td>41.0 b</td>
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<td>43.0 bc</td>
</tr>
<tr>
<td>SPI-2</td>
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<td>0.26 d</td>
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<td>37.0 c</td>
</tr>
<tr>
<td>LA</td>
<td>21.0 d</td>
<td>273.3 d</td>
<td>0.48 ab</td>
<td>44.7 abc</td>
</tr>
<tr>
<td>MPI</td>
<td>16.7 e</td>
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<td>0.50 a</td>
<td>42.0 bc</td>
</tr>
<tr>
<td>EW</td>
<td>38.7 b</td>
<td>400.0 a</td>
<td>0.53 a</td>
<td>51.3 a</td>
</tr>
<tr>
<td>WG</td>
<td>28.7 c</td>
<td>360.0 ab</td>
<td>0.44 ab</td>
<td>48.3 ab</td>
</tr>
</tbody>
</table>

* Significantly different between values with different letters (p < 0.05)
contrary, nonfish proteins tended to increase the tensile force of the fiberized products. It was not clear, however, whether such an increase in tensile force was an indication of stiffness or elasticity. The variation of gel properties among the nonfish protein-incorporated surimi gel was attributed to the differences in physical and functional properties of nonfish proteins (Table 3). Addition of nonfish protein having higher gel strength resulted in

Table 2. Sensory textural properties and shear force of the nonfish protein-incorporated fiberized surimi gel products

<table>
<thead>
<tr>
<th>PROTEIN SOURCE</th>
<th>SHEAR FORCE (g)</th>
<th>FIRMNESS</th>
<th>CHEWINESS</th>
<th>RUBBERINESS</th>
<th>OVERALL TEXTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONT.</td>
<td>933 a</td>
<td>7.3 a</td>
<td>7.2 a</td>
<td>7.0 a</td>
<td>(6.0) a</td>
</tr>
<tr>
<td>SPI-1</td>
<td>527 d</td>
<td>5.0 c</td>
<td>5.6 b</td>
<td>6.0 ab</td>
<td>(6.7) a</td>
</tr>
<tr>
<td>SPI-2</td>
<td>750 b</td>
<td>5.6 bc</td>
<td>5.7 b</td>
<td>5.3 b</td>
<td>(6.7) a</td>
</tr>
<tr>
<td>WPC</td>
<td>417 e</td>
<td>6.3 b</td>
<td>6.0 b</td>
<td>5.7 ab</td>
<td>(7.0) a</td>
</tr>
<tr>
<td>LA</td>
<td>550 d</td>
<td>5.3 bc</td>
<td>5.3 b</td>
<td>5.3 b</td>
<td>(6.3) a</td>
</tr>
<tr>
<td>MPI</td>
<td>650 c</td>
<td>5.5 bc</td>
<td>5.5 b</td>
<td>5.0 b</td>
<td>(7.0) a</td>
</tr>
<tr>
<td>EW</td>
<td>743 b</td>
<td>5.6 bc</td>
<td>5.7 b</td>
<td>5.3 b</td>
<td>(7.0) a</td>
</tr>
<tr>
<td>WG</td>
<td>600 cd</td>
<td>6.0 bc</td>
<td>5.7 b</td>
<td>5.3 b</td>
<td>(7.0) a</td>
</tr>
</tbody>
</table>

* Without parenthesis: intensity  
With parenthesis: desirability  
** Significantly different between values with different letters (P < 0.05)
formation of a weaker gel. It was reported that such a result was due to a disruptive effect of nonfish protein on the network formation of surimi gel (Lanier, 1986). Nonfish proteins react to various treatments in different manners depending on their physicochemical properties such as molecular size and weight, ionic effect, protein concentration, amino acid composition, and chemical bondings involved in gelation (Butkus, 1974; Beveridge et al, 1980).

Table 2 shows the results of the textural evaluation of fiberized products. The shear force of the control surimi gel was significantly greater (p < 0.05) than all nonfish protein-incorporated surimi gels. The intensity of sensory score of the control followed the same trend as the shear force. The desirability in terms of three textural characteristics and overall texture, on the other hand, showed an opposite trend. The lower score shown by the

Table 3. Gel strength and water binding ability of nonfish protein gels

<table>
<thead>
<tr>
<th>PROTEIN SOURCE</th>
<th>COMPRESSION FORCE(kg)</th>
<th>PENETRATION FORCE(g)</th>
<th>WATER BINDING (%)</th>
<th>THERMAL HYDRATION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI-1</td>
<td>0.60 d</td>
<td>25.0 d</td>
<td>98.3 d</td>
<td>100</td>
</tr>
<tr>
<td>SPI-2</td>
<td>0.61 d</td>
<td>29.0 d</td>
<td>97.4 d</td>
<td>100</td>
</tr>
<tr>
<td>WPC</td>
<td>3.08 a</td>
<td>275.0 a</td>
<td>76.1 a</td>
<td>79</td>
</tr>
<tr>
<td>LA</td>
<td>1.2 c</td>
<td>107.7 c</td>
<td>78.2 b</td>
<td>80</td>
</tr>
<tr>
<td>EW</td>
<td>1.98 b</td>
<td>116.0 b</td>
<td>91.27 c</td>
<td>100</td>
</tr>
<tr>
<td>WG</td>
<td>No failure</td>
<td>108.0 c</td>
<td>Trace</td>
<td>60.3</td>
</tr>
</tbody>
</table>

* Significantly different between values with different letters (p < 0.05).

1. \[
\frac{(1 - \text{moisture content of sample})}{\text{the amount of water upon compression}} \times 100
\]

2. \[
\frac{(1 - \text{moisture content of sample})}{\text{the amount of water upon centrifugation}} \times 100
\]
control was due to a higher intensity, but less desirable sensory score. However, addition of nonfish protein reduced the intensity score and thus increased the desirability score.

In an effort to determine what caused such variations in the textural properties of nonfish protein-incorporated surimi gel, the relationship of the functional properties of nonfish protein to the properties of nonfish protein-incorporated surimi gel was studied. The functional properties studied were water binding ability and gel strength. Woodward et al (1982) and Hermansson (1975) claimed that water binding ability of protein is one of the most important factors which control the textural and structural properties of heat-induced protein gel. There was a great deal of variation in water binding ability among proteins, where WPC showed the least water binding ability, but with the highest gel strength for both cohesiveness and rigidity (Table 3). Such a low moisture absorption by WPC may have facilitated more protein-protein interaction, resulting in the development of a firmer gel.

Table 4. Correlations among the water binding ability, gel strength of nonfish protein and nonfish protein-incorporated surimi.

1. \( r = -0.65 \) between thermal hydration (centrifugation) and compressive force of nonfish protein gel (Table 3).

2. \( r = 0.94 \) between water binding based on expressible moisture of nonfish protein by compression (Table 3) and compressive force of nonfish protein-incorporated surimi gel.

3. \( r = 0.97 \) between thermal hydration (Table 3) and compressive force of nonfish protein-incorporated surimi gel, WG excluded (Table 1).

4. \( r = -0.68 \) for rigidity between nonfish protein-incorporated surimi gel and nonfish protein gel.

5. \( r = -0.63 \) for cohesiveness between nonfish protein-incorporated surimi gel and nonfish protein gel.
Cohesiveness of nonfish protein-incorporated surimi gels highly correlated with thermal hydration \((r = 0.97, \text{ W}G \text{ excluded})\), as well as with water binding based on the expressible moisture \((r = 0.94)\) of nonfish protein gels. This result suggests that both thermal hydration and expressible moisture of nonfish protein are good indices of protein functionality to be related to the textural properties of nonfish protein-incorporated surimi gel. Thermal hydration of nonfish proteins inversely correlated with cohesiveness \((r = -0.65)\), rigidity \((r = -0.46)\), and % expressible moisture \((r = -0.97)\) of nonfish protein gel. In summary, nonfish protein with less thermal hydration and greater expressible moisture produced a stronger nonfish protein gel due to protein concentration, but it made surimi gel weaker when nonfish proteins were incorporated. Unlike cohesiveness, rigidity poorly correlated with thermal hydration \((r = 0.26)\) as shown in Table 4. Cohesiveness is the degree of protein binding in the matrix and its value is better considered for the gel forming ability than rigidity value (Lee and Chung, 1987). This may explain the discrepancy between two correlation coefficients.

The result of protein analysis suggested that water binding ability of nonfish protein was dependent upon its protein content. WPC having 74% protein content showed the least WBA, while SPI having 89% showed the highest WBA. The protein concentration of SPI is higher than that of WPC. It means that SPI has more solid concentration and thus more surface area which allows more water molecules for absorption.

Conclusions

Addition of nonfish protein to the surimi-based products improved the textural properties by reducing the intensity of undesirable rubberiness, chewiness and firmness, thus increasing the desirability of overall texture. The reduction in the intensity of such undesirable textural characteristics resulted in a soft mouthfeel.

Thermal hydration of nonfish protein inversely correlated with the cohesiveness of nonfish protein gel, but it moderately correlated with the cohesiveness of nonfish protein-incorporated surimi gel. Gel strength of both cohesiveness and rigidity of nonfish protein gel showed an inverse correlation with those of nonfish protein-incorporated surimi gel. It was concluded that the main
cause of variations in the texture-modifying effects of
different nonfish proteins was the differences in thermal
hydration and gelation properties of nonfish proteins.
Therefore, thermal hydration and gelation properties can be
effectively used in determining texture-modifying ability of
nonfish proteins

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   Technol. 38(11): 69

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