Fish Protein in Processed Meats

Tyre C. Lanier*

Introduction

The title of this paper will no doubt evoke either skepticism or fear in the minds of many in the meat industry. Skepticism, perhaps, in that many obstacles remain to be overcome before anyone really expects to see processed red meat products which contain any proportion of fish protein. For example, the USDA has questioned the adequacy of current inspection and handling practices for fishery products, as well as the safety of cured meat products containing fish due to the different microflora and nitrogenous composition of fish. Marketing experts also wonder how consumers would react to products which are mixtures of fish and other meats. On the other hand, many may fear that the allowance of fish into meat products may present a new threat to the sale of meat, similar to that posed in recent years by the introduction of poultry-containing processed meat products.

However, fish protein can be a very functionally viable and acceptable ingredient for processed meat formulations, and its use as such could actually promote the sale of those meats that are most difficult to market. This was the subject of a recent article in *Meat Industry* (Anonymous, 1985) which excerpted a presentation I made last fall at the 1984 Meat Industry Research Conference (MIRC). This presentation will expand upon these earlier comments.

Additionally, I would like to broaden the topic just a bit to mention certain aspects of fish protein science which might also find application in the science of processed meats. Published work on fish protein gelation properties, which has perhaps been overlooked by many meat scientists, might give insight into the molecular events which transpire during the preparation of processed meat items.

Surimi and Protein Gelation

Surimi is a bland, practically colorless, refined fish muscle protein prepared by fresh water leaching of mechanically deboned fish meat. Due to the type of deboner used, the meat is coarser and more free of bone contamination prior to leaching than is mechanically deboned poultry or red meats. The leached meat is dewatered by pressing, and cryoprotective agents are added. These are commonly sucrose and sorbitol in a 1:1 ratio, added to a final concentration of about 8%. Recently, we applied for a patent on the use of Polydextrose® as a muscle food cryoprotectant. This additive seems to work almost equally well at the same level of addition, and possesses a lower caloric value and no sweetness as compared to sucrose and sorbitol.

In our laboratories Park (1985) recently evaluated these cryoprotectants for their ability to maintain the superior functional properties of salted prerigor red meat. He found that, although the presalting (which purportedly halts the rigor process, Hamm, 1981) caused destabilization of the muscle proteins during frozen storage, the rate of destabilization could be greatly lessened by the addition of these cryoprotectants. Actomyosin solutions frozen with the addition of cryoprotectants also showed less tendency to aggregate and lose solubility during storage.

Montejano et al. (1984) compared the heat gelation properties of surimi with those of beef, pork and turkey. Using high-quality commercial meats in each case, he found that certain gels prepared from surimi were up to four times stronger and twice as cohesive as gels from the red meat and poultry samples. Such a marked gelling potential by surimi was attributed to two factors. First, surimi is a concentrate of the functional salt-soluble proteins of animal muscle (the only such material commercially available). Secondly, the surimi gels possessing the greatest strength and cohesiveness had been preincubated at 40° C (a treatment which had no effect on the gels from other species). Fish proteins, especially those of cold-water species, are much less thermally stable than those of warm-blooded animals. This explains the absoute requirement for cryoprotectant addition prior to freezing, and also the ability of fish proteins to "set" into elastic gels at very low temperatures. Upon further processing, these pre-"set" gels will possess greater strength.

Montejano et al (1984), using a thermal scanning rigidity monitor (TSRM) developed earlier by the same authors (Montejano et al., 1973), demonstrated that gel initiation during slow heating occurs at a temperature approximately 10° C lower than that of poultry or red meats, and that this initiation corresponds to a conformational change in the proteins which can be detected by differential scanning calorimetry. Subsequent work by Wicker et al. (1985) has indicated that this initial conformational change may involve the exposure of hydrophobic amino acid residues which leads to intermolecular hydrophobic associations and the formation of a gel matrix. Slow heating allows for the formation of a more "ordered" gel matrix, one which will presumably possess stronger and more elastic textural properties, and which is better able to entrap fat and water in a food system (Acton and Dick, 1984). Such an "ordered" structure is formed by some fish proteins at temperatures as low as 0° C. However, longer incubation times are required (generally 8 to 12 hours), and doubtless a different molecular mecha-

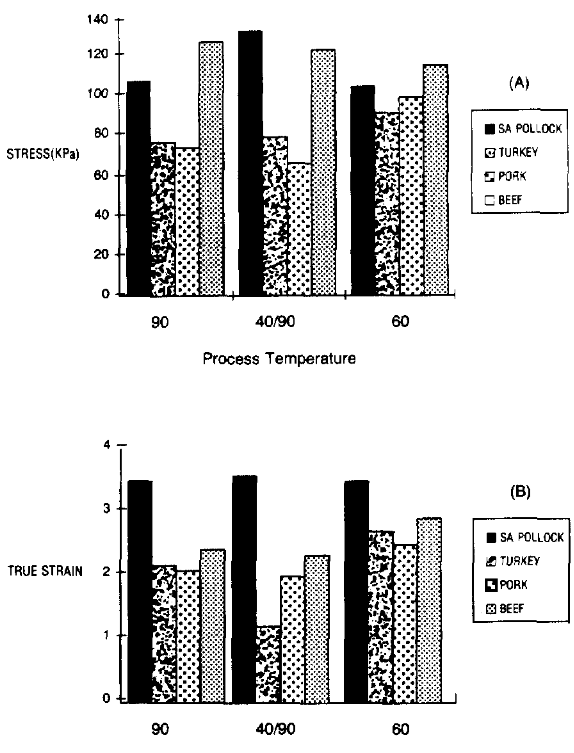
**T.C. Lanier, Food Science Department, North Carolina State University, Raleigh, NC 27695-7624*

Reciprocal Meat Conference Proceedings, Volume 38, 1985.

nism is involved than for the "setting" phenomenon observed at higher temperatures (near 40° C) (Kim, 1984).

Recently, we prepared samples of lean beef, pork, and turkey which were very fresh (24-48 hrs post-mortem) and which were ground and mixed with 8% of a 1:1 sucrose-sorbitol mixture prior to freezing. The amount of polyphosphate which is normally added to frozen surimi (0.3% sodium tripolyphosphate) was added to the meats along with salt as part of the preparation of heat-induced gels. Surprisingly, the textural properties of these gels (Figure 1) approached the levels of those reported for surimi by Montejano et al. (1984). Subsequent experiments indicated that phosphate addition only partially accounted for the large increase in textural measurements, compared to the samples of Montejano et al. (1984). Thus this preliminary experiment (repeated in triplicate) indicates that mammalian and avian muscle proteins may also benefit from the stabilizing treatments which have been developed for surimi, such that the bind properties of frozen meats may be much improved. Sampling for this experiment has thus far extended only over one month frozen storage; sampling at longer intervals is needed to determine the full extent to which the meat and poultry proteins were stabilized.

Figure 1



Plots of torsional (a) stress and (b) strain at mechanical failure of heat-induced gels prepared from four muscle sources. "SA pollack" is highly functional Alaska pollack surimi. Other meats are lean commercial cuts. (Unpublished data) Cooking temperatures are: 90 = 90°C for 20 min; 40/90 = 40°C for 20 min, followed by 90°C for 20 min, 60 = 60°C for 30 min.

This study also revealed that gel strengths of the meat and poultry proteins were enhanced by a 60° C process for 30 minutes as compared to a faster (15 minutes) cook at 90° C (Figure 1). As was expected from previous reports (Montejano et al., 1984), the 40° C preincubation for 20 minutes had little effect upon the properties of the meat and poultry gels. It may thus be concluded that these proteins also display a type of low temperature "setting" phenomenon, but at higher temperatures than surimi. This higher temperature for gel strength enhancement corresponds with the higher denaturation temperature of these proteins, compared with fish muscle proteins (Montejano et al., 1984).

Role of Surimi and Protein Gelation in Processed Meats Manufacture

It may be apparent that the only "functional property" mentioned thus far in this paper has been that of gel-forming ability, measured in terms of the strength and cohesiveness of pure protein gels. This is because I believe that water and fat binding, the other primary functional properties of meat proteins in highly processed products, largely result from the ability of the myofibrillar proteins to polymerize into a network structure which is capable of entrapping these liquid (at processing temperatures) components of the product. In restructured muscle foods, gelation of soluble myofibrillar proteins is responsible for a fourth function (similar to the first), that of "gluing" chunks or flakes of muscle together into a coherent mass.

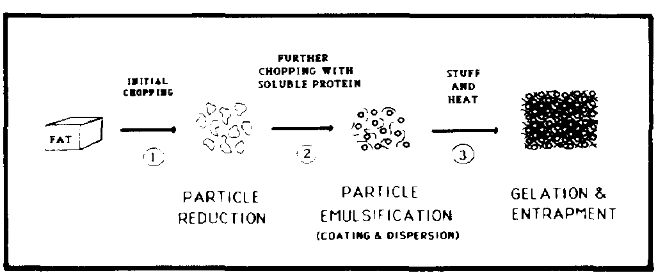
The surimi-based Kamaboko products of Japan, of which the shellfish analogs are a sub-category, represent the largest category of processed comminuted fish products being manufactured. A lesser amount of products known as fish "sausage" are also produced (Suzuki, 1981; Akahane, 1983). These sausage products are similar in composition to domestic comminuted meat and poultry products, such as weiners and bologna. The literature generally refers to Kamaboko products, which are low in fat (generally less than 2%) but high in starch and water content, as "gel" type products, while the latter high-fat (generally 20% to 30%) products have been termed "emulsions." This choice of terminology has also seemed to influence (or been influenced by) the approach to study of these systems by meat scientists. The properties of the "gel" type products have been largely attributed to the ability of the muscle proteins to gel, and thus studies of the heat denaturation and gelation properties have predominated in the meat (often *fish*) science literature of Japan. The properties of "emulsion" type products have been attributed more to the fat-coating ("emulsifying") ability of the protein, and studies of this "emulsifying" ability have predominated in the Western meat science literature. However, it is likely that these two types of food systems are actually very similar.

The "gel" type food product is considered to consist essentially of a protein matrix in which other food components, both liquid and solid, are entrapped. We recently showed (Lanier, 1985) that such products possess two fundamental textural or rheological properties, which may be termed the strength and the cohesiveness. These may be measured as the force (stress) and the deformation (strain), respectively, required to produce mechanical failure in the gel. A torsion geometry is preferred for this test (Kim, 1984; Montejano et al., 1983, 1985), but the measurements are fundamental properties of the material which, unlike the results of most "texture" tests, are independent of the test geometry. The gel rigidity may be computed from these values (stress/strain). We have found that the rigidity measurement is very responsive to changes in the protein or solids concentration of the gel, while the cohesiveness (strain at failure) is most responsive to the quality or "functionality" of the protein. Thus the addition of protein "fillers" to comminuted meat products at the expense of water or fat will generally result in a firmer or more rigid texture, whereas addition of these ingredients at the expense of functional muscle protein will primarily reduce cohesiveness of the product.

As yet, the effects of fat addition on textural properties of protein gels have not been fully documented. Such study should tell us much about how to replace the fat in "emulsion" products with other components to produce low-fat products of acceptable texture.

"Emulsion" products can thus be viewed as "gel" products in which one of the major non-gelling components is fat. This view, then, emphasizes the role of protein gelation, rather than protein coating of fat particles, as being the critical event in the stabilization of the fat within the product. As Jones (1984) concluded in a recent review paper on protein-fat interactions in processed meats, "The gel strength of the batter matrix is probably the single most important factor affecting the overall stability and fat-holding ability of most sausage products." Protein coating of the fat particles comes into play mainly in the dispersing of the fat in the aqueous protein sol (Figure 2). It is desirable to disperse the fat in fine particles in some products simply because it makes the product organoleptically more homogeneous; such fine dispersion is not required for stability of the fat. "Pre-emulsion" technology utilizes non-meat proteins, such as soy or caseinate, to form a fat dispersion prior to its incorporation into the muscle protein sol. This obviates the need to comminute the muscle proteins at temperatures where protein denaturation might occur prematurely (and functionality be reduced) solely for the purpose of dispersing the fat.

Figure 2



"Gel" theory of fat binding in processed meats.
(1) Fat is initially reduced to smaller particles, and (2) in the presence of a soluble protein, these particles are coated and therefore more easily dispersed in the meat protein sol. (3) After stuffing and during heating under the appropriate conditions, the proteins form a gel matrix which entraps the coated, dispersed fat (now melted).

Heating of the mixture induces melting of the fat and gelation of the proteins. Emulsion theory explains the adverse effects of too-rapid heating as being the rupture of fat particles due to expansion of melted fat within a coagulated and contracted protein membrane in an aqueous medium (Pearson and Tauber, 1984). However, this regards the system as being comprised simply of fat globules surrounded by protein membranes. Actually, the fat globules are encased in a gel network. The physical arrangement of this network (as evidenced by its rheological properties) is closely tied to the time/temperature profile, as has already been noted (Acton and Dick, 1984). Thus it would seem that deficiencies in the nature of the gel network caused by the rapid heating may be responsible for the poor binding properties under these conditions.

"Gel" theory would also yield different explanations for fat instability caused by such factors as overchopping and low-quality meats. According to "emulsion" theory, overchopped batters are unstable because not enough protein is available to cover the huge surface area of the too-finely chopped fat particles (Pearson and Tauber, 1984). However, it is unlikely that at the high protein-to-fat ratios found in meat batters such a problem could exist. At much higher fat concentrations of liquid oils, very little quantity of protein is needed to coat and thus stabilize the fat in an emulsion. Published reports also show that the emulsifying capacity (EC) of proteins, measured as grams of oil emulsified (stably dispersed) per 100 milligrams of protein, decreases to a minimum with increasing protein concentration, and that the total grams of oil dispersible does not increase proportionately with increases in protein concentration (Borderias et al., 1985). It is more likely that overchopping weakens the structure of the gel through the combined action of premature denaturation of the proteins, caused by chopping at elevated temperature, and greater disruption of the protein matrix, due to the finer dispersion of the fat throughout the protein sol.

The use of poor-quality or "short" meats would be expected to lead to poor fat stability because there is an inadequate quantity of salt-soluble protein available to form the proper type of gel network, and that network may be disrupted by the high content of non-gelling proteins present.

While as yet I can offer no proof that this "gel" theory is indeed the correct one, I think that it does in many cases offer a more satisfying explanation for the phenomena we observe in the processing of comminuted meat batters. Hopefully, this discussion will at least stimulate meat scientists to broaden their thinking on the subject, perhaps opening up new types of investigations which will more clearly elucidate both the biochemical and physical mechanisms of fat and water binding in comminuted meat systems. If the words of Jones (1984) quoted above prove to be true, then torsion testing of protein gels may prove to be a valuable laboratory test for evaluating the "bind" potential of various ingredients for processed meats.

Fish proteins in the form of surimi give the meat scientist a new tool for the study of meat batter systems. Our research has shown that the type of gel structure (as evidenced by rheological properties) can be easily influenced by manipulating the heating of these proteins (Montejano et al., 1985). This should facilitate studies of the relationships between gel structure development and fat/water binding functions. Additionally, because fish proteins are capable of gelling at such low temperatures, it is possible to induce gelation prior to the event of fat melting. It may be that the time sequence of fat melting and protein-protein associations is quite critical to the ultimate water and fat binding properties of meat proteins.

While I have placed much emphasis here on the physical entrapment of water, fat and other food components by a protein matrix, the role of chemical interactions should not be overlooked, particularly with regard to water binding. As was so aptly pointed out to me recently by my colleague, Dr. Allen Foegeding, the optimum pH for heat gelation of myosin is near 6.0, while the water-binding properties of proteins are known to increase with increasing pH. Thus it will be important to determine the relative role of physical entrapment versus chemical attractions in optimizing the water-and, possibly, fat-binding properties of muscle food systems.

The low-temperature "setting" properties of fish (surimi) proteins may be especially useful in restructured meat applications. Coating of the meat chunks or flakes with surimi of a cold-water species (i.e., pollack) would enable that product to be bonded into a coherent mass without heat processing. A freeze-dried preparation of surimi is now being commercially produced in Japan expressly for this application. Domestic sources of dried surimi are also presently being developed.

Conclusions

The excellent gelation properties of surimi should thus recommend it to meat processors who need to increase the "bind" level of a formulation at a reasonable cost. The highest-quality surimi presently is available at less than $1.00 per lb. Considering that its gelation properties will generally exceed those of bull meat priced perhaps 50% higher, this could be a significant improvement in least-cost formulations.

In order to produce surimi of this gelling quality, the fish must be extremely fresh and be handled with the utmost care. Too, surimi is generally a primary product rather than a by-product of a filleting operation. Extensive leaching may also be required. Thus a highly functional surimi is likely to also be of superior bacteriological quality, more homogeneous in appearance (no specks of skin or bone fragments), and possess a blander flavor and aroma, compared with the commercially available product known as minced fish. As such, it should receive more favorable attention by USDA as a potential ingredient for processed meat products. Additionally, the blandness and high quality of surimi should allay any consumer objections to its use in these traditional meat products.

References

Acton, J.C.; Dick, R.L. 1984. Protein-protein interaction in processed meats. Proc. 37th Ann. Recip. Meats Conf., p. 36.

Akahane, T. 1983. Processes and formulations for surimi-based products. In, "Pastries to Peanuts," Alaska Fisheries Development Foundation, Anchorage.

Anonymous, 1985. Surimi's binding solution. Meat Industry, June, p. 68.

Borderias, A.J.; Jimenez-Colmenero, F.; Tejada, M. 1985. Viscosity and emulsifying ability of fish and chicken muscle protein. J. Food Technol. 20(1):31-42.

Hamm, R. 1981. Postmortem changes in muscle affecting the quality of comminuted meat products. In "Developments in Meat Science – 2." Lawrie, R. (Ed.) Appl. Sci. Publ., London.

Jones, K.W. 1984. Protein-lipid interaction in processed meats. Proc. 37th Ann. Recip. Meats Conf., p. 52.

Kim, B.Y. 1984. Effects of cyclic freezing-thawing on viscosity and gel-forming properties of surimi. J. Food Sci. (submitted)

Lanier, T.C. 1985. Functional properties of surimi. In the symposium, "Engineered Seafood Products." Abst. 45th Ann. Meet. Inst. Food Technol., Atlanta.

Montejano, J.G.; Hamann, D.D.; Lanier, T.C. 1983. Final strengths and rheological changes during processing of thermally induced fish muscle gels. J. of Rheology 27(6):557-579.

Montejano, J.G.; Hamann, D.D.; Lanier, T.C. 1984. Thermally induced gelation of selected comminuted muscle systems – rheological changes during processing, final strengths, and microstructure. J. Food Sci. 49(6):1496-1505.

Montejano, J.G.; Hamann, D.D.; Lanier, T.C. 1985. Comparison of torsional failure and texture profile characteristics of selected heat-induced protein gels. J. Texture Studies (accepted).

Park, J.W. 1985. Effects of cryoprotectants on properties of beef proteins during frozen storage. Ph.D. Dissertation, N.C. State University, Raleigh.

Pearson, A.M.; Tauber, F.W. 1984. Emulsion type products. In, "Processed Meats" (2nd ed.), AVI, Westport, Conn. p. 206-209.

Suzuki, T. 1985. Fish and krill protein – processing technology. Appl. Sci. Publ., London.

Discussion

J. Regenstein: Among other things, I think it's important to recognize the similarity of the three species, the role of fish, and how it's now being used to deal with in the general area of meat and poultry. I think you did a nice job of bringing it all together. I have a few comments. Starting on the technical side, my work (reported at last year's AMSA meeting) showed a number of years ago that the emulsion capacity tests, if you consider the mils of oil actually emulsified, showed a very small change, probably due in part to viscosity and the ability to chop the oil droplet's size . I would rather strongly disagree with the interpretation of doing it on a protein-structure model type of approach. When you showed your pictures with the coating, I also suspect we have much less of a coating as you later came back than would be indicated by the drawings you showed.

T. Lanier: In fact, it's called a monolayer sometimes, so I think it's very good.

Regenstein: I'm not even sure we have a monolayer because in our work with exhaustively washed muscle, where we presumably got very little salt-soluble protein if any, we were still able to form emulsion-type products even at low temperatures. I also think we will see some of that setting in poultry also, at 0° C if you leave it. I think there is some discussion of the fact that if you make a sausage, you have to keep it moving once you start chopping it. I think all of the meat systems will gel in time at 0° C. I think there is a common ability, but I slightly disagree with your interpretation.

Lanier: Very often you will observe something that looks like gelation at 0°C overnight or in a long period of time. We have found with certain species of fish that once you chopped, it really does not affect it too much after it has set up at 0° C. If it had set up at 40° C, the gel may look the same as a gel that had set up at 0° C, but the one chopped again after setting up at 40° C would just destroy the gelling ability or the binding ability of that material. But set at 0° C, you have a beneficial effect of setting it, as in the case of pollock. If you chop that again, you are going to destroy a lot of the gelling ability. However, in the case of croaker and some other species, even though it seems to set into a gel, if you chop it again, it doesn't seem to affect it. In fact, setting it at 0° C does not seem to affect the final texture when it is cooked out at 90° C at all; but in the case of pollock, it does. So just the fact that it sets up in a gel does not mean that's an irreversible type of gel that's actually aiding in setting up a correct type of gel structure. So that needs to be investigated with beef, pork and turkey. We have found that only the cold-water species seem to set up a gel at 0°C, which is actually beneficial to the final gel structure.

Regenstein: There are people now actually looking at the surimi process on poultry meat. In the long run, it is a cheaper source of raw material than fish. The other point I want to remind the audience of about surimi is some of the negative aspects of going from minced to surimi. You are removing high-quality nutrients, such as vitamins, iron and fat. Also we are creating pollution, just as the dairy industry did with whey.

So I think there are a number of problems that suggest that surimi is not the solution to all things. Tyre and I agree that its use as an ingredient in some small proportion for its functionality is its real future. It has been very successful in the crab-like product because of the price difference. But when you consider shrimp, lobster and scallops, some of the price differential disappears. There are a number of us in the fish industry who think that may not be enough to sustain a product with that degree of additives and perceived value in the market place.

Lanier: We have a little publication out on our menhaden work. We call it "the soybean of the sea." I think that there is a lot of similarity between surimi and soybean in that there are products you can eat which are made from whole soybeans. I think you have to agree that, nutritionally, soy isolates would be quite different from whole soybeans. But soy isolates offer many advantages to the food technologist, where soybeans would be of not interest to them. I think we have to look at surimi that way too. There are things we can do with isolates, there are things we can do with minced fish and there are things we can do with surimi.

Regenstein: One final comment is that we have been doing some work in the restructured burger meat category with both fish and surimi. Rigidity and gelation can cause problems with texture in western-style products when used at high levels. I think what we need to learn is where on that 4-frame matrix you want products to be.

Lanier: Well, if you make a hot dog with 5% fat, it would probably make your mouth bounce all day long. You know it is very rubbery, so you can't say that surimi protein is more rubbery than beef protein. It is all salt-soluble myofibrillar protein. So we add fat to cut that back and make juicier and more palatable products. In crab sticks, we add starch and water to do the same thing.

Allan Foegeding has been working on a low-fat hot dog where he has tried to substitute fat with other materials. The strategy is to move it around on the little graph of rigidity and elasticity to where it meets consumer acceptability, using different ingredients. If you want to make it more rubbery, you add more high-quality protein. If you want to make it less rubbery, you lower the quality of the protein. You either heat-denature it or you substitute low-quality proteins in it. And if you want to increase rigidity, you raise the solids concentration. So that's how you play around with it and create almost any texture you want.

D. Bartholomew: Do you see this being useful for fresh-water species. You mentioned catfish and we are also interested in carp, which we have quite a bit of in the west. How much color can be removed from a darker meat that carp would have, for example?

Lanier: Not a whole lot from dark meat. We have done some work in our lab. Herchel Ball did the work with chicken meat. We have also done work with the hand-dissected dark and light meat of menhaden and we find that the light meat gets white but the dark meat only becomes pink. It really doesn't lighten up that much. You are not going to remove much myoglobin without just tearing the structure all to pieces. With regard to the light meat, you are not going to make light meat lighter. With regard to the species, fresh water or whatever, it's really a matter of economics. Can you catch enough fish consistently with the right functionality, and at a low enough price? I'm talking about cheap fish at 4 or 5 cents per pound.

Regenstein: There is another difference, Tyre. We have started some work on fresh-water fish. We are finding that we get a better binding and a more sausage-like product from fresh-water fish and that it survives the freezing. So some of the textural problems that you have with the frozen fish (at least the two species that we have worked with, white bass and yellow pike) are able to survive the freezing process. Some of the problems with cryo-protectants indicate that it seems to be handling as a very different material.

Lanier: It may have a much higher thermal stability because the work with catfish indicates that it did not set very well at 40° C, which would indicate that it is more stable. We didn't do any long-term storage on it, but I would guess that it would be more stable. Even the red meat protein changes, as we showed earlier. I think the idea of cryo-protectants in the red meat arena should be looked at much more closely.

O. Means: I found your data very interesting, especially adding cryo-protectants to the beef, pork and turkey meat. I was wondering what cryo-protectants you used and at what levels you added them.

Lanier: We added 4% sugar and 4% sorbitol in the study I discussed and we would use 8% polydextrose if we used it.

Means: Does the polydextrose change the DSE thermograms any? I know of some studies that show that adding starch causes a lump in the DSE thermogram and that was what was causing some changes in the gel parameters.

Lanier: I don't think we have studied the effects of cryoprotectants on the DSE thermograms but my guess is that it has a small effect by stabilizing the proteins, by raising the denaturation temperature a little bit.

Bill Shivar: You said that freeze-dried surimi had the highest functional properties. What does the freeze-drying process do to the price per pound? Is the $0.75 to $1.00 per lb. incorporating the freeze-dried process?

Lanier: Let's say it's $1.00 per lb. I think it's not a lot more per lb. of protein in the freeze-dried. The processing cost would have to be added. I don't know what the cost is, but I know the price is attractive enough that a large ingredient manufacturer is considering it now. One of the freeze-dried companies in this country is also looking at it. There are two or three suppliers in Japan. They evidently think it's economical enough to investigate. It would be used at very small levels in products also.