OREGON'S WHITING FISHERY: A CASE STUDY IN COOPERATIVE DEVELOPMENT

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I am a trawl fisherman. A few short years ago whiting was to me, and virtually every other fisherman of all gear types on this coast, a trash fish. In fact we spent considerable time trying to avoid it during the summer months when whiting was prolific off this coast. In those days we fished primarily for soles, founders, lesser amounts of rockfish, and ling cod. We were often driven from the grounds we wanted to fish because of the presence of whiting.

There were good reasons in those days for the lack of interest in Pacific whiting. These reasons all added up to a "chicken and egg' situation. Our boats were too small and primitive to catch or handle the whiting effectively. The average trawler in those days here on the coast was a 50 to 65 footer with 175 to 350 hp. Our electronics and our fish preservation systems were primitive. We were a far cry from the modem trawlers that you see in the whiting fleet today: vessels ranging from 70 to 100 ft long, with horsepower ranging from 600 to 1200 and with a vast array of sophisticated electronics costing many hundreds of thousands of dollars. Above all, these efficient trawlers of today are pelagic trawlers that can effectively zero in on the whiting at any possible depth.

The plants in those days were neither capitalized nor equipped sufficiently to handle whiting. They had very limited ice-making and refrigeration capacity. The plants in general had a low capital intensity, and the fixed costs were low. Practically all of their costs were operating costs with a high degree of hand labor so that if you didn't handle much product it didn't affect your bottom line too much. The plants focused their attention on the traditional species of salmon, crab, and halibut (all species with high unit value), and increasing amounts of shrimp. Relatively small amounts of groundfish were bought from trawlers. Here was the chicken and egg situation. There were constant market limits on what the trawler could produce; hence, the vessel's capitalization costs and fixed and operating expenses had to be low. In other words, both trawlers and plants were too small and inefficient to handle whiting, a low unit value species, in volume.

In addition to this set of obstacles, Pacific whiting also presented what were apparently other insurmountable difficulties. The fish had a soft fiber and delicate texture which rapidly became too mushy to fillet. The fish also contained a parasite, myxosporidia, whose enzyme caused the fiber to deteriorate in 5% to 15% of the fish.

To catch, process, and distribute whiting, therefore, would demand that a product he produced and processed in great volume at a low price into several product forms, all of which would require large investments in automated processing machinery, refrigeration systems, and cold storage capacity. The low capital intensity of the plants would have to change to one of very high capital intensity with considerable investments.

Correspondingly, it was obvious that the whiting would require larger and much more sophisticated vessels with greater horsepower and expensive electronics. In this period, 1965 to 1976, the first tentative experiments were being made in holding fish in refrigerated seawater or "champagne slush" seawater systems. It also must be remembered that the automated processing machinery that is much in vogue today was in its infancy in the 1960s and 1970s.

Yet interest in the development of the whit ing resource was there. A few visionary fishermen were interested; we knew the stuff was worth something because the Soviet fleet was here in great numbers, taking huge amounts of fish every summer. There had to be a way to utilize this resource. This random interest was shared by a few plants that were constantly experimenting with whiting. There were ongoing efforts to market small lots of fillets or headed and gutted whiting to the traditional California trawl fish markets.

Throughout this period the Oregon State University Seafood Laboratory in Astoria was continuing to experiment with whiting with efforts primarily concentrated on the parasite and its destructive enzyme.

Of greater significance in other parts of the world, great strides were being made in fishing gear technology (in particular pelagic trawling and its associated requisite electronics, such as sonars and net sounders). A rapid profusion of automated processing equipment was being produced, and considerable progress was being made in preservation systems from the vessel to the retail store. This era also saw the beginnings of commutated products and analog products and a growing recognition that certain types of seafood lent themselves very well to the production of consumer-ready, fully manufactured seafood products.

But a further catalyst was needed to bring about a mode by which Oregon coastal boats could successfully enter the whiting fishery. The Fisheries Conservation and Management Act of 1976 provided the missing link. This "200-mile bill" gave Americans exclusive control of the fisheries resources within their 200-mile fishery conservation zone. The Soviets recognized the priorities implicit in these controls and entered into a joint-venture company with American interests. The Soviet economy, even in those days, was very weak. The Soviets required continued access to our fish stocks, and they also needed a constant stream of hard currency for trade purposes since their own currency was inconvertible on the world money markets. A joint Soviet-American company could successfully reach both of these objectives.

In 1978, after exhaustive political battles within the American fishing industry, the new Soviet-American joint venture began operation. In August 1978, I purchased an 86-foot trawler with 780 hp, pelagic trawl gear, and associated electronics. We began fishing operations off the central Oregon coast, and after a disastrous two weeks during which we taught ourselves how to midwater trawl, we hit "pay dirt" The pay dirt was modest. In a 24-day period we harvested 958 metric tons (MT) of Pacific whiting, which was processed by two Soviet BMRTs into headed and gutted (H&G) whiting and some whiting block fillets. That first year we all lost money, but the concept of small catcher boats delivering transferable cod ends with tows of up to 25 tons to the processor vessel and the subsequent rapid processing and freezing of the fish was firmly proven. The joint venture would work.

In 1979 the Soviet-American joint venture fleet took approximately 11,000 MT of whiting. In 1980 approximately 48,000 MT were delivered, and by this time all of us involved-the independently owned American catcher boats, the leased Soviet processing ships, and the Soviet-American joint-venture company-were making good profits.

An expansion of operations into the Alaskan area was planned to go after various flounders and cod fish. The first bottom fish joint venture also proved to be enormously successful. By this time other American fishermen were beginning to realize the potential the joint ventures offered for their efforts, even though American processing companies, by and large, were not interested in the enormous resources of whiting off the Pacific Northwest coast and the pollock, cod fish, and flounder resources in the Gulf of Alaska and the Bering Sea.

A stroke of fate provided the next impetus for a very rapid development in the Pacific whiting fishery. In 1979 the Brezhnev regime in the Soviet Union invaded Afghanistan. The U.S. government almost immediately canceled future allocations of any groundfish resources in the American fishery conservation zone to the Soviet Union. In one stroke of fortune the Soviets lost some 350,000 to 450,000 tons of direct allocations in the American zone. This fish had to be made up in some form, and the only vehicle remaining to ensure product for Soviet consumption was the Soviet-American joint venture. By the early 1980s the Soviet-American joint venture was taking over 100,000 MT of whiting off this coast and better than 260,000 MT of flounder and cod fish in Alaska.

This amount of fishing activity, as well as joint ventures between American vessels and Korean and Japanese companies, brought about a boom in vessel construction and conversion on the Oregon coast for vessels to fish in the new joint ventures. Almost overnight the economic potential for larger and more powerful trawlers could be realized, not only in the rapidly developing joint ventures with several nations, but because these same vessels could also harvest large amounts of rockfish in the winter fisheries off the Pacific Northwest coast. This sizable fleet was rapidly acquiring the experience necessary to fully prosecute the whiting fishery in great volume. One part of the equation necessary to develop this important fishery in the State of Oregon had been obtained: the catcher fleet was a reality.

Concurrently, considerable progress was being made in a number of contingent necessary areas. The 1980s witnessed an explosion of interest and effort in the production of surimi. The Japanese fishing vessels had been largely pushed out of the Alaskan pollock fishery by the joint ventures.

The Japanese continued to procure their surimi requirements from the pollock fishery by using surimi production factory ships as joint venture partners with American catcher boats. By the mid-1980s considerable effort was applied to the production of pollock surimi in Alaskan shore plants. After a few false starts, a rising volume of high-quality surimi products streamed from these plants. The requisite processing was highly automated, and it was recognized that this same automated equipment could be used to produce surimi from whiting if the characteristics of whiting would lend themselves to the production of surimi.

Intensive marketing efforts were also made in the United States for the analog products that were manufactured from the surimi base. The public acceptance of these products proved to be very positive.

Work at the Oregon State University Seafood Laboratory intensified. Great attention was being paid to efforts to counteract the effeds of the parasite. Product forms were being tested and evaluated, and preservation systems were being studied in order to overcome the characteristics of whiting which led to short shelf life in the vessels, plants, and retail outlets. From all of these efforts, a quality surimi product from whiting began to be produced.

Simultaneously, small but important efforts were being made in northern California to produce round whole whiting, H&G product, and whiting fillets for the traditional California markets. Each year saw the production of some 1,660 to 2,099 MT, which provided some "market reality experience."

Economic greed can be an appreciable human behavioral dynamic. More and more shoreside processors were recognizing the simple lesson that a great deal of money could be made from whiting after all, the catcher boats were doing it. It was evident that vast quantities of this product were being consumed in the Eastern European community, the Third World, and of greater import, the West em European market. The domestic processors were also beginning to feel the pinch of reduced quotas in the traditional groundfish fisheries. Suddenly, as the markets expanded over more and more space and versatile processing machinery was being introduced, their access to resources was diminishing.

Whiting became more and more of a conversational topic on the waterfronts of Newport, Coos Bay, and Astoria. It became obvious to everybody that not only was the Oregon Seafood Laboratory heavily involved with whiting, but the National Marine Fisheries Service's seafood technologists were continuing their pioneering efforts, which had really begun in the late 1960s with NMFS-sponsored programs to process and manufacture fish protein concentrate, a fish flour, from whiting.

In August 1989, I requested a meeting with officials of the Oregon State University Sea Grant program, the Oregon Department of Agriculture, the Oregon Economic Development Department, and the Oregon Trawl Commission. During that meeting I quickly sketched the development of the Oregon trawl fleet into the whiting fishery and presented our catching capability. I described the effective automated processing machinery which was now available to process whiting. I reviewed the market opportunities for a variety of product forms that I felt could come from the whiting resource. I described improved refrigerated preservation systems that would allow the fish to be transported to shore and processed in shoreside plants.

I next described the status of the traditional groundfish stocks and pointed out that they would become overstressed if the new wbiting trawler fleet had to revert to fishing upon those traditional stocks. I surveyed the successful Alaskan campaigns to produce surimi from pollock as well as pollock fillets and fillet blocks and stated that I felt the same thing could be done with whiting.

All of the vital components for shoreside processing of whiting seemed to be in place. I told the group that I felt that a catalyst was necessary to bring Oregon fully into the whiting business, from the fish in the ocean through product output from the doors of the processing plants. I felt that catalyst should be a detailed, thorough, and intensive study of whiting's potential. We should look at the strength and viability of the resource, competitive resources worldwide, the outlook and market opportunities for products that could be produced from these resources, an intensive study of both the domestic and international markets for whiting products in the form of H&G whiting, whiting fillets, whiting fillet blocks, minced whiting products, and, of course, surimi. Other areas that a study should cover were the requisite type and cost of capital for both vessels and shore plants to successfully produce these products, and all infrastructure requirements in terms of available utilities, water resources, labor, environmental criteria, permitting requirements, transport routes, and so on.

I felt that the study should issue from a single administrative source and that because whiting was such an important resource to the State of Oregon, the funding should come from (1) industry, (2) the Oregon State University Sea Grant program, which could provide the requisite seafood technology, (3) the Oregon Department of Agriculture (ODA), which was already engaged in the marketing of Oregon seafood product, and (4) the Oregon Economic Development Department (OEDD), which would be a potential source of demonstration grants and low-cost capital.

I then placed on the table my check for $10,090 and made the remark that it was time to "ante up." The stakes were high and the Oregon coastal communities would benefit greatly if we could succeed in bringing ashore for processing and distribution the greater part of this enormous resource off our coast.

The response was overwhelmingly positive. By the time the meeting concluded, the director of ODA, the Sea Grant director, and the director of OEDD had signed on with concrete pledges of support Within a very few weeks the monies had been secured. ODA and OEDD came up with approximately $112,990 in direct support of the study. OSU committed an enormous amount of in-kind research capability from the OSU Seafood Laboratory, organizational services from the OSU Marine Extension program, and marine resource economic expertise from the Coastal Oregon Marine Experiment Station.

It was decided that the Oregon Coastal Zone Management Association (OCZMA) should be the administering agency for the study because of its long history of positive accomplishments on the Oregon coast and because the agency had the full support of the Oregon Legislature, from whom, of course, the funds would be obtained.

The first order of business was to decide that a policy-setting Whiting Steering Committee should be established to supervise the study. Accordingly the steering committee consisted of the director of OCZMA, the executive director of the Oregon Trawl Commission (a commodity commission to which all Oregon trawlers engaged in groundfish production belong and whose principal activity is the promotion of marketing efforts for Oregon trawl-caught product), a representative of the ODA, a representative of OEDD, and me, a representative of the Oregon whiting trawl fleet.

The various phases of the study were laid out, and appropriate consultants and institutions were given the authority and responsibility to commence specific parts of the study. Each component had a well-defined scope of work, and critical relationships between the components were identified and established. Great care went into the design of the marketing survey, which proved to be one of the most comprehensive and well-designed marketing studies ever attempted in the seafood industry.

The Whiting Steering Committee met on an almost monthly basis to review progress. During the tenure of the study, key grants and low-interest loans were obtained for a Newport based processor who was enthusiastic about moving into the whiting market. We learned a great deal as the result of this plant's activities in handling whiting from the point of capture through processing and into H&G frozen whit, ing, fresh H&G product, and fresh and frozen whiting fillets.

The ODA began an immediate andeffective campaign featuring whiting products and promotional activities nationally and internationally. Valuable marketing experience was a constant input from the ODA back to the study group.

The OSU Seafood Lab began an intensive series of research projects to produce fresh and frozen whiting surimi; continued effort was devoted to overcoming the effects of the myzosporidian enzyme. The Seafood Lab also concerned itself with experimental work on whiting protease and inhibitors to be used in the production of whiting surimi.

A related activity of the Coastal Oregon Marine Experiment Station was to establish computer modeling techniques regarding efforts and methods needed to extract the highest possible use of revenue from the whiting resource over time and space, from fishing vessels through to the consumer% plate.

The Whiting Steering Committee decided that a technical conference and seminar on Oregon whiting would be a desirable and useful activity. We wanted to tell the Oregon whiting story. We realized that the product was not popular in the marketplace, and indeed that market experience was limited. A conference was organized, and in August 1990,400 invitations were mailed to an audience that consisted primarily of seafood brokers and wholesalers who had handled Pacific whiting and also great quantities of competing whiting products from all over the world.

The conference was a great success. Over 140 people attended from all segments of the seafood industry: fishermen, processors, institutional agencies, brokers, and wholesalers. The feedback from this conference provided

valuable information for the authors of the study. It afforded all of us a great slice of market reality. The experience engendered from this meeting provided not only feedback but cogent guidelines for the conclusion of the study and for industry, the ODA , OEDD and OSU.

The study was completed in February 1991 and was presented to the Oregon State Legislature and the industry. The study yielded great dividends. It clearly established for the Pacific Northwest seafood industry that there was now a body of considerable expertise that could be relied on to provide advice on any phase of what was now being called the whiting industry. The study and the conference also clearly established in the industry not only the need for interdisciplinary cooperation but a general climate of cooperation between fishermen, processors, and marketers of whiting products. Finally, the whiting study conclusively established a means of entry into the whiting business for several large outside firms desirous of obtaining or enlarging their presence in the seafood industry.

The cooperative planning and cooperative efforts also allowed the industry to speak with a concerted, positive, and definitive voice in the realm of fishery politics. It became obvious that the industry would have to procure a guaranteed allocation of the whiting resource over time in order for the industry to succeed. It was now able to go to the Pacific Fishery Management Council to seek guaranteed allocations on an annual basis of sufficient resources to develop the industry.

These political efforts to date have been successful, and a united coastal whiting industry is in the last stages of securing the requisite allocations. Here again, in the area of fishery politics, the whiting industry is accepted as just that, a coherent industry.

The United States Secretary of Commerce recognized in August 1991 the validity of the concept of guaranteed access to the whiting resource for catcher boats delivering whiting to shoreside processing plants. These guaranteed quotas established a priority over at-sea processors. Direct allocations proved to be the medium by which intensive investments would be made in both processing plants and the catcher vessels that would deliver the resource.

Enough market experience had been gained in 1991 to dictate that whiting products were competitive and would be broadly accepted, providing that a quality product could be delivered to these markets.

Landings of whiting to shore plants quadrupled and quintupled from August 1991 to the end of the season in November 1991. The fall and winter of 1991 witnessed a rapid buildup of catching and processing capability and capacity. Several major plants on the Oregon coast decisively entered the whiting business with great emphasis being made on the production of surimi for the 1992 season. Industry surveys dictated that the plants' requirements for whiting in 1992 would approach 105,000 MT. Unutilized plant space has rapidly begun to fill with automated processing machinery. The shipyards on the Pacific Northwest coast have been full all winter long with trawlers converting to refrigerated seawater holding systems and undergoing all the requisite reconstruction necessary to preserve fish in this mode. Several vessels have acquired cod-end pumping systems to rapidly and safely bring the catch aboard and preserve it in adequate refrigerated seawater systems.

It was against this backdrop of energy and activity that the Whiting Steering Committee decided to schedule this conference.

I think we on the Oregon coast have learned some valuable lessons in the past two years. The resource has always been there. We fishermen were given a couple of breaks that allowed us to catch that resource. We were able to prove that very good profits could be made from a resource with low unit value, ***providing that the resource could be harvested in great volume.*** However, we were stymied in all attempts to progress beyond this point until such time as we recognized the other obstacles that must be overcome. We recognized that there was a lot more to the fish business than just catching fish. Markets had to be created. The market places worldwide had been undergoing great changes. Technology had brought us to the point where we could profit from these changes but only if we attacked our problems in a cooperative fashion and used a multitude of talents across a broad array of problems. A system was needed. A system was created. It was that system, enforced by a comprehensive study, that brought us to the point where we are today, on the threshold of a new industry.

No one group-fishermen, processors, managers, researchers, or government officials-could have succeeded alone in building this industry. Under the rigid discipline of a cooperative effort, we have achieved success. In 1992 and the years to come, the entire coast will profit from this new industry. Oregon whiting products are now ready to enter the domestic and international markets.

Seafood Technology

QUALITY ISSUES IN THE PACIFIC WHITING FISHERIES

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INTRODUCTION

Pacific whiting *(Merluccius productus) is* the *largest* stock of trawl fish off the west coast of the contiguous United States. It has an average maximum sustainable yield (MSY) of ap proximately 200,000 metric tons (MT) per year. The fishery had been considered underutilized, since only a small proportion of the harvest was processed by the U.S. industry. Figure 1 shows the number of fishing sectors that have been involved in the Pacific whiting fisheries since the late 1980s (Radtke 1992). During the early part of the 1980s the fishery consisted of foreign fisheries (Korean, Japanese, and Russian) and joint venture (JV) operations between foreign mother ships and coastal trawlers. The foreign fisheries were phased out by 1989. In 1991, there was sufficient interest by U.S. processors for Pacific whiting that JV operations with foreign processing vessels were also excluded from the quota. The U.S. shoreside plants increased their operations from 0.5 MT in 1983 to 22.6 MT in 1991.

There was a dramatic change in the domestic utilization of Pacific whiting last year. This was driven by (1) the high price of surimi in the global market and (2) technological advances in using Pacific whiting for surimi. These advances focused on the use of protease inhibitors in surimi that would slow the proteolytic breakdown of muscle proteins that

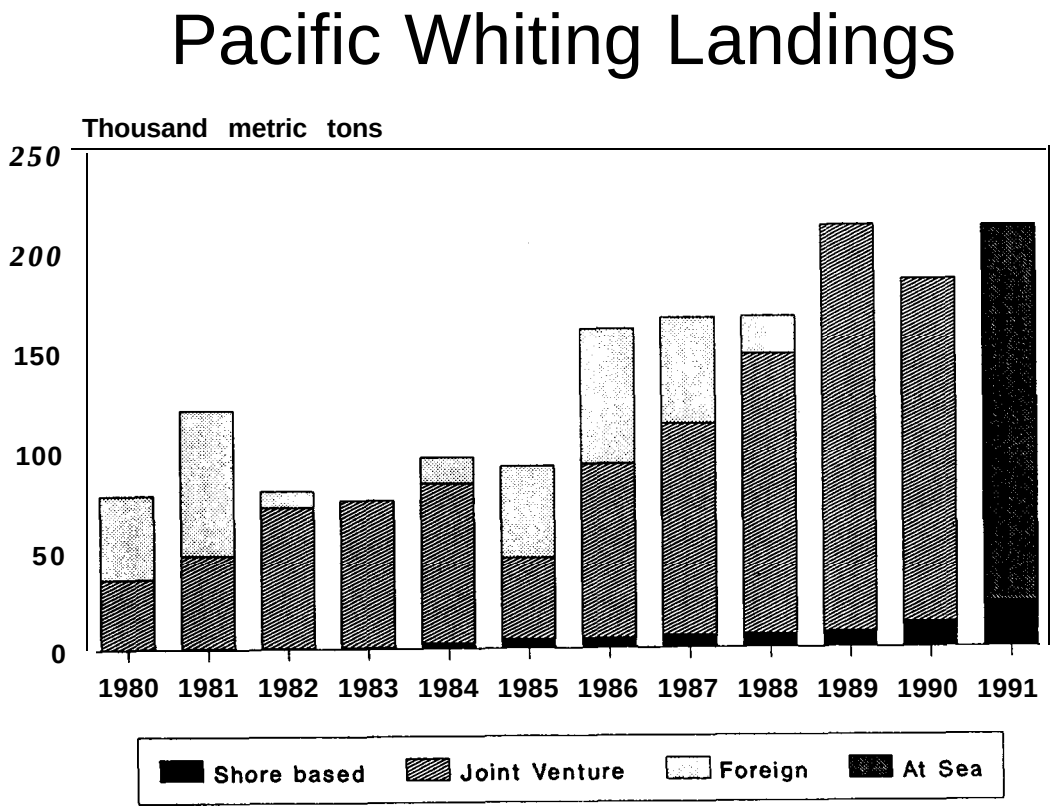


Figure 1. Description of Pacific whiting harvest 1980 through 1981.

lead to weak gel strength. Nonetheless, even with these advances it has become obvious to the fishing industry that Pacific whiting cannot be treated as other trawl-caught species. Intrinsic characteristics of the species, such as relatively soft flesh, the presence of a fat layer associated with rancidity, the infestation of Myxosporidean parasites, and the high levels of protease that rapidly break down the tissue, make it imperative that the fish be handled differently than other species. The Coastal Oregon Marine Experiment Station (COMES) has been awarded several grants to study the quality aspects of Pacific whiting and help the industry develop quality guidelines for the harvesting, handling, and processing of the fish.

Currently, there is a large variation in handling practices among fishermen and processors. Several of the processes required to produce a product with the quality characteristics necessary for generating profitable market prices may not be suitable or cost effective for coastal trawlers and processors (Sylvia and Peters 1990). Consequently, fishermen and processors must carefully consider the trade-offs between quality and cost in developing industry standards for Pacific whiting. To maximize profit potential, it may not be cost-effective to necessarily produce the bestquality product Quality guidelines must be based on optimizing the industry profits, rather than only on product quality. With this type of objective, dialogue between industry and researchers becomes easier and more productive. Data presented in the following sections represent the first phase of determining what some of the quality parameters are for Pacific whiting as observed in both the laboratory and local processing plants. Over the next several years, ongoing research will allow us to look at seasonal and regional variations. This data will complement the research into how handling and processing affect quality in the Pacific whiting fisheries; the results will assist the industry in establishing profit-driven standards.

METHODOLOGY

To relate quality parameters to handling and processing practices, we need to develop a standard method of measurement. In this study, both objective and subjective evaluation techniques were used. The subjective measurement used was a Descriptive Evaluation System (DES). The DES was developed from the Canadian Groundfish Guide (Woyewoda and Shaw 1995) and modified for Pacific whiting. This technique uses an observer in processing plants to subjectively determine quality parameters, such as relative texture, degree of discoloration, number of blood clots, and overall appearance. The objective measurements included the use of a Torrymeter, which is an instrument that measures electrical current along two points on the instrument in contact with the fish. Torrymeter values gradually decrease as the electrical properties of the tissue change after death. The values from this instrument are related to the quality of the fish and can be correlated to specific quality parameters such as texture.

Processing plants were visited on 35 different occasions during the 1991 season, and a total of over 1,500 fish were sampled. Random samples from each lot of fish were taken and each fish was analyzed and recorded. Table 1 illustrates the sample data collection sheet used in this research and shows the attributes measured. Figure 2 demonstrates the DES and standard methods for measuring the temperature and texture of the fish.

Table 1. Sample data sheet for in-plant descriptive evaluation of Pacific whiting.

Whole Fish

Weight										
Length										
Temperature (°C)										
Fish texture										

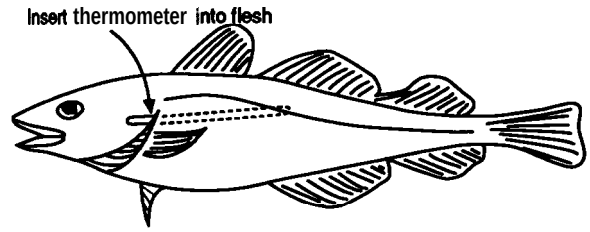
Fillets

Blood clots										
Discoloration										
Fillet texture										
Black spots										

Torrymeter reading										

1. Record temperature

In order to assess whether fish has been properly iced at sea, determine its temperature. Insert a thermometer into the collar of the fish and push it through the flesh to a point midway down the flank.



Ensure that the tip of the thermometer is completely embedded in the flesh. Leave it in place for about 1 minute before reading and recording temperature.

Any accurate thermometer that can be inserted into the flesh is suitable. A dial or probe type may provide tha least resistance. Accuracy of thermometer should be checked; temperature of ice and freshwater mixture is 0° C.

PROCEDURE	GRADE
2 Assess texture of fish flesh	
Press thumb along lateral line for the anterior two thirds of the fish. Do not press along the tail section, as it contains little flesh and mostly bones, and will not give a true indiin of texture.	0 - flesh is firm and resilient, and springs back immediately when released.
	1 - reasonably firm, some loss of resiliency, thumb indentations slowly fill out.
	2 - moderately soft, thumb indentations may remain in flash.
	3 - excessively soft flesh.

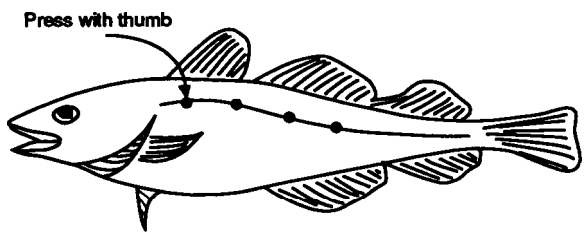


Figure 2. A sample instruction sheet for descriptive evaluation of Pacific whiting.

Another objective evaluation technique, used in this study, was the torsion test. This test was developed by researchers at North Carolina State University (Kim et al. 1986). The torsion method evaluates the stress and strain of gels formed from the flesh of the fish. The stress gives a measure of gel strength. The strain is related to the protein functionality of the gel and measures the cohesiveness. A strain value of 1.8 is the lower limit for making a quality surimi product

The torsion test is useful not only in determining gel strength and functionality in order to make quality surimi, but also as a tool in determining the quality of fillets. To use the torsion test as a quality measurement, the researcher must mince the fillet and process it into a gel.

Surimi Production

One potential use for Pacific whiting is the production of surimi. The texture problem prevalent in Pacific whiting can be circumvented in surimi with the addition of protease inhibitors (egg white, potato extract, beef plasma protein) mixed into the surimi. Surimi is basically a mince, and so the inhibitor can be mixed more uniformly and is more effective than in fillets. With the addition of protease inhibitors, Pacific whiting can be processed into a high-grade surimi. The color is white, and the gelling characteristics are similar to those of pollock surimi.

During surimi production, the fish were obtained from processing plants within 12 hours of capture. Fish were then transferred in ice to the Oregon State University Seafood Laboratory, where processing was immediately initiated. Fish were subsequently filleted and then minced to begin surimi production. The minced flesh was washed in polyethylene tanks (95-L capacity) with water and ice at a ratio of one part flesh to three parts water (W/W) and mechanically stirred for five minutes, then dewatered in a Sano-Seisakusho screw press, model SD-8 (Ikeuchi Tekkosho, Ltd., Japan). The washing and pressing procedure was repeated three times, with the final wash water containing 0.33% salt (NaCl). The first pressing was carried out rapidly to separate flesh and water. The press was operated more slowly during the second and third wash/press exchanges to produce the lowest possible moisture content in the flesh, approximately 75%. The dewatered flesh was refined with an Akashi strainer, remove impurities such as fat and small bits of skin. Surimi was prepared by mixing the refined flesh with 4.0% sucrose, 4.0% sorbitol, and 0.3% polyphosphate in a Hobart Silent Cutter, model VCM (Hobart Manufacturing Co., Troy, OH) for two minutes. Beefplasma protein, a proven protease inhibitor in Pacific whiting surimi, was added at a 1% level. Product temperatures were maintained near or below 10°C. Aliquots of 600 g surimi were packed into individual plastic trays, vacuum packaged, and frozen at -30°C. Accurate weights of flesh were recorded throughout processing to estimate yield.

Gel Preparation and Testing

Partially thawed surimi was used for the preparation of all gels. The formulation for the gel was adjusted to 78% ± 1% and 2% salt during the gel preparation stage.

All gels were blended under vacuum with a Stephan Universal Chopper (model UM 5, West Germany) for six minutes after the addition of each ingredient. Caution was taken to keep the temperature below 10°C to minimize protein denaturation. The batters were packed in stainless steel tubes (1.9 cm diameter and 17.5 cm long), sealed with rubber stoppers, and then heated at 90°C for 15 minutes in a Thelco Precision Scientific bath Model 83. Gels were tested for strain and shear stress by the torsion method. Shear stress is a measure of gel strength shown to correlate with sensory hardness; true strain, a measure of gel deformability, is shown to correlate with sensory cohesiveness (Hamann and Lanier 1987).

RESULTS AND DISCUSSION

In-plant Observations

An important part of our research during the 1991 season was to apply the methods we were learning in the laboratory to the fish-processing plants. DES results were obtained from more than 1500 fish evaluated in 35 plant visits during the summer and fall of 1991. Table 2 summarizes these results using analysis of variance tests (ANOVA) comparing seven different quality parameters to time. Using the statistical test, we related fish and fillet texture, the number of blood clots, and the Tonymeter reading to preprocessing storage time at a significance level of 95%. Discoloration of fillets was almost significant ($p = .055$). This table illustrates the significant impact of time on quality attributes and restates the necessity which included factors such as gill color, skin

defects, and so on, was not significant with time nor was black spotting on the flesh. Black spotting refers to hair-like black striations which have been shown to be older cysts of Myxosporidean parasites (Patashnik et al. 1982). These are present in the flesh of the fish when captured and do not increase with time or appear to be related to other defects such as texture and discoloration. Our work has shown that they appear in 45% of the fish that are off-loaded Although they present no health hazard, they are easy to see and are unacceptable for aesthetic reasons.

The Tonymeter proved to be a valuable tool as a fast, nondestructive, objective measurement that could be related to quality. Torrymeter values, in general, showed a steady decrease with time, as shown in figure 3. Torrymeter values, however, can be quite variable between individual fish, and a suit able quantity (40 to 50 fish) must be tested to obtain a representative sampling of the lot.

The majority of fish sampled during in-plant testing were from lots maintained in slush-ice after capture. There is some concern about the use of the Torrymeter and Pacific whiting with vessels that have refrigerated sea water systems for cold storage. It has been reported that the high salt content in these systems could make it difficult to obtain accurate results using the Torrymeter. Additional research will be directed toward answering this question.

Attribute	P-Value
Fish texture	.007*
General appearance	.093
Blood clots	.044
Fillet texture	.005
Discoloration	.055
Black spots	.572
Torrymeter reading	.002

n = 1540

*A p-value off .05 is significant at the 95% level.

Table 2. Results of analysis of variance tests performed to determine the significance of relationships between time and quality parameters for Pacific whiting.

Laboratory Experiments

The results of the DES analysis undertaken daily with fish kept in ice and daily surimi production and gel evaluation are shown in figure 4. These results correlate well with the results found during the in-plant observations. The results demonstrate that texture, measured in both whole fish and fillets, deteriorated rapidly with time. Pacific whiting, because of the presence of an active protease, has softer flesh than most ground fish, a factor which makes it important that the fish be landed and processed as quickly as possible. The percent of fish which had poor texture increased from approximately 27% after one day to over 70% after being held in ice for five days. This rapid decline in texture underscores the need for quick processing times. There was not a significant increase in blood clots or discoloration with time when the fish were kept on ice. How-

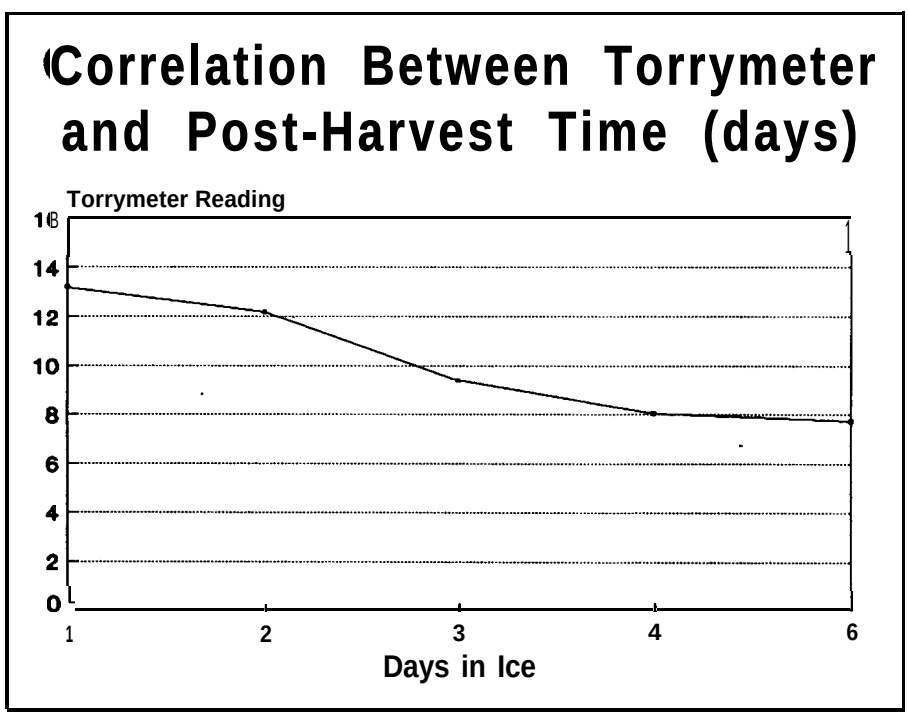


Figure 3. The effect of preprocessing storage time on the torrymeter value Of Pacific whiting.

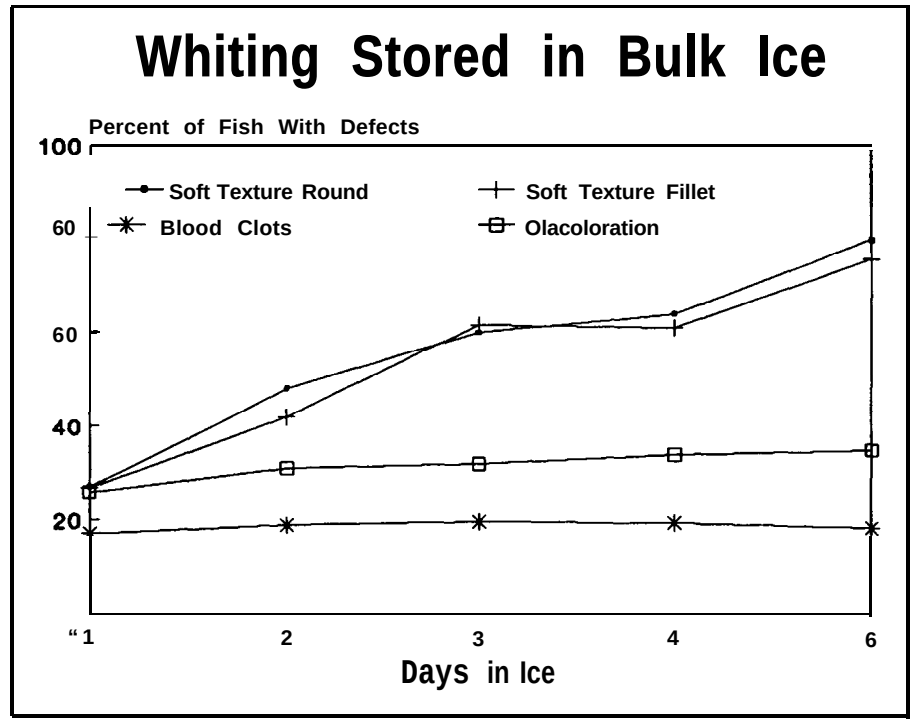


Figure 4. The effect of preprocessing storage time on quality parameters of Pacific whiting.

ever, as shown in the graph, the percentage of fish with defects in these categories ranged from 20% to 30% at day one. Similar results were obtained during the in-plant analysis as well. It is unclear whether these poor-quality fish are the result of capture methods, handling, or unloading practices, or whether problems were intrinsic to the fish and would be present regardless of capture or handling techniques. A preliminary study was conducted comparing vacuum unloading to bucket unloading, but there was no significant difference between the two methods. More research needs to be done on the fishing and handling practices in order to determine their actual effects on product quality.

The torsion test was run on surimi made each day from Pacific whiting kept on ice. These results are shown in figure 5. There was a 10-20% decrease in stress and strain value with each day of processing up to day four of the experiment. On the final day there was a slight increase in the values. As mentioned previously, the torsion test is a newly developed method for determining protein functionality and can be used to objectively determine quality as well. During the 1991 fishing season, there was a great deal of interest in the use of Pacific whiting for surimi. The use of protease inhibitors during the production of surimi would allow for its use in this area. However, if whole Pacific whiting is stored for a number of days, the muscle tissue will deteriorate and surimi with inferior gelling properties will result A critical question, especially for shoreside production, is how long the fish can be kept at refrigerated temperatures and still be processed into a good-quality product If a strain of 1.8 (which is the minimum strain value that correlates with the traditional Japanese double-fold test for surimi) is used as a cut-off point, then our results show that approximately two days may be the maximum time that Pacific whiting can be stored in ice before it is made into an acceptable grade of surimi. However, fish processed into surimi within 24 hours of capture possibly will yield stronger gels and a higher-grade product commanding higher market prices.

CONCLUSIONS

The initial phase of this project was designed to provide researchers with insights into the quality parameters of Pacific whiting, especially as they pertain to onshore processing. Preliminary results suggest that time and temperature are the most critical parameters for maintaining good raw material for quality processed product The protease activity in Pacific whiting muscle tissue warrants that the fish be captured, brought to shore, and processed immediately. A 24-hour delay in offloading or processing could have a significant impact on the final product quality and be responsible for the rejection or low price of the

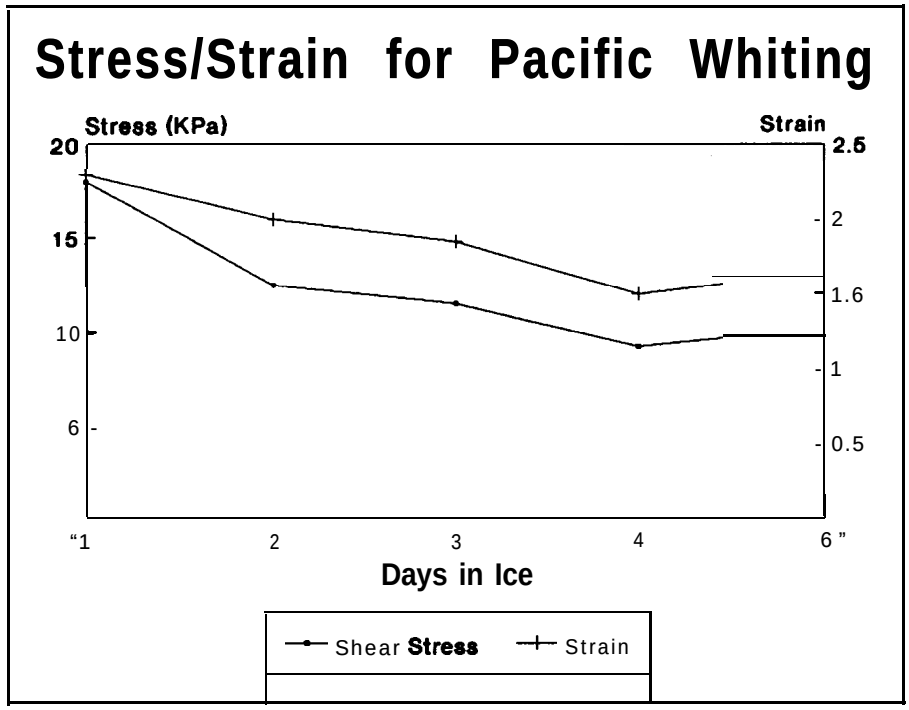


Figure 5. The effect of preprocessing storage time on the stress and strain values for Pacific whiting.

product. The texture of the flesh is the quality parameter that is the most significantly affected during storage time. This is especially evident in the production of surimi from Pacific whiting. Quality, as measured by gel strength, is reduced by 10-20% for each day of storage of the raw material Since the surimi market is extremely sensitive to quality, one could assume that a reduction in quality would be accompanied by a reduction in price. Further, if the fish were stored for a period of longer than two days after harvest, there is a high probability that the final product would have low gel-forming abilities and ultimately be rejected as even a low-quality surimi product.

Handling may be an important factor for other quality parameters such as discoloration and blood clots. How these defects may affect quality and price is less clear. Future research is needed on the effect of tow sizes and length of tow on quality parameters of Pacific whiting. It is possible that large tow sizes or lengthy tows may crush the fish and could have an effect on parameters such as blood clots and discoloration and consequently final product quality. However, there is no question that an efficient and well-coordinated harvesting, off-loading, and processing operation is crucial in maintaininghigh quality and minimizing the number of defects. During the first phase of this project the Torrymeter has shown good potential as an objective measurement of fish quality. There is strong correlation between Torrymeter measurements, loss of surimi gel strength, and overall fish texture. Additional work will be undertaken to determine if these correlations hold for other quality parameters After the quality measurements are completed, economic analysis will be conducted to compare the costs of improving product quality with market prices. This information will then be used to determine which standards would maximize profits or market opportunities.

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USE OF VARIOUS GRADES OF SURIMI WITH AN APPLICATION OF LEAST COST FORMULATION

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INTRODUCTION

Least cost (LC) formulation is a computer-aided technique that has been used successfully for many years in the food industry, particularly in conjunction with formulated products such as processed meats. The technique is useful in allowing a manufacturer greater variability in the properties of the raw materials while insuring that the quality of the finished product consistently meets rigid standards. The computer selects the type and amount of each raw material in a formulation on the basis of raw material price, properties (compositional and functional), and targets of quality standards. In initiating use of the technique, we first have to determine the relationship between raw material properties and the quality of the finished products. We do this by accurately analyzing the properties of raw materials in current formulations of a product. Several batches should be examined to set up an acceptable range for each property, thus establishing a quality control "window."

HOW TO APPLY IN SURIMI-BASED SEAFOODS

With respect to a surimi-based food, we must determine an acceptable range of values in color, flavor, and texture of surimi, since surimi forms the base protein matrix in which are imbedded all other constituents. Because surimi generally has a bland odor and is white, the flavor and color are generally derived from other ingredients. Therefore, the flavor and color are held to the minimum in most cases. The gel-forming ability of surimi becomes of prime importance in the acceptance of surimi seafoods. Textural properties can be measured by preparing a test gel from surimi, salt, and ice or water and determining the properties of shear stress (strength of gel) and shear strain (cohesiveness and rubberiness) of the gel, using a torsional test. The gel properties of the batter of the finished product can be measured in the same way. A window of acceptance constituting the upper level control and lower level control of each parameter for both a raw material (surimi) and a finished product can be plotted on a stress vs. strain diagram, as shown in figure 1.

While this approach ensures a finished product of the desired quality, it follows that tight specifications for the raw material (surimi) may eliminate many available lots of surimi from consideration as an ingredient. This can not only present a challenge to the company buyer trying to locate sufficient raw material for production, but could also force up the price of that surimi which is in demand. The lower-cost surimi may not meet the specification; thus, surimi which does meet the specification becomes more expensive, and the cost of manufacturing the product goes up. Among commercially available low-to-medium grade surimi, certain quality parameters show the quality of high-grade surimi.

A more ideal approach for quality control would entail setting specifications on surimi to be used, but would allow for blending of other lots outside that specification in order to meet the target window (figure. 2). The selection of surimis for blending with the wide diversity of surimi qualities and price available will meet the desired objective of consistent product quality at least cost only when the quality parameters of all available surimis are analyzed accurately and applied properly.

Optimum use of the LC formulation for surimi-based seafoods will be obtained when the linear program is allowed to select differing levels and types of functional ingredients in addition to surimi, such as starch and protein additives. Each ingredient must be tested at various levels in a surimi gel under standard conditions. The slope of the resulting plot of stress and strain values versus ingredient level becomes the factor, or constant, used in the LC equation to predict the effect of its addition on the product

CONCLUSION

The LC formulation is an optimization technique. It is an effective means of controlling the quality of formulations while minimizing ingredient costs. Implementing a standardized testing procedure for all incoming ingredients is the first step. The various range of raw ma-

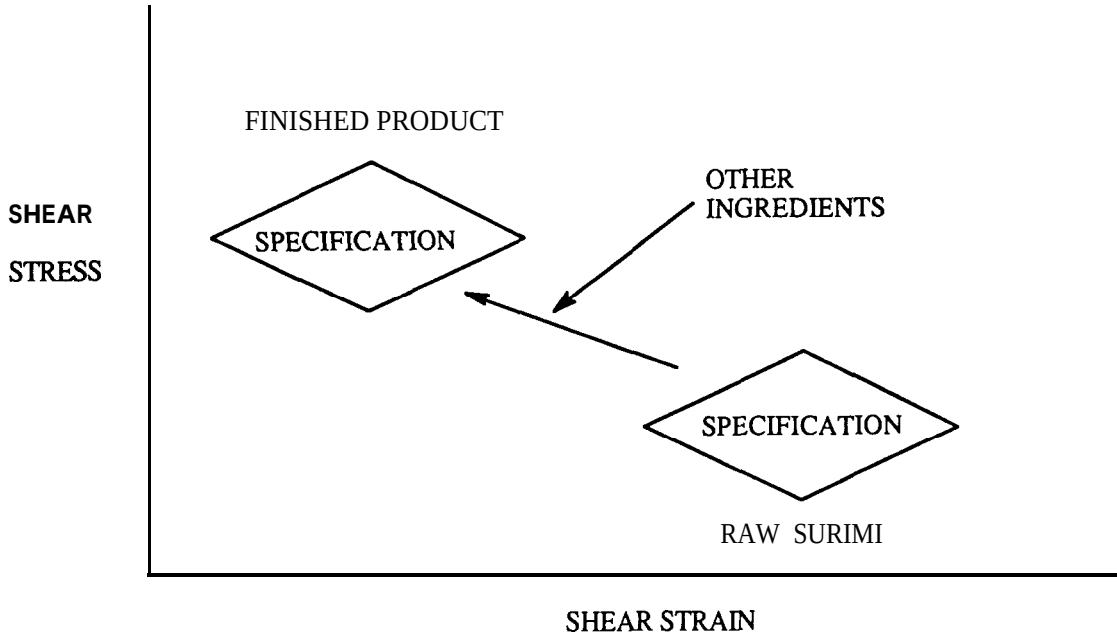

Figure 1. Control of finished product specification using a single surimi.

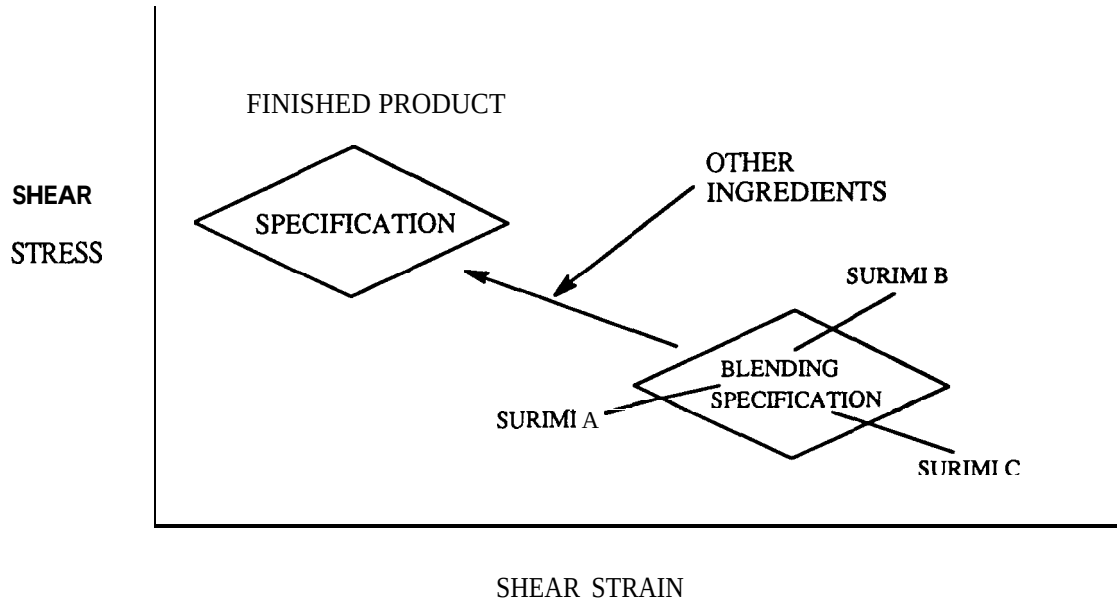

Figure 2. Control of finished product specification using a blending technique

terials (including Pacific whiting) can be used in surimi-based seafoods formulation with an adoption of the least-cost program approach.

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CRYOPROTECTION OF SURIMI[1]

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INTRODUCTION

The myofibrillar (muscle) proteins of most fish, being cold-blooded, are known to be more labile to denaturation than the contractile proteins of homeotherms commonly converted to meat for food, including beef, pork, and poultry (Connell 1961). For this reason, surimi, the refined myofibrillar component of fish muscle, requires the inclusion of a cryoprotective component prior to freezing to ensure long-term stability of the proteins in frozen storage. This in turn assures good functionality of the material in food manufacture, expressed primarily as gel-forming potential with its manifestations of texture formation and water-binding properties.

Red meat (mammalian) and poultry muscles are commonly stored frozen without cryoprotective additives and certainly suffer less deterioration in functionality than would surimi under the same conditions. The former materials have greater stability, not only because of their homeotherm origin, but also because red meats and poultry are more commonly stored in whole muscle form, in which reactive components of the muscle are more compartmentalized from one another. Additionally in these materials, the myofibrillar proteins have not been refined from the water-soluble fraction, certain components of which are known to have a stabilizing effect on myofibrillar proteins during frozen storage (Jiang et al. 1987a, c; Loomis et al. 1989).

Figure 1 summarizes some of the changes which may occur in a muscle protein system during freezing and frozen storage (Haard In press; Shenouda 1980; Sikorski et al. 1976).

Muscle proteins express their functionality only when the salt-soluble proteins are fully

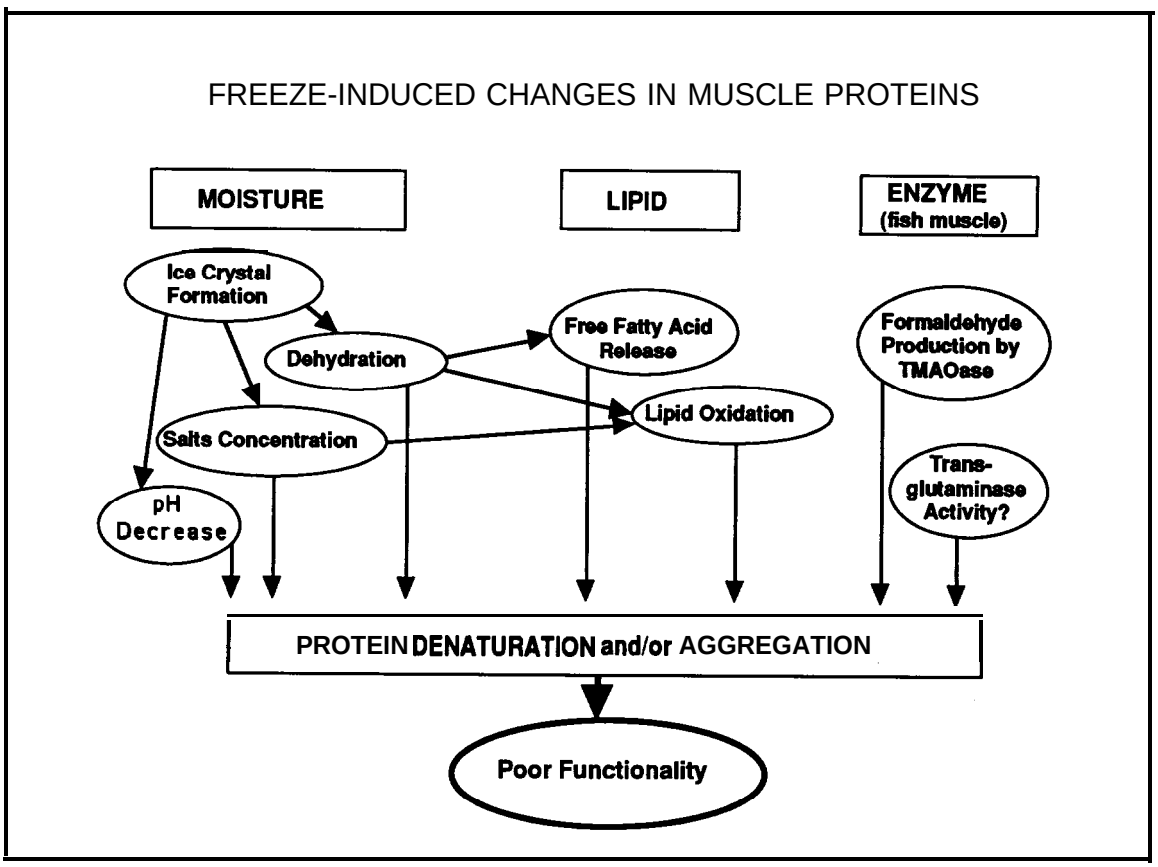

Figure 1: Factors that affect, directly or indirectly, muscle protein denaturation and consequent loss of protein functionality during frozen storage. Adapted from Shenouda (1980).

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extracted (solubilized), and cryoprotection is possible only when intimate association of the cryoprotectant and the protein molecules occurs. Thus, both the expression and cryoprotection of muscle protein functionality will optimally occur in a minced or comminuted muscle system like surimi.

CRYOPROTECTIVE ADDITIVES

Noguchi (1974) surveyed a wide variety of chemical compounds for their ability to maintain the solubility of carp actomyosin (muscle protein) in dilute solutions over brief periods of frozen storage. This model system was demonstrated to predict well the ability of compounds to cryoprotect the functionality of surimi during extended frozen storage. Besides a variety of carbohydrate compounds, including most of the mono- and disaccharides evaluated and several low molecular weight polyols, many amino acids and carboxylic acids were also found to be cryoprotective.

Other workers have also reported the cryoprotective action of a number of amino acids, quaternary amines, and other compounds with regard to the stability of various proteins and enzymes (Jiang et al. 1987a, b; Loomis et al. 1988, 1989).

The nucleotides ATP, ADP, and IMP have been shown to exert a protective effect on fish actomyosin stored at -20°C while the nucleotide catabolites inosine and hypoxanthine destabilized these proteins (Jiang et al. 1987c). This finding may help explain why fresh fish, with consequently higher concentrations of ATP, ADP, and IMP, are more stable during frozen storage than less fresh fish (Dyer and Peters 1969; Fukuda et al. 1984).

Watanabe et al. (1988) demonstrated the cryoprotective ability of certain surfactants, particularly certain polyoxyethylene sorbitan esters and sucrose esters, in preventing loss of gel-forming ability in surimi. These are common additives in many Japanese cryoprotectant formulas. A cryoprotective effect has even been attributed to triglycerides (fats), in that free fatty acids, which may be released through hydrolysis of phospholipids and react to denature proteins, are thought instead to preferentially react with triglyceride, thus indirectly protecting the proteins (Wessels et al. 1981).

Sucrose or sorbitol, typically alone or mixed 1:1 and added at 8% w/w to leached fish muscle, serves as the primary cryoprotectant in the manufacture of surimi from Alaska pollock. Polyphosphate at 0.2-0.3% is also commonly added, ostensibly as a synergist to the cryoprotective effect of the carbohydrate additives, although its effectiveness in this regard is questionable in light of recent evidence (Park et al. 1988). These carbohydrates were chosen because of their relatively low cost, good availability, and low tendency to cause Maillard browning in the bright white kamaboko products typically enjoyed by the Japanese. However, these additives impart a considerably sweet taste to the surimi that many Western consumers have found objectionable for certain product applications. Thus, there has been some effort in the United States to select nonsweet additives with a cryoprotective effect equal to that of sucrose or sorbitol

Lanier and Akahane (1986) discovered and patented the use of Polydextrose®, a nonsweet, low calorie, bulking agent, for the cryoprotection of muscle proteins. They compared its effectiveness with that of sucrose and sorbitol and a 10-DE maltodextrin (also having no sweetness) in maintaining the salt-solubility and gel-forming properties of Alaska pollock surimi. While the three additives maintained similarly high levels of solubility in the myofibrillar proteins at -28°C over several months compared to a control, the surimi containing the 10-DE maltodextrin failed to form strong and cohesive gels (figure. 2). These results were interpreted as indicating that the 10 DE maltodextrin interfered with the gelation of the surimi myofibrillar protein, in much the same way as occurs with pregelatinixed starch and certain gums (Lim et al. 1990; Foegeding and Ramsey 1986, 1987). A more recent study (Anderson 1990) indicates the potential of using higher DE starch hydrolysis products as effective cryoprotectants with less interference in the gelation process of the proteins.

Many other low-MW sugars and polyols that could be used as muscle cryoprotectants are currently or soon to be available. Lactitol and lactulose reportedly have low sweetness, the former having also been demonstrated to effectively cryoprotect surimi protein (Sych et al. 1990a, b). Maltitol, isomalt, and hydrogenated glucose syrups could also be considered for special applications (Sych et al. 1990a). Edible gums have been proposed to function as effective cryoprotectants, but tests have failed to demonstrate their effectiveness (da Ponte et al. 1985a, b, c). The reduced functionality of muscle proteins in the presence of gums may result from their competition for water with protein, or from interaction with proteins,

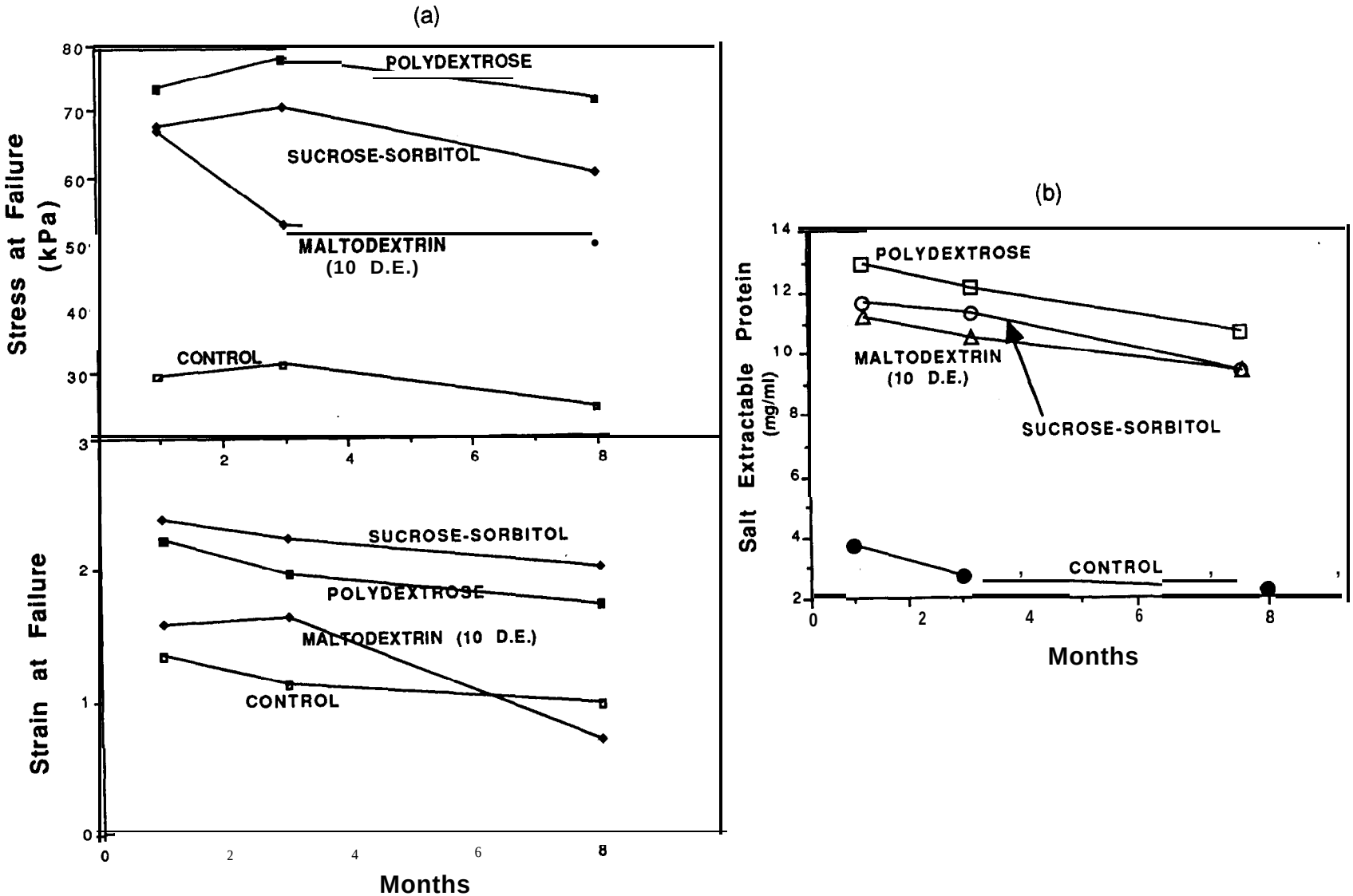

Figure 2: *Surimi: Effects of added ctyopmtectants on maintenance of (a) gel-firming properties and (b) protein extmctability during frozen storage. Stress and strain at failure correspond to the strength and cohesiveness, respectively, of heat set gels prepared from surimi containing 2% salt.*

which results in poor protein gelation. Adding gums in the fully hydrated form without adding excess water, and attaining concentrations sufficient for cryoprotection are additional problems in the practical application of gums as cryoprotectants.

MECHANISMS OF PROTEIN CRYOPROTECTION

The most commonly used cryoprotectants in the food industry have been low-MW sugars and polyols, such as sucrose and sorbitol used in surimi manufacture. While the mechanisms of cryoprotection by such molecules are not fully understood at present, it is known that they are able to stabilize proteins through their interaction with the surrounding water. Higher-MW carbohydrates seem to work by another, or additional, mechanism and will therefore be discussed separately.

Low Molecular Weight Carbohydrates

Sucrose and sorbitol not only act as cryoprotectants, but are also known to stabilize proteins to the denaturing effects of heat (Back et al. 1979; Park and Lanier 1987, 1990). Similarly, sodium chloride addition, which was found to promote freeze denaturation of beef (Park et al. 1987), has been shown to destabilize myofibrillar proteins to heat denaturation (Wu et al. 1985). Thus, the mechanism of heat stabilization by low-MW carbohydrates may also explain their cryoprotective properties.

By means of high precision densimeter measurements, Arakawa and Timasheff (1982) were able to show that the stabilizing solute molecules (sugars, low-MW polyols) were excluded from the surface of the protein molecule, thus Upreferentially hydrating' the protein (figure 3). While this "preferential hydration" of the protein has sometimes been identified as the primary protective effect of solute exclusion (implying that the protein is thus protected against surface dehydration during freezing), the true protective effect is explained thermodynamically. The addition of protective solutes results in a positive (unfavorable) free energy change because the sugar is excluded from the protein surface. The magnitude of this unfavorable free energy shift is assumed to be in proportion to the surface area of the protein, that is, the volume of the cavity occupied by the protein and its hydration shell. Since the protein cavity is assumed to be greater when the protein is unfolded, this means that the native state of the protein is thermodynamically favored in a solution of sugar and low-MW polyol.

This explanation of the mechanism of cryoprotection by low-MW sugars and polyols is in direct contradiction to that forwarded by Matsumoto (1979), who envisioned a protective coating of the protein by cryoprotectant molecules. Arakawa et al. (1990) noted that certain compounds, such as DMSO, proline, PEG, and ethylene glycol, are known to be preferentially excluded from the surface of proteins at room temperature and are equally effective cryoprotectants. However, at temperatures above ambient, these compounds preferentially interact with the protein surface and as a result destabilize proteins at these temperatures. Crowe et al. (1990) noted that the protein denaturants urea and guanidine hydrochloride act by binding to the the protein surface. They concluded that therefore "it does not seem likely ... that stabilization of proteins during freezing involves direct interaction with the solute."

The preferential exclusion of solutes from the protein surface has been largely attributed to the effects of the solute in increasing the surface tension of water (Arakawa and Timasheff 1982; Carpenter and Crowe 1988; Arakawa et al. 1990). However, several cryoprotective compounds are thought to be

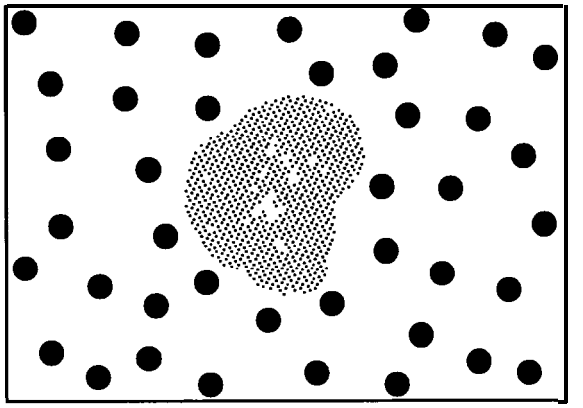

Figure 3: Solute exclusion from the cavity occupied by the protein and its hydration shell (shaded area), the black dots signifying solute molecules.

excluded by other mechanisms, such as by stearic hindrance. Glycerol, which actually decreases the surface tension of water, is, however, excluded from the protein surface by an unknown mechanism.

That many of the cryoprotectant sugars and polyols do increase the surface tension of water may be important in other ways to protein stabilization. Back et al. (1979), from careful measurements, noted that "hydrophobic interactions between pairs of hydrophobic groups are stronger in sucrose or glycerol solutions than in pure water" and concluded that "this is the mechanism by which sugars and polyols in general may stabilize proteins to heat denaturation." Similarly, Melander and Horvath (1977) addressed the issue of why certain salts of the Hofmeister or lyotropic series have a stabilizing effect on proteins. They were able to demonstrate that such stabilization results from a strengthening of the protein intramolecular hydrophobic interactions in the presence of these salts and concluded that "the property of a salt that affects hydrophobic interactions is quantified by its molal surface tension increment."

Thus, it may be concluded that those polyols and sugars which do increase the surface tension of water may act to stabilize proteins dually by favoring solute exclusion from the protein surface and by enhancing the strength of intramolecular hydrophobic interactions.

Because several workers have shown that the addition of such sugars as sucrose and trehalose can stabilize proteins to the denaturing influences of drying (Matusuda 1979, 1981; Carpenter et al. 1987a, b, 1988, 1990; Crowe et al. 1990), it has been tempting to ascribe to both the cryoprotection and "dryoprotection" properties of these compounds the same mechanism. However, Crowe et al. (1990) and Carpenter et al. (1990) have demonstrated that, in the case of preserving protein structure in desiccation, it is a preferential *interaction* of solute with the protein surface that is required. Only certain disaccharides, among them sucrose, maltose, and trehalose, seem to meet the stearic requirements such as to allow them to, in effect, replace water molecules on the surface of the protein and thus stabilize the native protein structure in the virtual absence of water. Many other compounds known to be effective cryoprotectants were found to be ineffective in protecting proteins from the denaturing effects of drying.

High Molecular **Weight Carbohydrates**

Carpenter and Crowe (1988) theorized that certain high MW polymers, such as polyvinylpyrrolidone, polyethylene glycol, and dextran, are good cryoprotectants because they are stearically excluded from the protein surface by their size. However, an entirely different mechanism has been postulated by other workers to explain the cryoprotective effects of many high MW polyols and glucose polymers (starch hydrolysis products). This so-called "cryostabilization" theory is based upon the ability of high-MW solutes to raise the glass transition temperature (Tg) of a solution (Levine and Slade 1988a, b).

Figure 4 illustrates the glass transition temperature of a simple solution. At higher concentrations of solute, the Tg occurs at temperatures above freezing. Thus, the mixture cools to form a "candy" glass directly from the liquid state. At solute concentrations below the point Tg', when the temperature falls below the freezing curve, the solution will exist either as a viscous supersaturated solution in the liquid state or more commonly as a mixture of ice crystals and supersaturated solution. Under these conditions, the system is termed a "rubber," exhibiting a high viscosity caused by the presence of ice crystals or strong, intermolecular solute interactions and entanglements. In the rubber state, ice crystal numbers and sizes may increase, the various chemical deteriorative processes of figure 1 continue to proceed, and thus the stability of proteins under these conditions is poor. The rate of freezing and the constancy of storage temperature will of course influence ice crystal sizes and numbers, and likewise the solute concentration (Pranks 1985a, b). Thus, Tg may be altered by time factors not shown in this two-dimensional phase diagram.

In contrast, the glassy state is a much harder solid, with viscosities near 1014 Pa.s (Franks 1985a), in which reactions become diffusion limited as the result of immobilization of the water within a solute structure (Treloar 1970). This structure is formed when solute-solute interactions supersede solute-water attractions and occurs at the Tg for the given solute and concentration. The structure is amorphous, like that of the liquid, with no crystallinity other than that of the enmeshed ice crystals.

Cryostabilization of proteins, then, involves addition of a solute to raise the Tg to a temperature above that of the storage temperature, thereby ensuring that the system is in

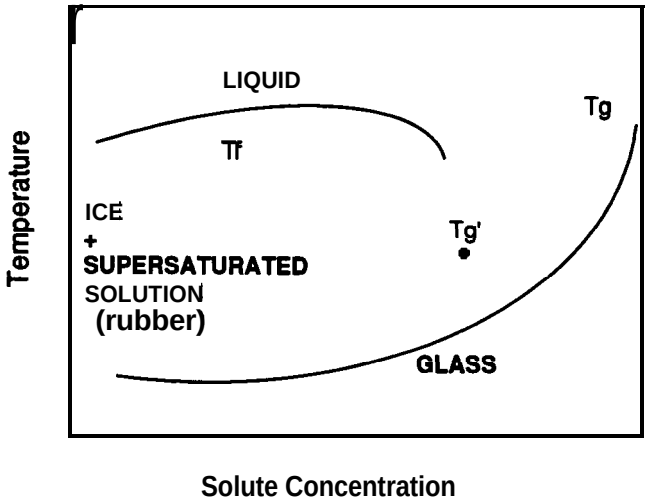

Figure 4: Schematic *phase diagram for* a *binary system in which the solute component does not crystallize.*

the glass state. This effectively shuts down the deteriorative processes depicted in figure 1, including ice crystal formation, since the water is immobilized in the glass structure. Thus there are fundamental differences between the mechanisms of "cryoprotection" by low-MW sugars and polyols and "cryostabilization" by high-MW polymers: cryoprotectants function by altering the thermodynamics of the system to favor the native state of the protein, while cryostabilixers act to enmesh the protein in a glass wherein all deteriorative processes are greatly slowed.

The requirement in cryostabilization for use of polymers exhibiting relatively large MW arises from their ability to form glasses at higher temperatures. This is due to their propensity to entangle as well as to form hydrogen and other bonds, imparting a greater viscosity at any given concentration. Levine and Slade (1986, 1988b) published tables and graphs which indicate a generally direct relationship between molecular weight (or, inversely, dextrose equivalent, DE, for starch hydrolysis products) and Tg. Branching of the molecule will affect the solution properties of polymers, such that a strictly direct relationship between MW and Tg will hold only for a homologous series. Selection of the proper polymer thus effectively narrows the temperature range between Tf (on the freezing temperature curve) and Tg, in which the system exists as a less stable rubber.

Lim and co-workers (Lim et al. 1990; Lim 1989) recently attempted to demonstrate the principle of cryostabilization in the freezing of leached fish muscle (surimi). In model studies using salt-soluble protein to represent the surimi, they found that maltodextrin (Tg = -10°C) protected the solubility of the protein in a much more temperature-dependent fashion than did sucrose. However, there was not a dramatic change in the stability of the maltodextrin-containing system when they compared the response to storage temperatures just above and below the Tg of maltodextrin at that concentration, as might be expected if a sharp glass transition took place in the system. Surimi also behaved similarly to the model system with respect to the stability of the proteins in the presence of these two carbohydrates.

Carboxymethylcellulose was also tried in these systems (Lim et al. 1990; Lim 1989), but it failed to protect the proteins and seemed to interfere with their heat-induced gelation. Thus, in practice, there may be limitations in applying the cryostabilization approach to maintain muscle protein functionality in frozen storage.

PRACTICAL CONSIDERATIONS

Although several workers have attempted to employ cryoprotectant compounds in the freezing preservation of intact muscle, their efforts have not met with much success (Krivchenia and Pennema 1988a, b, Krueger and Pennema 1989). Obviously, either of the mechanistic approaches outlined in this article depends on intimate association of the cryoprotectant molecules and the protein, which is difficult to achieve in other than a comminuted system.

In surimi production, sucrose and sorbitol have been adopted as the primary cryoprotective additives for several reasons: relatively low cost, good availability, good safety record, broad legal status, good solubility, and beneficial functional effects (with only one minor exception, sweetness). There is currently no reason to suspect that cryoprotectants now used for pollock are not equally well suited for Pa-

cific whiting surimi. Much of the attention paid to alternative cryoprotectants for surimi has focused on sweetness reduction, with minor emphasis on caloric reduction. In this area of concern, cryostabilization by polymers such as maltodextrins or Polydextrose® could be viable alternatives, and maltodextrins are also less costly than sucrose and sorbitol. Dextrose is also a cheaper alternative, but Maillard browning reactions from reducing sugars may limit application in light or white-colored products of fish and poultry. More serious is the detrimental effect, discussed above, which certain high-MW polymers have on gelation properties of muscle proteins.

CONCLUSIONS

Carbohydrates have generally been the most acceptable cryoprotectants for muscle applications (that is, surimi). New carbohydrates are becoming available which may be considered in order to achieve cost, sweetness, or caloric reductions. It is considered that all carbohydrates that are effective in protecting proteins from the denaturing effects of freezing and frozen storage act by at least one of two mechanisms: cryoprotection, in which the addition of primarily low-MW sugars and polyols thermodynamically favors the maintenance of the native protein state; and cryostabilization, in which primarily high-MW polymers effectively raise the glass transition temperature and ensure a less reactive glass state in the system at conventional freezer temperatures.

A future direction in cryoprotection may be to combine various compounds to create "cryoprotectant cocktails," which may be more effective than simple compounds alone. In this respect, it is interesting that the gall fly larva *(Eurosta solidaginis)* is known to generate intracellularly a mixture of carbohydrates and polyols to allow it to survive overwintering in cold climates (Wasylyk et al. 1988). Such an approach may prove to yield synergies, as may the exploration of interactions between carbohydrates and certain ions, organic acids, or amino acids.

Processors of surimi may as a result determine approaches for better maintaining the functionality of their raw materials in both frozen and dry forms, thereby realizing both cost savings in usage and more consistent quality control in production.

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PRODUCT ALTERNATIVES FOR PACIFIC WHITING

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INTRODUCTION

Several studies are currently underway at Oregon State University to evaluate whiting product alternatives. We describe three of them: fillets, fresh surimi, and stabilized mince. For frozen fillets, questions arise concerning shelflife, or storage stability, and how it changes with various conditions that might be controlled or optimized. A second altemative is fresh surimi: washed, minced fish that is made directly into analog products without freezing and therefore without a need for the customary 8% cryoprotectant ingredients. Whiting surimi is of particular interest because it enables effective application of protease inhibitors and creates a stable seafood product from a fish protein that is inherently less stable. Stabilized mince, a third altemative, involves a technology that would allow minced trimmings and some excess product to be frozen with cryoprotectants, and then later thawed to make surimi-based products.

FROZEN FILLETS

Whiting were caught in August and hand filleted at an Astoria plant. A "K-value" of 15% indicated the fillets to be very fresh. Within 15 hours of catch, they were frozen in 750 g (1.7 lb) packages (four to six random fillets per bag) at the OSU Seafoods Laboratory. Storage is currently ongoing at four carefully controlled temperatures: -8°C (17.6°F); -20°C (-4°F); -34°C (-29.2°F); and -50°C (-58°F). At various time intervals, two packages (1.5 kg) were taken from each temperature, mixed together, and tested. Our engineering goal was to describe (mathematically model) the quality change we might expect with time and temperature, and so be able to trade off quality with the increased costs of lower storage temperature. We measured protein denaturation, assuming it to represent the most significant quality change, associated as it is with toughening and a loss of succulence and water-holding capacity.

The results through five months of storage appear in figures 1-3, which picture three different means for measuring denaturation. (1) The most sensitive indication is the de-

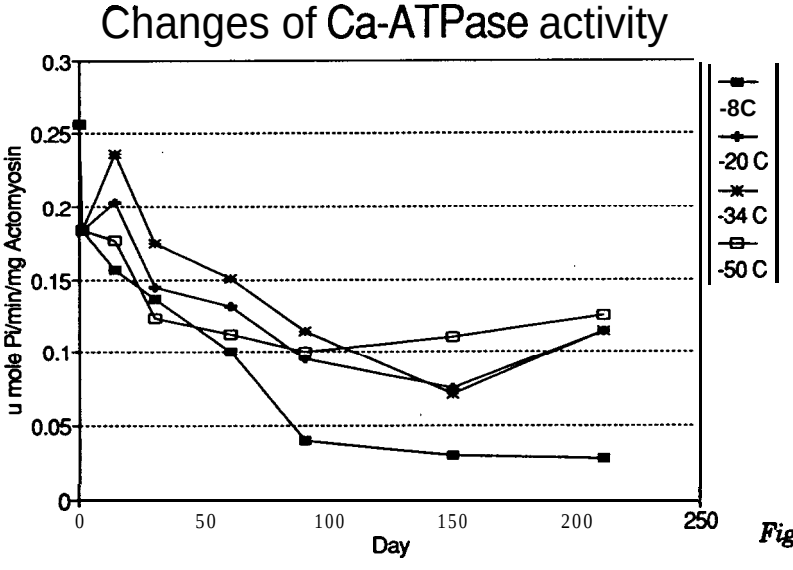

Figure 1.

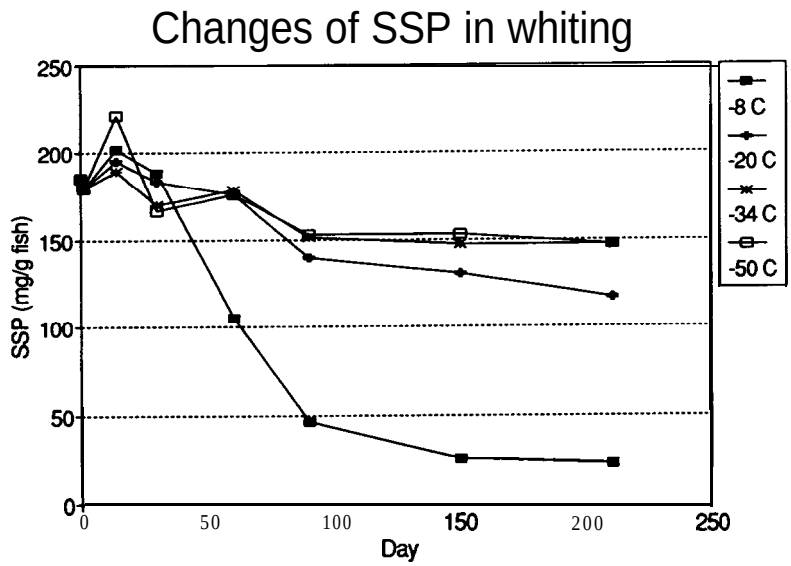

Figure 2.

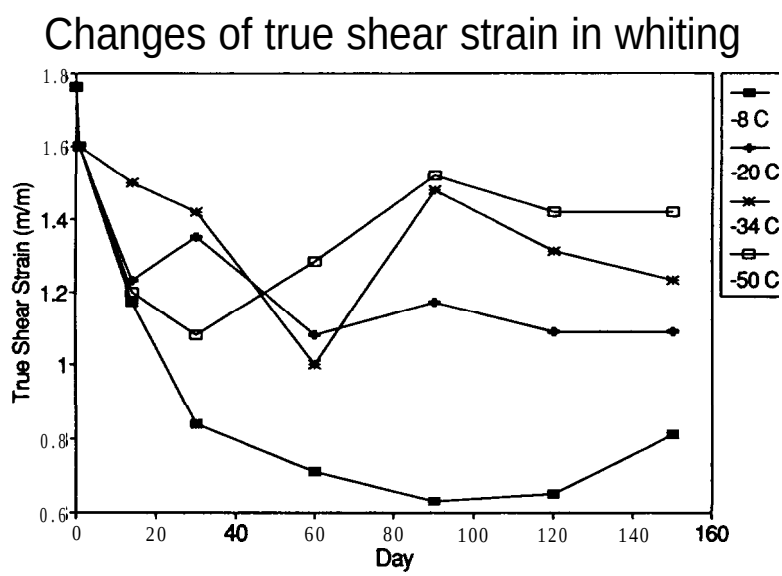

Figure 3.

crease in ATPase enzyme activity (figure 1). (2) Salt-soluble protein is a traditional measure of denaturation (figure 2). (3) Shear strain values indicating protein selling ability are determined by the torsion method (figure 3) commonly employed to measure surimi quality. The higher the torque angle of gelled cylindrical samples, the higher is the cohesive strength and the lesser the degree of protein denaturation. Although the numbers in each of these three graphs don't tell us when the product is no longer any good, we can make some general observations. Within one to two months at -8°C, significant denaturation and quality losses have occurred compared to those at lower temperatures. Within the five-month period shown, texture quality at -20°C has remained reasonably high, although lower temperatures appear to give slightly better results. The -50°C level holds no significant advantage over that at -34°C.

A few additional notes or questions might be made from this and related work. (1) At one point (day 120), torsion tests were run on four different packages removed from each temperature level. A very large variation was found between packages (figure 4), explaining in part the scatter and nonsmooth curves shown, for example in figure 3.

(2) Results in both figures 1 and 3 showed a significant decrease in the quality value at day 0. These values were measured before and after freezing, raising a question about how important the freezing rate might be. These differences could also result from the package-to-package scatter, noted above. More work is needed to clarify this.

(3) In one related test over a three-month period, vacuum-packaged fillets were compared with those that were not vacuum packaged. No differences were found either in the denaturation values or in oxidation rates.

(4) Tests on whiting several years ago indicated SSP values that fell rapidly at a -20°C storage temperature, in contrast to the relatively constant value shown in figure 2. This raises a question as to the significance of the uniformity of storage temperature used in our tests, or of the effects of fresh quality prior to freezing.

FRESH SURIMI

There can be a considerable marketing advantage to developing a fresh surimiproduct made from Pacific whiting. The major one is that there would be no need for the use of cryoprotectants, such as sorbitol and sucrose, which are viewed by most consumers as unwanted. The production of fresh surimi would

be very feasible for an onshore processing plant, where the surimi can be shipped to an analog processor for quick production.

Our studies showed that fresh surimi can be made with gel strength comparable to that of good-quality surimi. Potato starch was used as a substitute for the normal cryoprotectants (sucrose and sorbitol) in an effort to control moisture content. In a five-day study, it was evident that the shellfish analog needs to be made within three days of making the fresh surimi. After day three, the product quality suffered, especially color and odor.

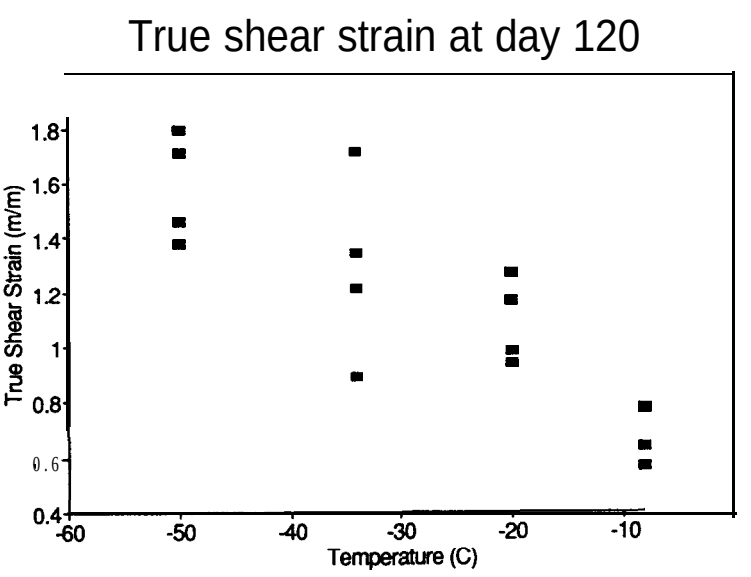

Figure 4.

Crab stick analogs were made from both fresh and frozen surimi at Kyotaru Oregon, in Salem. Although minor problems were encountered in the first run (too much starch in the fresh surimi), the overall results were promising. The personnel at Kyotaru responded favorably to the use of Pacific whiting. A production run of fresh surimi was made in early September 1991 with a new formulation and reduced starch content Results were very satisfactory, with good gel-forming characteristics and sensory properties. Several samplers said that the fresh surimi without the cryoprotectants has a more natural seafood flavor.

STABILIZED MINCE

Whiting can be held only a short time in chilled storage before it must be processed, this is especially true for production of good quality surimi. We are currently evaluating a technology that would enable minced whiting to be frozen, then later thawed and washed to form a fresh surimi that could be used for analog products.

Whiting were caught off Newport, chilled immediately, landed the same day, and trucked to Astoria. Fillets had a K-value of 8%, indicating a high degree of freshness, when they were processed and frozen approzimately 24 hours after catch. Frozen headed and gutted (H&G), unstabilized mince (UM), and mince stabilized with 12% sucrose (SM) were all stored at -20°C (-4°F) and -50°C (-58°F). The cryoprotectant and temperature levels were selected to "bracket" conditions that might verify initial feasibility.

Some of the whiting was initially made into surimi and stored at -34°C (-29°F) for a comparative control. At various time intervals, the H&G and mince were thawed, made into surimi (with the usual 8% cryoprotectants), and refrozen, so we could test it against the surimi that was already in storage. In all cases, 1% beef plasma protein was used as an enzyme inhibitor.

Figures 5 and 6 show some of the results for six months of storage. Torsion results giving strain at failure (figure 5) indicate that surimi made from -20°C UM was of poor quality, but with stabilizers (SM), it was good compared to the surimi control. UM at -50°C gave surimi with a relatively lower strain value (about 1.8). It did not vary much with storage time, indicating perhaps that the major reduction was caused by freezing without cryoprotectants. The following data were not shown in the figures: SM at -50 showed no improvement over SM at -20; and H&G at -20 and -50 showed roughly the same results as UM at the same temperatures.

Figure 6 gives stress values for the strain conditions of figure 5. These stress (strength) values are somewhat low.

These results show that whiting mince stabilized with 12% sucrose and stored at -20°C can potentially be used to make good quality surimi. Some significant questions remain. What kind of yields can be achieved with pilot-scale production? What optimum cryoprotectant, level, and storage temperature can be found? What freezer configuration can produce a continuous frozen product that will store well? These questions will be addressed following the start of the 1992 whiting season.

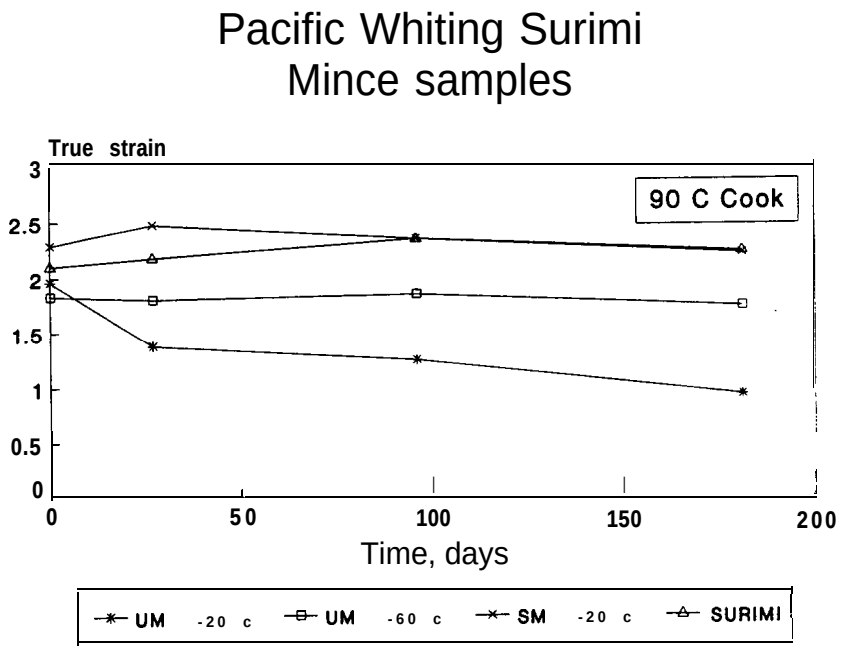

Figure 5. Change in true strain at failure during storage.

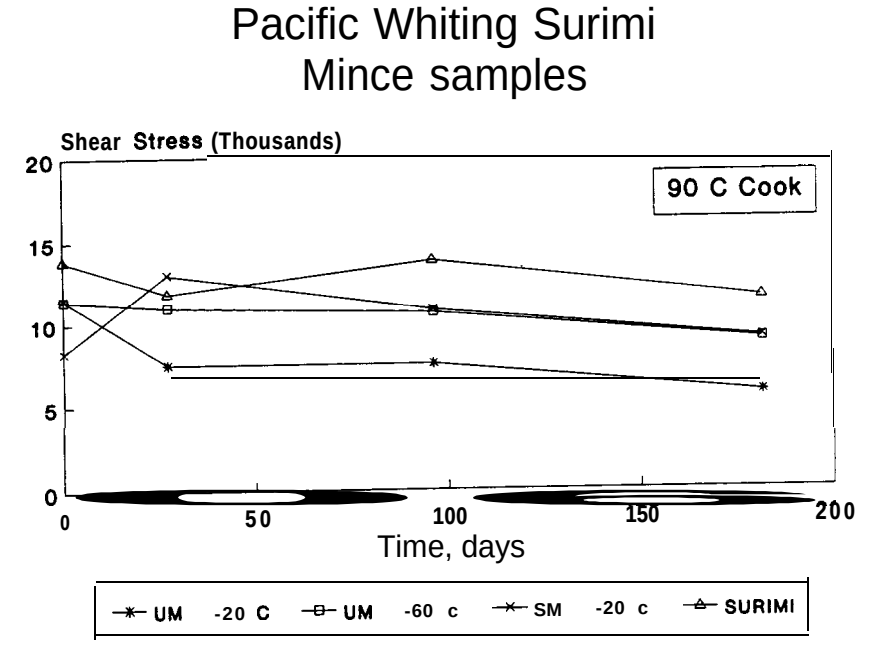

Figure 6. Change *in shear stress at failure during storage.*

USE OF POTATO INHIBITOR IN PACIFIC WHITING SURIMI

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This laboratory has studied the problem of muscle softening in Pacific whiting over a several-year period and realized early that the softening was caused by protease enzymes in the muscle tissue (Patashnik et al. 1982; Kudo et al. 1987). Several studies have attempted to correlate the degree of softening with the incidence of myzosporean parasites *Kudoa thyrsitis* and *Kudoa paniformis,* but there does not appear to be a clear relationship.

Before any discussion of the use of inhibitors, it is helpful to look at a few basic principles regarding enzyme activity in Pacific whiting, outlined in figure 1.

- Protease enzymes are catalysts
  - are not consumed in the reaction
  - each protease enzyme molecule can act as long as conditions permit
- Bate of breakdown depends on several factors
  - enzyme concentration
  - temperature
  - pH
  - physical integrity of muscle tissue

Figure 1. Protease enzyme activity in Pacific whiting muscle.

Enzymes are catalysts and as such are not consumed in the reaction. Consequently, as long as conditions for activity permit (that is, temperature, pH, substrate availability), the enzyme will continue to degrade the muscle tissue. The rate of breakdown depends on several factors, such as pH, temperature, enzyme concentration, and the physical integrity of the muscle tissues. Some of these factors are outlined briefly in figure 2.

The physical handling of the round fish is extremely important to prevent smashing of the fish and crushing the tissue. This destroys the muscle integrity and natural compartmentalization of enzymes and substrates and thus accelerates softening.

- Physical handling of the round fish
  - abusive procedures crush tissue and destroy integrity and natural compartmentalization
- Time and temperature before and during processing
  - these two factors are inseparable: both must be kept to a minimum
- Enzymatic damage is irreversible

Figure 2. Factors affecting enzymatic breakdown in Pacific whiting muscle.

Time and temperature must be kept to a minimum before and during processing to retard enzymatic activity. These precautions are necessary because enzymatic damage to muscle tissue is irreversible and the use of inhibitors only prevents further degradation. It does not repair damage that has already occurred.

Freezing does not destroy the activity of the enzyme. It only retards the activity, which can resume again upon subsequent thawing of the product and a return to more favorable temperatures for activity. We have stored for eight years frozen Pacific whiting fillets that have retained much of their original activity. This suggests that anyone considering a twice-frozen product from Pacific whiting would be ill-advised to even contemplate such a product

Figure 3 represents a pH vs activity curve of a crude enzyme preparation from Pacific whiting.

The muscle pH observed in Pacific whiting is around pH 6.8-6.9, which is above the optimum for enzymatic activity but in the range where considerable activity is still present. As would be expected, considerable variation in enzymatic activity occurs between various lots of Pacific whiting. Figure *4* shows the temperature vs activity observed in two samples having large differences in activity. Inside Puget Sound, whiting is does not have a texture problem and, as shown in figure 4, has considerably less enzymatic activity than Pacific whiting from the west coast of Washington. Pacific whiting taken from the coast is made up of a

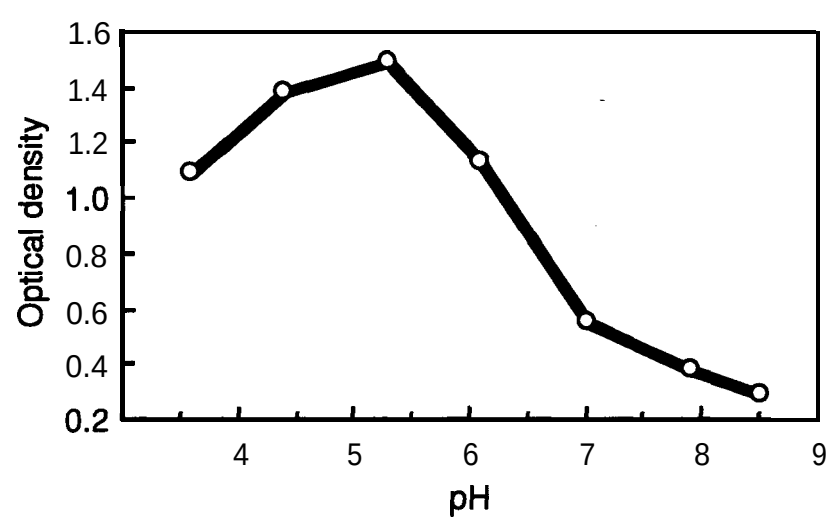

Figure 3. pH effect on protease activity.

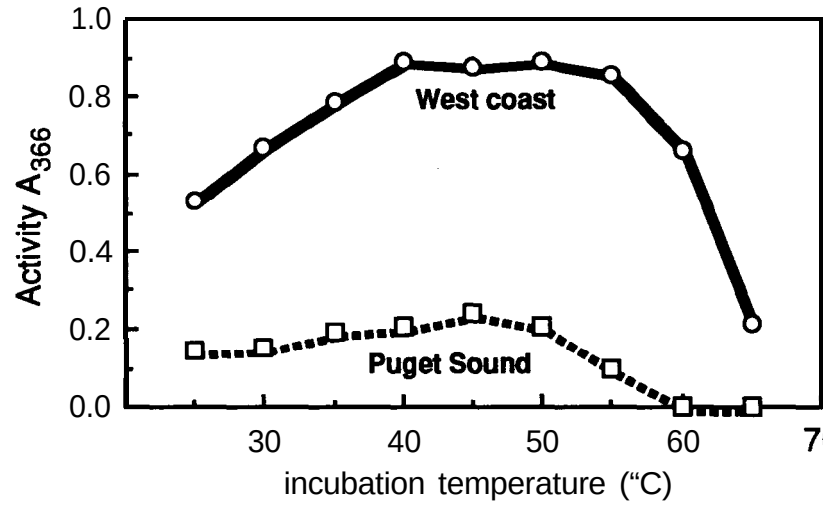

Figure 4. Temperature-activity curves for Pacific whiting extracts.

different stock and does have the softening problem. This gives an indication of the extreme ranges of enzymatic activity that can be found between lots of Pacific whiting. Also, it is clear that the enzyme is active over a broad range of temperatures.

I would like to re-emphasize the need for minimizing physical damage during handling and keeping time and temperature to a minimum between catching and subsequent processing and freezing.

There are several inhibitors which are effective against the protease enzymes in Pacific whiting. Among them are egg white, mammalian blood plasma, and potato inhibitor. Egg white and potato contain specific proteins that act as competitive inhibitors for the active site on the enzyme molecule, whereas mammalian blood is considered to trap the enzyme within one of the large molecular weight macroglobulin proteins, resulting in inactivation of the enzyme (Laskowski and Kato 1980.).

At the Seattle Laboratory of NMFS, we have done extensive research on the effect of potato inhibitor in preventing enzyme degradation in Pacific whiting surimi. I would like to remove any misconceptions regarding potato as an effective component and would direct attention to figure 5.

It is clear that the starch component of the potato has no inhibitory activity against the protease enzymes as shown by the fact that there is no improvement over the control surimi with no additives. The potato extract, which has the starch removed and contains a protein fraction from the potato, exhibits excellent gel characteristics. Also shown is the addition of dried whole potato to the same surimi to illustrate the efficacy of adding the inhibitor in this form. NMFS was granted a patent on the preparation and use of this inhibitor preparation, and it is being produced and marketed by Nonpareil Corporation of Blackfoot, Idaho (Porter et al. 1990).

Additive	Percent added	Gel strength (GM-CM)	Force (GM)	Deformation (CM)	Fold test (3 mm slice)
Control	—	20	77.0	0.26	1.0
Potato starch	3.0	26	98.8	0.26	1.0
Dried potato extract	0.3	569	517.1	1.1	5.0
Dried whole potato	3.0	564	594.0	0.95	5.0

Figure 5. Evaluation of kamaboko from Pacific whiting treated with potato starch, driedpotato extract, or dried whole potato.

The potato ingredient, currently made from whole potatoes, is functional at the 3-4% level and should be blended with the cryoprotectants during surimi processing just prior to freezing. Pacific whiting surimi made with potato inhibitor levels of 34% has been used as the complete source of surimi in different analog processes with excellent results with respect to both processing characteristics and product quality.

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PROTEOLYSIS OF PACIFIC WHITING AND ITS INHIBITION

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Gelation is a process in which a continuous network is formed by random cross-linking of proteins. The gel strength of surimi is closely related to the ability of component proteins to form an ordered, three-dimensional network. The main components of surimi are myofibrillar proteins, which include proteins participate in muscle contraction such as actin and myosin. Myosin, with a unique structure of two globular heads and a long tail, makes a significant contribution to formation of the gel structure. When heated, myosin loses its noncovalently stabilized structure of α-helix followed by intermolecular association. Myosin then develops into a rigid structure held by strong covalent disulfide bonding and noncovalent interactions such as hydrophobic and ionic interactions.

Proteases are a group of enzymes that can hydrolyze a variety of proteins into shorter peptide chains. Proteases either present in the muscle tissues (endogenous) or introduced from other sources (exogenous) can degrade myofibrillar proteins, including myosin, thus weakening network formation of surimi gel (figure 1). There are several types of proteases that can act to hydrolyze muscle fibers of fish: alkaline proteases (Lanier et al. 1981), calpains (Tsuchiya and Seki 1991), and cathepsins (Erickson et al. 1983). Pacific whiting shows high activities of proteases in comparison to other firm-textured fish species, and the activities are further increased when the flesh is infected with myxosporidian spores (Nelson et al. 1985). Therefore, unless properly handled and processed, Pacific whiting may suffer from severe quality defects caused by proteolysis.

Proteolysis of Pacific whiting can be controlled by the use of protease inhibitors such as beef plasma proteins (BPP), egg white, and potato extract. Generally, the gel strength of surimi is increased 20% to 30% by addition of these protease inhibitors during manufacturing. When BPP is added up to 1% in Pacific whiting surimi, gel strength increases substan-

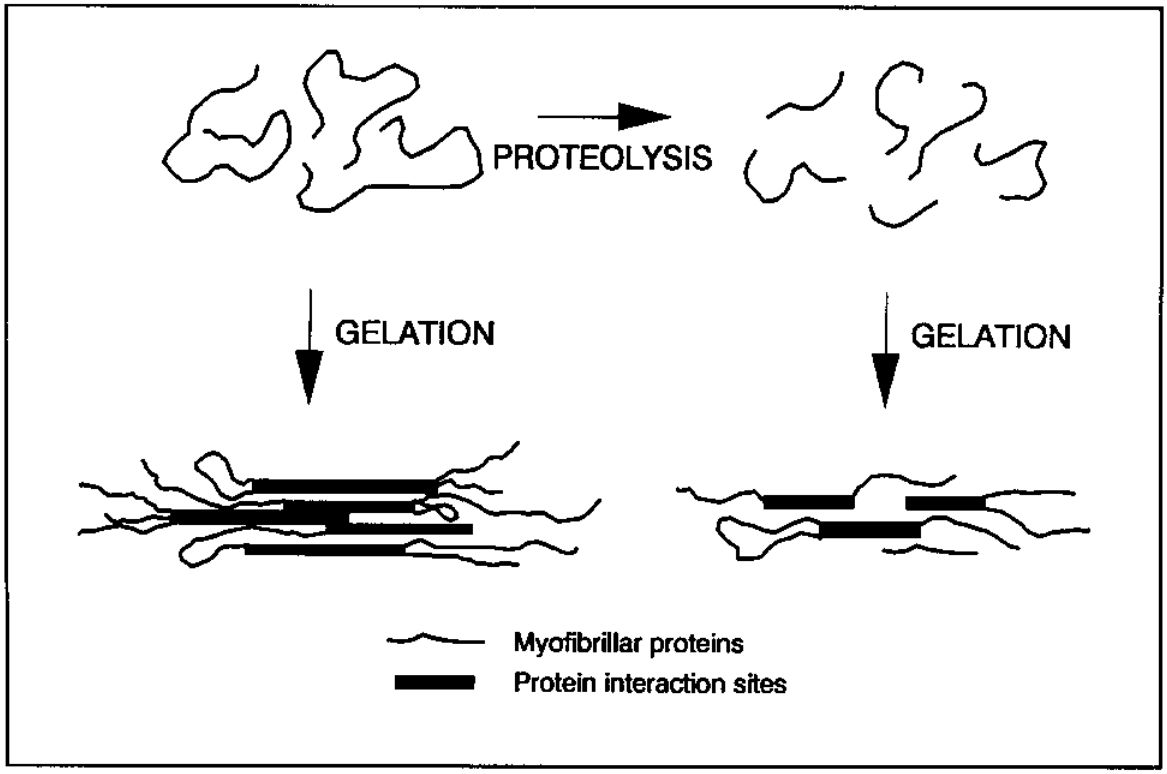

Figure 1. Effect of proteolysis on the gell formation.

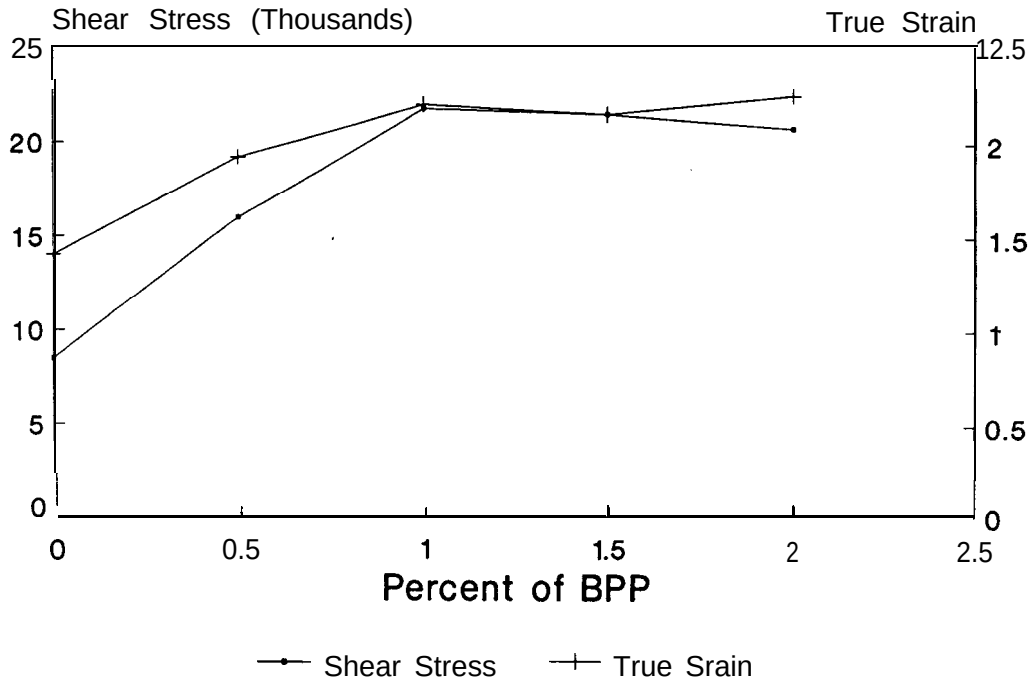

Figure 2. *BPP effect on PW surimi.*

tially as measured by true strain and shear stress. The highest true strain and shear stress values were observed at the level of 1% BPP with 1.58- and 2.67-fold increase, compared to that of surimi without protease inhibitors (figure 2). At the levels above 1%, there was no additional benefit, since true strain and shear stress leveled off. A true strain value of 2.2 or higher indicates good-quality surimi. These data indicate that good-quality surimi can be produced from Pacific whiting by adding protease inhibitors and practicing proper processing methods.

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PANEL DISCUSSION OF SEAFOOD TECHNOLOGY

Session leader: ***David Crawford.*** Panel members: ***Roy Porter, Haejung An, Larry Meyer (American Meat Protein Company) Jae Park, Edward Kolbe, and Tyre Lanier.***

All questions were held until the panel / audience discussion period.

Q: Michael Morrissey, from the audience) Could Larry Meyer, from the American Meat Protein Company, clarify the the FDA's current position on the "GRAS" (generally recognized as safe) status of the beef plasma product that has been found an effective protease inhibitor in OSU Seafood Laboratory's experiments and has been used by the Japanese for at least five years?

A: (Larry Meyer) A competitor of ours informed the FDA of the American Meat Protein Company's use of beef plasma, asking whether this use was permitted. The FDA responded that the product was not defined as either a food or a food additive, nor had it ever been accorded GRAS status by the agency. Since that time, the American Meat Protein Company has sought reconsideration of the matter and the FDA has agreed to rescind its previous determination, accepting the use of the plasma for this purpose. The FDA will be informing regional offices soon that its prior letter on the subject should be disregarded.'

Q: What are the current labelling requirements for the plasma product?

A: (Meyer) The labelling requirements depend on whether the product is intended for domestic consumption or international sale. This product has been used in a hydrolyzed form in meat products and labelled as "flavoring." In March 1991 the USDA changed its regulations covering flavorings. Now it appears that if the product is to be used in surimi seafoods for domestic consumption, it must be labelled "blood plasma protein" unless a hydrolized formulation of the product is used, in which case it may be labelled "flavoring." For international trade purposes, it may be labelled "flavoring."

Q: Is there any advantage, in terms of shelf life, to the use of beef plasma vs. potato concentrate?

A: Morrissey reported that the Astoria Seafood Laboratory plans to study this issue. So far, over the six-month period the lab has held surimi containing the beef plasma, it has proven effective. Roy Porter further stated that both products have proven effective in NMFS laboratory tests for 10, 12, and even 18 months. An audience member asked if gel strength would decrease over time, and Tyre Lanier answered that there was no reason to believe so.

Q: Could the panel clarify the meaning of the term GRAS (generally recognized as safe)?

A: (Meyer) Most substances are considered GRAS until questions are brought up about their use. Such substances can be used while the approval process for their use is going on. He claimed that it is currently legal to use beef plasma as long as the labelling requirements for domestic and international use are met.

Q: (Jae Park, from the audience) Is the dried potato extract used in inhibiting protease commercially available?

A: An audience member responded that his company had the patent to use this product, and it is currently available at $.95/lb. FOE3 Idaho. The product is still being developed.

[1]On April 23, 1991, the FDA issued a letter stating that it "[does] not wish to contest ... at this time" the claim that beef plasma protein is a safe ingredient. This statement essentially gives the green light for use of beef plasma protein (it must be labelled) as an ingredient in domestic surimi. It should be noted that the FDA is leaving the door open for decision making in the future.